OPTIMAL BROILER PRODUCTION VIA NUTRITION

by

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(Under the Direction of Michael E. Wetzstein)

ABSTRACT

Today's nutritionists employ the concept of dietary balanced protein (BP) in feed formulation in order to minimize the excess of crude protein and amino acids contents in broiler diets, which also minimize feed cost, while at the same time maintain broiler growth performance. The BP concept is when other AAs are set relative to lysine, thus, the main focus of this research was on lysine, especially at digestibility level in poultry. For that reason, the digestible lysine (dLys) levels were discussed throughout this research. The analysis was done using a dose-titrations trial. The data were used to evaluate the optimal economic dLys level to maximize profits using linear and nonlinear programming. The Cobb-Douglas functional form was proposed as an alternative model for performing production functions. The optimum responses were a function of current market prices of whole carcass or cut-up parts, and feed ingredients. The optimum dLys level during grower and finisher phases were determined and used to formulate the most profitable diets at a given targeted market and price scenario. The historical prices of major feed ingredients were used to evaluate the impact of low and high volatile prices to maximize profit under optimum feeding condition.

INDEX WORDS: Dietary Balanced Protein, Digestible Lysine, Maximum Profit, Broiler Production, Linear and Nonlinear programming

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CHAPTER 1

INTRODUCTION

1.1 Background Information

In broiler production, feed ingredient costs account for 60 to 70% of the overall production costs (Agristat, 2010). Least-cost feed formulation is a common method to formulate broiler diets; it minimizes feed costs at given feed ingredients and nutritional values. However, nutrient requirements of this method always assume constant profits. Furthermore, the method does not determine the output for each formulated diet regarding broiler performance. This output can vary depending on the maximum profit of feeding the formulated diet to broilers under various feed ingredient and broiler market prices. Profitability can be improved when revenue and costs are both considered in the formulation of broiler diets. Broiler growth and feed intake are two key components in determining the profit, which are not considered in least-cost feed formulation.

About one-third of the feed ingredient cost comes from ingredients that purposely provide the nutritional content to meet crude protein (CP) and amino acid (AA) requirements of broilers. Thus, decreasing the excess of CP and AA contents based on the bird's requirement would improve feed formulation efficiency, which eventually reduces production costs. Replacing soybean meal (SBM) with supplemental AA is a method to minimize the excess of CP and AA contents. When SBM is replaced with supplemental AA, some of the AA (essential and non essential AA) levels has been removed which also reduces CP levels. Determining the levels of supplemental AA to maintain or improve growth performance has been widely studied. However, earlier systems of listing broiler requirements for all essential AA at various stages of growth and maintenance were difficult to follow. These led to research focusing on a better solution by using the optimal proportion of the other AA to just one AA (say, lysine) (Baker et al., 2002; Emmert and Baker, 1997; Mack et al., 1999; Wijtten et al., 2004). Thus, today nutritionists employ the dietary balanced protein (BP) or ideal protein concept or ideal amino acid ratios as all essential amino acids are held in ratios to lysine. Lysine has been selected because it is a second-limiting AA in corn-soybean meal diets for poultry. It is only used for protein synthesis, and is relatively easy to assay. Moreover, dietary lysine does not interact metabolically with any other amino acids and is used primarily for protein accretion, not as a precursor for other functions, unlike methionine (D'Mello, 2003).

When modeling the response to BP, the key amino acids are kept proportional to dietary lysine levels such as the response measured by Baker, et al. (2002) and Lemme et al (2008). Moreover, the needs for the essential and non-essential amino acids as well should be accounted for. Diets containing low dietary lysine in early development result in reducing breast meat formation because protein accretion from protein synthesis and RNA content decline (Tesseraud et al., 1996). Thus, dietary lysine is more precise to use as a target in feed formulation compared with crude protein which is an indirect calculation from the lab, by determination of nitrogen level. Digestible lysine level (dLys) is addressed within this thesis. It does not mean only lysine level was considered, but also represents the nutrient density of the diet. Hence the "optimal nutrient density" or the "derived recommendation" is really the point of maximum economic efficiency. Because it was an economic measure, it will change with changing economic conditions.

A profit maximization model is developed in this research to evaluate the optimum feeding levels of dLys, based on a balanced protein concept, where input (corn and SBM) and output (whole carcass or cut-up parts) prices are varied. The consumer preferences for processed chicken were also accounted in the model. The preferences varied from consuming whole carcasses to cut-up parts, which were sold as frozen or seasoned by chicken producers or local grocery stores. The optimum dLys levels, which provided the maximum profit, for this research were determined from both sides of the production and processing of chicken. Thus, the input and output markets are considered in the analysis and provide the effective feeding levels to meet the consumer preferences or demand.

The model is operated under Microsoft Excel® spreadsheet. The spreadsheet makes the analysis accessible to chicken producers and integrators. The spreadsheet can focus producers' decision making when facing major input and output price volatility. The model can determine the optimum conditions where a producer utilizes its production, inputs, and processing plant to obtain the maximum profit.

1.2 Research Objectives

The research within this thesis is conducted to determine the maximum broiler profitability, efficient feed compositions based on BP or ideal amino acid ratios for a particular commercial broiler strain. Emphasis is placed on determining the optimal dLys level of two feeding periods, grower and finisher phases based on variations in production costs and meat prices. Given the price of live broilers, the broiler grower can determine the economically efficient method to produce broilers. This research will be able to help the broiler growers and nutritionists to determine nutrient levels, estimated body weight and feed consumption that would provide the most profitability at certain days of grow-out.

The optimum BP of broilers production uses a Cobb-Douglas functional form, as a growth function, to solve for maximum BW as a function of dLys levels during the grower and finisher phases. The experimental data used in this research were based on nutrient dose-response experimental data of Sriperm and Pesti (2011). Variations of feed ingredients and broiler market prices were used to estimate the optimum dLys levels which maximize profit.

1.3 Brief Overview of Thesis

The review of economic theory on production functions, profit maximization, and mathematical programming will be discussed. This review is useful in explaining how the profit-maximizing nutrient levels, body weight, and feed intake are determined in the programming model. An experimental data was used to obtain the data necessary to evaluate the broiler production responses (body weight and feed intake) of dietary balanced protein (based on digestible lysine level). The experiment was based on a specific broiler strain (Ross 708) with male birds during 15 to 49 days. Different scenarios of feed ingredient and live broiler prices and historical prices of major feed ingredients were discussed. The optimum nutrient levels during grower (15 to 34 days) and finisher (35 to 49 days) phases were determined. The method used in this research provides a broiler producer company a useful guideline in formulating profit-maximizing diet and decision making for broiler growers.

CHAPTER 2

LITERATURE REVIEW

2.1 Balanced Dietary Amino Acids in Broiler Diets

Protein consists of at least 20 different amino acids (AA) bound together by peptide bonds between the carboxyl and amino groups of adjacent AAs (Garrett and Grisham, 2007). In poultry, ten AAs are required via the diet as called essential or indispensible AAs. They are methionine, lysine, threonine, tryptophan, arginine, valine, isoleucine, leucine, histidine, and phenylalanine. The remaining AAs are called non-essential or dispensable AAs, which poultry are able to synthesize; these are glutamate, glutamine, glycine, serine, alanine, aspartate, asparagines, cystine, tyrosine, and proline (D'Mello, J. 2003). In poultry, methionine is the first-limiting AA, lysine is the second-limiting AA, threonine is the third-limiting AA, valine is the fourth-limiting AA in corn-soybean meal diets without animal by-products (Corzo, 2008), and tryptophan is the fourth-limiting AA in corn-soybean meal diets with meat blend of poultry meal, meat and bone meal, and feather meal (Kidd and Hackenhaar, 2006). Lysine requirement has been considered as a basis target, at the proper ratios of the other AA, in poultry feed formulation. This was mainly due to protein synthesis, which is a primary function of lysine in the body, lysine is relatively easy to assay, and it is not involved in any other biochemical pathways, unlike methionine (D'Mello, J. 2003).

Dietary Balanced Protein (BP) or Ideal Protein (IP) or Ideal Amino Acid (IAA) ratios are basically the same concept of using lysine as the reference AA. By setting the other AA as a proportion to lysine requirement, the other AA can be easily calculated. The ideal AA ratios would not change based on environmental (such as temperature, stress, and disease), dietary (low or high CP or energy), and gender, while the other AA and lysine requirements would change (D'Mello, J. 2003). Thus, lysine requirement is important to determine under different rearing environments, diet and gender, while ideal AA ratios can be derived via previous recommendations.

2.2 Profit Maximization Models for Broiler Production

2.2.1 Linear Programming

Least-cost feed formulation is a common method of formulating diets for broilers; it minimizes the feed cost at given feed ingredients and their nutritional values. On the other hand, nutrient requirements of this method always assume constant profits. Additionally, the method does not determine the output for each formulated diet regarding broiler performance. The output can be changed depending on the maximum profit of feeding the formulated diet to broilers under various feed ingredient and broiler market prices. The profitability can be improved when the revenue and cost are jointly considered in the formulation of broiler diets. The traditional least-cost feed formulation using linear programming (LP) has been applied to formulate broiler diets at a given set of nutrient requirements (Allison and Baird, 1974; Brown and Arscott, 1960). A common objective of the formulations is to maximize bird performance (body weight (BW) or feed efficiency) by determining the least-cost ration. A shortcoming of a LP is not considering optimal bird performance in the production period. Although, the concept of a 95% asymptote has been applied to the maximum nutrient requirement, to ensure the safety margin of the formulated feed, it is still unknown whether the set requirements yield the profit maximum. Allison and Baird (1974) reported that the concept of LP was to minimize feed ingredient costs, which provided maximum performance regardless of feed ingredient prices. Feed nutrients, such as AA, were set at a minimum constraint in order to provide the maximum animal performance. Brown and Arscott (1960) estimated BW and feed consumption (FC) production functions in calculating the optimum ration specification, CP and metabolizable energy (ME) contents. Using a quadratic model to fit to the average data of 24 pens, they predicted BW as a function of CP and ME consumed. The predicted pounds of FC per bird was measured as a function of time, CP and ME content per pound of feed. A variable, measured as feeding period, was specified to interacted with the feed composition terms, CP and ME contents, because time is required for feed consumption regardless of feed composition. the resulting FC model was used to estimate pounds of feed consume per bird at given CP and ME contents for a variety of feeding periods. The LP was applied to calculate least-cost feed mixtures for various CP and ME specifications. The margins over feed cost for these various points on the production surface were calculated. Then, the highest profit was selected at the ration specification.

2.2.2 Nonlinear Programming

Pesti *et al.* (1986) proposed a quadratic response surface model of energy and protein to estimate growth responses. Quadratic programing was used to evaluate the optimum operation points in broiler production. The optimum operation points were defined as maximizing production or live body weight at a given fixed level of cost (feed cost per bird) and a set of inequality constraints on nutrients and feed ingredients. Economic theory was used to illustrate how the model estimated cost per pound of broiler production within a specific time interval and broiler quality (measured by carcass fat). They applied the law of diminising returns which states as nutrient levels increased, the bird performance increased at a decreasing rate. Least-cost feed formulation was studied under changing prices of corn and SBM affected CP and energy levels, which minimized cost per pound of meat. They concluded that quadratic programming can determine the most profitable CP and energy levels at variation in feed ingredient prices.

Talpaz et al. (1988) proposed a dynamic model to select the economically optimal growth trajectory of broilers. They also computed the feeding schedule that satisfies the nutritional requirements along this trajectory. They used nonlinear programming to determine the optimum growth path for a broiler and considered the essential AA profile for maintenance and requirement as major variables to evaluate optimum growth. Dynamic least-cost rations for the potential growth rate, subject to the nutritional requirement, were determined. The model estimated the daily optimal growth rates along with the corresponding requirements of total protein, amino acids, and energy in obtaining the optimal diets. Result indicated that as feed ingredient prices increased, more feed restrictions reduced the corresponding optimal growth trajectory. Thus, a substantial increase in profits can be achieved by following their methodology.

Gonzalez-Alcorta et al. (1994) used nonlinear programming techniques to determine the precise energy and protein levels that maximize profits. The BW and cumulative FI functions were generated as a quadratic function of energy and protein levels and age of the birds at time of processing. They found that as the price of corn increased, the energy level decreased and protein level increased. In addition, as the price of SBM increased, the protein level decreased while the energy level increased. They concluded that setting CP and energy levels at various input and output prices could increase profits compared with fixed levels of CP and energy based on nutritional guideline.

Costa *et al.* (2001) developed a two step profit-maximization model based on minimizing feed cost while maximizing revenue in broiler production. The minimizing feed cost was determined at the optimal feed consumed, feed cost, and overall production cost, which included cost of growing broilers, optimal length of time that the broilers stay in the house and interest rate. The maximum revenue was estimated at various broiler prices, either whole carcass or cut-up part prices, and optimum live or processed BW of the birds. Profit maximization was estimated at the optimal protein levels, which provided minimizing feed cost while maximizing revenue. They compared peanut meal as an alternative protein source for SBM and concluded that using peanut meal could generate more profit for growing broiler compare with SBM.

Guevara (2004) proposed nonlinear programming over the conventional linear programming to optimize broiler performance response to energy density in feed formulation because the energy level does not need to be set. The BW and FC were fit to quadratic equations in terms of energy density. The optimal ME level and bird performance were estimated by using Excel solver nonlinear programming. The variation in corn, SBM, fish meal and broiler prices were used. The nonlinear programming indicated that when the protein ingredient prices decreased, the energy density increased compared with the linear programming least cost formulation. The increased broiler price had a positive impact to BW and feed conversion and also increased energy density. The conclusion was that nonlinear programming can be used to define the optimal feed mix which maximizes margin over feed cost.

Eits *et al.* (2005b) focused on evaluating margin over feed costs (revenue minus feed costs). This return over investment concept as shown by Eits *et al.* (2005b) is the difference between increasing feed costs with increasing nutrient density and the decreasing incremental technical performance response from increasing nutrient density. Their model indicated the effect of dietary balanced protein on revenue and feed costs and from the difference of the two the margins over feed costs. The idea behind maximizing profitability through nutrition is to formulate the optimal nutrient density which maximizes profit.

Sterling *et al.* (2005) applied a quadratic growth response equation to estimate BW gain as a function of dietary lysine and CP intake using a quadratic programming model. The program was used to estimate maximum profit feed formulation and provided a working tool to demonstrate the interdependencies of costs, technical response functions and meat prices. Based on the quadratic programming model, increasing the price of SBM decreased CP and Lys level that gave maximum BW gain. They concluded that using maximum profit model instead of least cost model could generate improved profits.

Cerrate and Waldroup (2009a) proposed a maximum profit feed formulation model as an alternative for least-cost feed formulation. Based on Ross male performance, BW and cut-up parts were used to determine changes in dietary nutrient density which was the level of metabolizable energy (ME). The models accounted for livability, temperature, processing cost, ingredient and broiler prices, starting and ending broiler prices. The relative BW and feed consumption (FC) were estimated using a quadratic function of ME at 49 days of age. The absolute BW was estimated from the final day of feeding (49 days of age) using a Gompertz equation, while the absolute FC was predicted from the absolute BW using a quadratic equation. Carcass weight was calculated from the actual BW and yield (as a quadratic function of ME at 63 days of age). Cut-up parts were calculated by the multiplication of carcass weight and the constant of each cut-up part. They found that as the price of poultry fat increased, the ME level tended to decrease drastically, which reduced the usage of poultry fat and SBM in the diet while increasing the usage of corn. Their model had higher profits compared with least cost and provided improved profits when poultry oil prices increased by 150%.

Cerrate and Waldroup (2009b) compared four different economic nutritional models for maximum profit feed formulation of broilers. As there are many methods of feed formulation: consider the ratio of energy and some nutrients such as protein (Gonzalez-Alcorta *et al.*, 1994); or increase protein and AA levels while maintaining constant energy levels (Eits *et al.* (2005a,b); or increase energy levels while maintaining AA and CP (Dozier III *et al.*, 2006). The different feed formulation methods certainly provided different growth performance. The four models, which represented different methods of feed formulation, were a constant calorie-nutrient ratio (C-E:P: Model 1), a variable calorie-protein ratio (V-E:Pg: Model 2), a constant protein-amino acid ratio (DBP: Model 3) and a variable calorie-protein ratio for the finisher period (V-E:Pd: Model 4).

Using relative performance, economic nutrient requirements, and profitability to compare the four models. Cerrate and Waldroup (2009b) found that changing feed ingredient prices had some impact on the enery and protein contents based on the four models. For example, as corn or broiler price increased, the energy and protein contents of model 1-3 increased except the energy content of model 2 decreased. The opposite was found when SBM or poultry oil (fat) price increased. They concluded that model 1 was dominant in terms of feed formulation that provided the maximum performance and profitability. Model 4 dominated in terms of profits as well but with a narrow range of price changes and inconsistency of growth responses. Model 3 can be used at low corn or high SBM prices. The data set of Model 1 came from the past ten years that contained a new strain of birds and responses to increasing all the nutrients. Thus, the predicted BW from Model 1 was higher than Models 2 and 3, which resulted in the most profitable model. They commented that modern broilers with rapid growth do not adjust feed consumption to meet a fixed energy need. This resulted in the birds eating more energy as the energy content increased, especially when AA and CP increased along with the energy. However, when AA and CP were kept constant, the increase of energy content reduced feed consumption to balance the energy intake.

2.3 An Alternative Production Function: the Cobb-Douglas Production Function

According to Douglas (1976), the Cobb-Douglas function was found by computing the index numbers of the total number of manual workers (L), employed in American manufacturing by years from 1899 to 1922, and fixed capital (C), expressed in logarithmic terms, against the index for physical production (P). The product curve located about one-quarter away from the labor curve while further away from the capital curve, thus the formula was $P = bL^kC^{1-k}$. After finding the value of k by the method of least squares to be 0.75, the estimated values of P closely approximated the actual values for the 23-year period, which occurred to be the business cycle.

The Douglas (1976) study supported the hypothesis that production processes are well described by a linear homogeneous function with an elasticity of substitution of one between factors. During 1937 and 1947, the function formula was changed to $P = bL^kC^j$. The exponent of C, j, was then independently determined instead of calculating as a residual in a homogeneous linear equation. Thus, the production function was no longer constrained to be homogeneous of degree 1, but instead if $k + j = 1$, the economic system was subject to constant returns to scale. If $k + j$ was greater than 1, then a one percent increase in both L and C would be convoyed by an increase of more than one percent in P, and the system as a whole would operate under increasing returns. If $k + j$ was less than 1, then the system was characterized by diminishing returns.

According to Zellner *et al.* (1966), the function is broadly applied in economic theory because inputs, output, and profit of a firm are determined the production function, the definition of profit, and the conditions of profit maximization. The production function using the CD type with two inputs can be used as a production model of a firm as follows:

(1) $Y = aK^bL^d$ Production Function

(2) $\pi = pY - rK - wL$ Profit Function

(3) $\frac{\partial \pi}{\partial K} = 0$, $\frac{\partial \pi}{\partial L} = 0$ Maximizing Condition

where π is profits, Y, K, L are quantities of output and capital and labor inputs, respectively, and p, r, and w are their respective prices.

In broiler production, Heady (1957) applied CD function to determine the least-cost ration for different weight ranges based on the ration of corn and soybean oilmeal (two input variables). Kennedy *et al.,* (1976) used the CD form to determine broiler production models to estimate daily weight gain or daily energy intake as a function of ages, phases, BW and energy density (three input variables), and mortality as a function of age and BW (two input variables).

Zuidhof (2009) applied a nonlinear model based on a Cobb-Douglas form and a stepwise procedure to estimate feed intake as a function of BW, ME, Lys, gain, and sex (five input variables). These factors provided reasonable accuracy of predicted ME. Romero *et al.,* (2009) studied metabolizable energy utilization in broiler breeder hens and applied CD function to the interaction between BW and average daily gain or egg mass. The advantages of using CD function in this study are 1) the CD is asymptotic; 2) the CD follows the law of diminishing returns as similar to Monomolecular (Kuhi *et al.,* 2009), Satuation Kinetic and Logistic (Pesti *et al.* 2009c); and 3) it is widely used by many researchers (Heady, 1957; Walter, 1963; Zellner, 1966; Kmenta, 1967; Douglas, 1976; Kennedy *et al.,* 1976; Romero *et al.,* 2009; Zuidhof, 2009). Thus, this research applied the CD function to the profit maximization that has not been reported in the previous literature.

Most of the previously cited studies did not include time in their profit maximization model, except for the studies done by Brown and Arscott (1960), Gonzalez-Alcorta et al. (1994) and Costa *et al.* (2001). Time constraint is necessary to be accounted for in the model because an additional day of broilers stay in the house raises an additional cost to the overall broiler production. Moreover, time is required in growing broilers to reach the maximum profit weight (Costa *et al.*, 2001). Therefore, this research does consider time in the profit maximization model.

Besides, least cost feed formulation models of this research were based on BP concept while most of the research found did not apply this concept. Today's market prices of broilers are dramatically more volatile, compared with the scenarios presented in the previous research. Thus, the market price information of this research is up to date and reflects the current changes of nutrition and the economics of broiler production.

CHAPTER 3

ECONOMIC THEORY REVIEW

3.1 Production Functions

The production function is a relationship between the quantities of inputs used per time period and the maximum quantity of output that can be produced (Mansfield, 1988). A production function can be a table, a graph, or an equation that uses the amounts of N inputs (e.g. labor and raw materials) to produce an output (Timothy *et al.*, 2005). The production function explains the characteristics of existing technology at a given point in time (Mansfield, 1988). In order to explain the firm's technology, the generation of a production function for the firm is an important starting point, because the function provides the maximum total output that can be produced by using each combination of inputs. The average product of an input is determined using the total output divided by the total input used to produce this amount of output. The marginal product of an input is determined by the derivative of total output with respect to the change in an input. The production function can be slightly more complicated by increasing the number of variable inputs from one to two. Thus, the output becomes a function of two variables while the maximum amount of output is still the relationship between various combinations of inputs (Beattie and Taylor, 1985). The production function can be explained as

$$q = f(x) \tag{1}$$

where q is output, x = $(x_1, x_2, \dots, x_N)'$ is an N x 1 vector of inputs. The average product of the input is $\frac{q}{x} = \frac{f(x)}{x}$. Thus, the marginal product of the input is $\frac{dq}{dx} = \frac{df(x)}{dx}$ (Mansfield, 1988). An example of the production function with two variable inputs can be written as $q = f(L, K)$ where q is the output that can be produced under current technology at any given labor, L and capital, K (Hyman, 1988). A production process is called "Technological Efficiency" when it yields the highest level of output for a given set of inputs.

3.1.1 Properties of Production Functions

Although production functions vary by firm technology, they are based on a set of general assumptions (axioms). The properties of production functions certainly explain the relationship between the output and use of inputs when technology is given (Hyman, 1988).

i. Nonnegativity: The value of $f(x)$ is non-negative and finite real number (Timothy *et al.,* 2005).
ii. Monotonicity or nondecreasing in x: The additional units of an input that will cause a decrease in output will be disposed. Thus, the marginal products of the variable inputs are positive at the profit-maximizing level.
iii. Concave in x: Marginal products are non-increasing or approach zero as x increases, according to the law of diminishing marginal productivity (Timothy *et al.,* 2005).
iv. Monoperiodic: A firm's production activity in one time period is independent of production in following time period (Beattie and Taylor, 1985).

The production function of one input variable is shown in Figure 3.1. According to the properties, the production function violates the monotonicity property in the region after point C and violates the concavity property in the region 0A. The economically-feasible region of production is then region AC which follows all the properties. Point B is the point where the average product is maximized. The marginal product of x is positive along the curved segment between points 0 and C. The marginal product, which is the slope of the production function, is equal to zero at C.

When there is more than one variable input in the production function, the graphical analysis becomes more difficult. A three dimensional graph can be used to represent the production function in the case of two variable inputs. The plot of the relationship between two variable inputs (x_1 and x_2) while holding all other variable inputs constant and outputs (q_1, q_2, and q_3) are fixed (Figure 3.2). The isoquant provides information of all possible combinations of x_1 and x_2 that are capable of producing a certain quantity of output (Mansfield, 1988) where $q_3 > q_2 > q_1$. At fixed output of q_1, q_2, and q_3, the curves of Figure 3.2 show the output isoquants are non-intersecting functions and convex to the origin. The negative of the slope of the isoquant is called the marginal rate of technical substitution (MRTS) which measures the rate of substitution between x_1 and x_2 in order to retain the same output.

3.2 Cost Functions

A firm decision of choosing a combination of inputs is the one that minimizes the firm's cost of producing any level of output (Mansfield, 1988). The firm's cost is the sum of the price of the input times the amount of each input; $\mathrm{c}(\mathrm{r},\mathrm{q}) = \min_{\mathrm{x}} \mathrm{r}\,\mathrm{x}$ such that $q = f(x)$ where $\mathrm{r} = (\mathrm{r}_1, \mathrm{r}_2, \ldots, \mathrm{r}_\mathrm{n})$ is a vector of input prices.

3.2.1 Properties of Cost Functions (Timothy *et al.*, 2005)

i. Nonnegativity: A firm's cost can never be a negative value.

ii. Homogeneity: $\mathrm{c}(\mathrm{kr},\mathrm{q}) = \mathrm{kc}(\mathrm{r},\mathrm{q})$ where k is a constant and $k > 0$, that is k times increase in all input prices will increase costs by k times.

iii. Nondecreasing in r: If $\mathrm{r}^0 \geq \mathrm{r}^1$ then $\mathrm{c}(\mathrm{r}^0,\mathrm{q}) \geq \mathrm{c}(\mathrm{r}^1,\mathrm{q})$, that is if input prices increase then costs also increase.

iv. Nondecreasing in q: If $q^0 \geq q^1$ then $c(r, q^0) \geq c(r, q^1)$, that is more outputs are produced will not decrease costs.

v. Concave in r: Input demand functions cannot slope upwards.

3.3 Revenue Functions

A revenue function is used to determine the maximum revenue that can be obtained from a given input vector x (Timothy *et al.*, 2005). The function for a multiple input and output firm can be written as; $r(p, x) = {}^{\max}_{q} p\, q$ such that $q = f(x)$ where p= $(p_1, p_2, \ldots, p_m)$ is a vector of output prices of a perfectly competitive firm.

3.3.1 Properties of Revenue Functions (Timothy *et al.*, 2005)

i. Nonnegativity: A firm's revenue can never be a negative value.

ii. Homogeneity: $r(kp, x) = kr(p, x)$ where k is a constant and k > 0, that is k times increase in all output prices will increase revenue by k times.

iii. Nondecreasing in prices, p: If $p^0 \geq p^1$ then $r(p^0, x) \geq r(p^1, x)$, that is if output prices increase then revenues also increase.

iv. Nondecreasing in input quantities, x: If $x^0 \geq x^1$ then $r(p, x^0) \geq r(p, x^1)$, that is more inputs are used will not decrease revenues.

v. Convex in p: Output supply functions cannot slope downward.

3.4 Profit Functions

A profit function explains how firms use the information of input and output prices to select levels of inputs and outputs simultaneously. The function for a multiple input and output firm can be written as; $\pi(p, r) = {}^{\max}_{q,x} p\, q - r\, x$ such that $q = f(x)$ and maximum profit varies with p and r (Timothy *et al.*, 2005).

3.4.1 Properties of Profit Functions (Timothy *et al.*, 2005)

i. Nonnegativity: A firm's profit can never be a negative value.

ii. Homogeneity: $(\mathrm{kp}, \mathrm{kr}) = \mathrm{k} \; (\mathrm{p}, \mathrm{r})$ where k is a constant and k > 0, that is k times increase in all input and output prices will increase profit by k times.

iii. Nondecreasing in output prices, p: If $\mathrm{p}^0 \geq \mathrm{p}^1$ then $\pi(\mathrm{p}^0, \mathrm{r}) \geq \; (\mathrm{p}^1, \mathrm{r})$, that is if output prices increase then profit also increase.

iv. Nonincreasing in input prices, r: If $\mathrm{r}^0 \geq \mathrm{r}^1$ then $\pi(\mathrm{p}, \mathrm{r}^0) \geq \; (\mathrm{p}, \mathrm{r}^1)$, that is if input prices increase then profit will decrease.

v. Convex in output and input prices, (p, r): Profit functions cannot slope downward.

3.5 Profit Maximization

A profit-maximizing firm decides to choose the combination of inputs to produce any given level of output in order to maximize its profit rather than to constrained-maximum and constrained-minimum solutions. For a perfectly competitive firm, total revenue is the amount of output the firm produces multiply by the fixed unit price (p) the firm receives. The difference between its total revenue and total cost is profit. The firm can increase its profit as long as the additional revenue from using additional unit of an input exceeds its cost (first-order condition of profit functions). Moreover, profit must be decreasing with respect to additional unit of inputs (second-order conditions of profit functions, Henderson and Quandt, 1980).

3.6 Linear Programming

A general linear model in standard minimization or maximization form by using the summation sign to explain the objective function can be written as: Minimize (or Maximize) $r = \sum_{j=1}^{n} c_j x_j$ where the ith constraint is $\sum_{i=1}^{m} a_{ij} x_j \leq, = or \geq \; b_i$ and $x_j \geq 0$. The typical constraint is represented by i that run from 1 to n. The j represents the typical variable and run from 1 to m. The coefficient a_{ij} is the coefficient associated with the jth variable when it appears in the ith constraint (Mills, 1984).

Linear programming has been widely adopted by nutritionists in broiler production in order to determine a least-cost ration of feed ingredients under several nutrient constraints, such as metabolizable energy and protein, which essential in supporting broilers growth. The least-cost ration provides a fixed profit and productivity; it does not consider profit maximization.

3.7 Nonlinear Programming

Nonlinear programming is used to describe any computational algorithms that solve a problem in which a nonlinear objective function is to be optimized subject to linear constraints (Mills, 1984). The general approach to the nonlinear optimization problem is called gradient method. The direction of previous feasible solution point to a new point is determined by the gradient of the objective function at the previous solution point conditional on the new point is also feasible. Determination can be obtained by taking the first and second derivatives of the objective function and set it equal to the domain of interest for the variable.

Figure 3.1 Graphical illustration of a one input production function

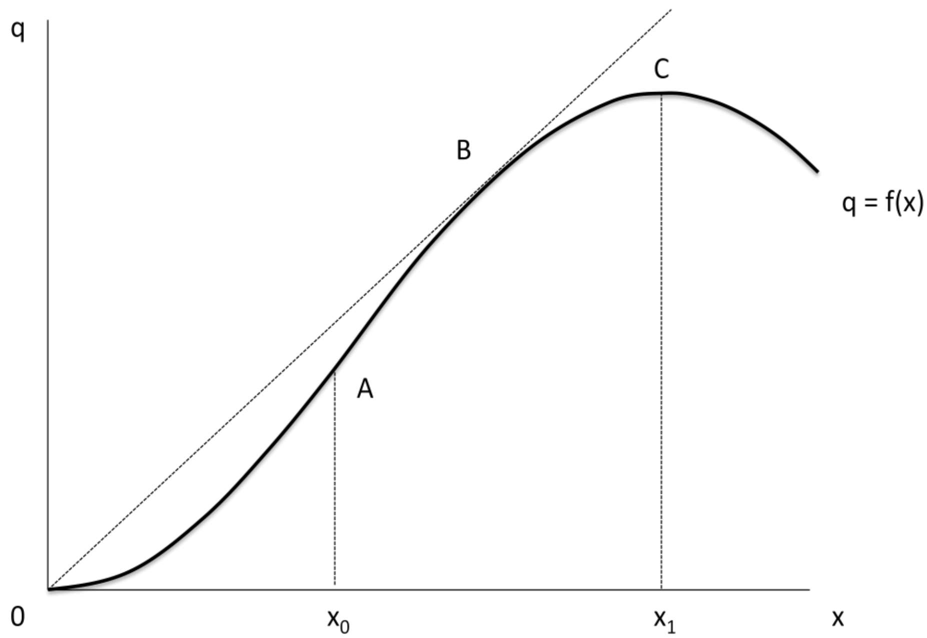
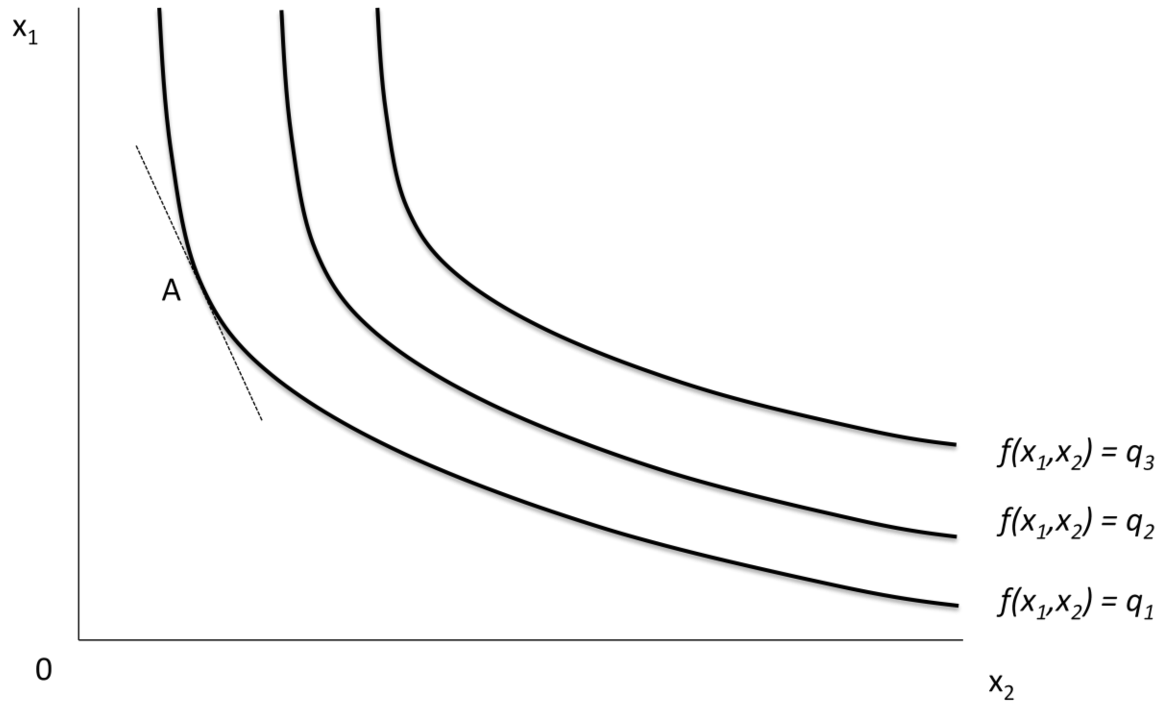


Figure 3.2 Graphical illustration of output isoquants of two inputs production function



CHAPTER 4

PROFIT MAXIMIZATION USING NONLINEAR PROGRAMMING OF BROILERS FED DIETARY BALANCED PROTEIN DURING GROWER AND FINISHER PHASES

4.1 Introduction

The model developed in this study is based on Costa et al. (2001). In contrast to Costa et al., 2001, Cobb-Douglas (CD) production functions were developed instead of quadratic functions; the optimum nutrient content in feed formulation was focused on digestible lysine (dLys), rather than crude protein (CP); the formulation ration fed during the experiment was formulated on dietary balanced protein concept (DBP) where essential amino acids (AA) were set proportional to lysine to ensure the balanced protein content in the diets and minimized the nitrogen excretion from broiler manure; the historical prices of major feed ingredients (corn and soybean meal) were used to evaluate the impact of low and high volatile prices to maximize profit under optimum feeding condition.

The model was then used to generate the optimum responses based on targeted markets: selling whole carcass or cut-up parts. The optimum responses were a function of current market prices of carcass, cut-up parts, and feed ingredients. The optimum dLys level during grower and finisher phases were determined and used to formulate the most profitable diets at a given targeted market and price scenario.

4.1.1 Linear Programming

Within the literature, the traditional least cost feed formulation using linear programming (LP) has been applied to formulate broiler diets at a given set of nutrient requirements (Allison and Baird, 1974; Brown and Arscott, 1960). A common objective of the formulations is to maximize bird performance (body weight [BW] or feed efficiency) by determining the least-cost ration. A shortcoming of a LP is not considering optimal bird performance in the production period. Although, the concept of a 95% asymptote has been applied to the maximum nutrient requirement, to ensure the safety margin of the formulated feed; it is still unknown whether the set requirement is optimal in terms of profitability.

Allison and Baird (1974) reported that the concept of LP was to minimize feed ingredient costs which provided maximum performance regardless of feed ingredient prices. Since feed nutrient such as AA were set at a minimum constraint in order to provide the maximum animal performance. Brown and Arscott (1960) estimated BW and feed consumption (FC) production functions in calculating the optimum ration specification, CP and metabolizable energy (ME) contents. Using a quadratic model to fit to the average data of 24 pens, they predicted BW as a function of CP and ME consumed. The predicted pounds of FC per bird was measured as a function of time, CP and ME content per pound of feed.

A variable, measured as feeding period, was specified to interacted with the feed composition terms, CP and ME contents, because time is required for feed consumption regardless of feed composition. The resulting FC model was used to estimate pounds of feed consume per bird at given CP and ME contents for a variety of feeding periods. The LP was applied to calculate least-cost feed mixtures for various CP and ME specifications. The margins over feed cost for these various points on the production surface were calculated. Then, the highest profit was selected at the ration specification.

4.1.2 Quadratic Programming

Quadratic programming (QP) has been widely discussed by many researchers (Miller *et al.,* 1986; Gonzalez-Alcorta *et al.,* 1994; Costa *et al.*, 2001; Guevara, 2004; Sterling *et al.*, 2005). The advantage of the QP over LP is it considers the optimal profit allocation of feed ingredient ration, while LP only considers the minimum feed cost ration. Miller *et al.* (1986) used QP, including a production function of growth responses to protein and energy, during 3 to 6 weeks of age of male broilers. In contrast to LP, their QP calculated the least-cost per pound of gain based on optimum bird performance which maximized profit at changing feed and broiler prices. They found that quadratic response is a concave function which represented broiler growth. The production response was transformed into a QP objective function and predicted live weight as a function of cumulative nutrient intake and intake as a function of growth.

Gonzalez-Alcorta *et al.* (1994) employed nonlinear programming techniques to determine the precise energy and protein levels that maximize profits. The BW and cumulative FC functions were generated as a quadratic function of energy, protein levels, and age of the birds at time of processing. They concluded that setting CP and energy levels at various input and output prices could increased a company's profit compared with fixed levels of CP and energy based on nutritional guideline.

Guevara (2004) proposed nonlinear programming over the conventional linear programming to optimize broiler performance response to energy density in feed formulation because the energy level does not need to be set. The BW and FC were fit to quadratic equations in terms of energy density. The optimal ME level and bird performance were then estimated. The variation in corn, SBM, fish meal, and broiler prices were considered. The conclusion was nonlinear programming can be used to define the optimal feed mix which maximizes margin over feed cost.

Sterling *et al.* (2005) applied a quadratic growth response equation to estimate BW gain as a function of dietary lysine and CP intake using a quadratic programming. The program was used to estimate maximum profit feed formulation and provided a working tool to demonstrate the interdependencies of costs, technical response functions, and meat prices. They concluded that using a maximum profit model instead of a least cost model could generate more profit for broiler production.

Costa *et al.* (2001) developed a two-step profit-maximization model based on minimizing feed cost while maximizing revenue in broiler production. The minimizing feed cost was determined at the optimal feed consume, feed cost, overall production cost, which included cost of growing broiler, optimal length of time that the broilers stay in the house and interest rate. The maximum revenue was estimated at the various broiler prices, either whole carcass or cut-up part prices, and optimum live or processed BW of the birds. The profit maximization was estimated at the optimal protein levels which provided minimizing feed cost while maximizing revenue.

4.1.3 Cobb-Douglas Production Function

The CD function hypothesis was production processes are well described by a linear homogeneous function with an elasticity of substitution of one between factors (Douglas, 1976). According to Zellner *et al.* (1966), the function is broadly applied in economic theory because inputs, output, and profit of a firm are determined by the production function, the definition of profit, and the conditions of profit maximization. The production function using the CD type with two inputs can be used as a production model of a firm as follows:

(1) $Y = aK^bL^d$ Production Function (assuming a concave function)

(2) $\pi = pY - rK - wL$ Profit Function

(3) $\frac{\partial\pi}{\partial K} = 0$, $\frac{\partial\pi}{\partial L} = 0$ Maximizing Condition

where π is profits, Y, K, L are quantities of output and capital and labor inputs, respectively, and p, r, and w are their respective prices.

Heady (1957) applied CD function into broiler production by determining the feeding interval based on the ration (corn and soybean oilmeal) in which average least-cost over a weight range instead of minimizing cost of feed. Zuidhof (2009) applied a nonlinear model based on a Cobb-Douglas form and a stepwise procedure to estimate feed intake as a function of BW, ME, Lysine, gain, and sex. These factors provided reasonable accuracy of predicted ME. The modeling of feed intake was the key because feed cost accounted for the largest portion of total broiler production cost. Romero *et al.*, (2009) studied ME utilization in broiler breeder hens. The CD function was applied to the interaction between BW and average daily gain or egg mass.

4.2 Materials and Methods

4.2.1 Experimental data

The experimental data from a dose-responses trial with Ross x Ross 708 male broilers were used (Sriperm and Pesti, 2011). Briefly, the study was conducted to evaluate the digestible lysine (dLys) responses to bird performance (body weights (BW), cumulative feed consumption (CFI)) and processing characteristics (carcass, breast meat, tenderloin, leg quarters, and wings weights) during grower (15 to 34 days) and finisher (35 to 49 days) phases. The dLys levels were maintained in a constant ratio to other essential AAs (Dietary Balanced Protein) across five experimental diets for each phase according to Ajinomoto Heartland LLC (2009) recommendations. The five treatment diets for each phase were formulated to contain the constant ME, sodium, calcium and phosphorus levels. There were 9 treatment combinations of dLys and crude protein levels for grower and finisher phases according to the central composite rotatable design used in the experiment. The data of bird performance and carcass characteristics at the end of day 42 and 49 were used to generate the models.

4.2.2 Model Composition

The objective function is profit per bird per feeding time, π, defined as average price of a broiler (P_{BW}) times live body weight (BW), minus total cost (TC). The optimum condition necessary to grow a broiler to the day (d) where BW, CFI and market condition is

$$\max \pi = P_{BW} * BW - TC \quad (4)$$

Subject to: $TC = [(r_{FC} + DEL)CFI * I] + [(GRO + FDOA) * BW * I] + TFC$ (5)

Least-cost feed in algebraic terms:

Minimize $r_{FC} = \sum_{j=1}^{n} c_j x_j$ (6)

Subject to $\sum_{i=1}^{m} a_{ij} x_j \leq, = or \geq b_i$ (7)

Constraints: $x_j \geq 0$ (8)

$\sum_{i=1}^{m} x_j = 1.0$ (9)

Nutritional Ratios: $lb \leq \frac{\sum_{j=1}^{n} a_{lj} x_j}{\sum_{j=1, l \neq k}^{n} a_{kj} x_j} \leq ub$ (10)

Equation 5 states that TC is the calculation of least-cost feed (r_{FC}) plus feed delivery cost (DEL) times feed consumed and interest (future cost accounted for feed consumption at d); plus the sum of grower cost (GRO) and field DOA and condemnation cost (FDOA) times broiler weight and interest (future value of chicken at d); plus fixed cost (TFC) such as chick cost, vaccination, supervising, and miscellaneous costs. The interest cost (I) was the calculation of $(1 + \frac{i}{365})^d$, where d is feeding days and i is the annual interest rate. Equation 6 is least-cost feed (r_{FC}), determined by selecting a set of decision variables and their quantities, which minimize a linear objective function that is subject to a set of linear restrictions (Equation 7), some constraints (Equation 8 and 9) and nutrition requirements (Equation 10). Coefficients of decision variables in the objective function, c_j, were cost per kg of dry matter for the j^{th} feed ingredient, x_j; b_i were nutrient requirements for the specified growth performance (e.g. ME); a_{ij} was the quantity of the i^{th} nutrient per kg of the j^{th} feed ingredient. (e.g. ME per kg corn, Black and Hlubik, 1980). The requirement cannot be negative (Equation 8). The summation of all ingredients was equal to a feed unit or one (Equation 9). Equation 10 is the nutritional model structures. The summation of all l nutrient content as a ratio to the summation of all k nutrient content is either set at the maximum ration of ub or the minimum ration of lb (Equation 10), where a_{lj}, a_{kj} are the quantity of l and k nutrients per kg of the j^{th} feed ingredient; ub was an upper bound and lb was a lower bound.

The calcium and available phosphorus ration was set at the maximum ration of 2.0. The DBP concept is the summation of digestible total sulfur amino acid (dTSAA) content was set at the minimum ration of 77 and 78 percent to the summation of dLys content during the grower and finisher phases, respectively. The summation of digestible Threonine (dThr) content was set at the minimum ration of 67 and 68 percent to the summation of dLys content during the grower and finisher phases, respectively. The summation of digestible Isoleucine (dIle) content was set at the minimum ration of 68 and 69 percent to the summation of dLys content during the grower and finisher phases, respectively. The summation of digestible Tryptophan (dTrp) content was set at the minimum ration of 16.5 and 17 percent to the summation of dLys content during the grower and finisher phases, respectively. The summation of digestible Arginine (dArg) content was set at the minimum ration of 108 and 110 percent to the summation of dLys content during the grower and finisher phases, respectively. The summation of digestible Valine (dVal) content was set at the minimum ration of 77 and 78 percent to the summation of dLys content during the grower and finisher phases, respectively.

The production functions (Equations 11, 12, 13) were estimated by ordinary least squares (OLS) using the Cobb-Douglas function applied to the experimental data.

$$BW = A * CFI^{\alpha} * \text{GdLys}^{\beta} * \text{FdLys}^{\gamma} \quad (11)$$

$$CFI = A * \text{GdLys}^{\delta} * \text{FdLys}^{\rho} * d^{\theta} \quad (12)$$

$$W_i = A * BW^{\eta} * \text{GdLys}^{\varphi} * \text{FdLys}^{\lambda} \quad (13)$$

where $A, \alpha, \beta, \gamma, \delta, \rho, \theta, \eta, \varphi$and λ were regression coefficients; GdLys and FdLys were the dLys levels during grower and finisher phases, respectively. Equation 11 models live broiler BW as a function of feed consumed per broiler (CFI), dLys levels provided during grower and finisher phases. Equation 12 models feed consumption per broiler as a function of dLys levels provided during two phases and feeding time (d). Equation 13 models the yield function of a whole carcass or cut-up parts as a function of BW and dLys levels provided during two phases, where i represented whole carcass or skinless boneless breast or tenderloin or leg quarters or wings or the rest of carcass. Equations 11 to 13 were analyzed in terms of log linear using PROC REG of SAS (2004).

When considering the targeted markets, in which the broilers will be sold, they can be divided into two sections: 1) selling whole carcass, or 2) selling cut-up parts. The derived average price of a broiler (P_{BW}) was calculated by using the live value of broilers delivered to the processing plant (LV_i) divided by the number of birds finished per house on the delivered day (BF) as shown in Equation 14. Equation 15 indicates that LV_i was calculated from the number of birds finished times percent of birds that were not dead at the processing plant and their values

(DP), plus those that were dead on the arrival multiplied by their price (PD). The DP was the average derived price per kg depended on the targeted market. It was calculated from the value of processed carcass or cut-up parts depending on the targeted market (W_i) times the dock price of each processed part i (P_i) that was subtracted from the processing cost (PC) and catching and hauling cost (CH, Equation 16).

$$P_{BW} = \frac{LV_i}{BF} \tag{14}$$

$$LV_i = [BF * (1 - DOA) * DP_i] + [BF * DOA * PD] \tag{15}$$

$$DP_i = \frac{\sum_{i=1}^{n}(W_i * (P_i - PC_i - CH_i))}{BW} \tag{16}$$

The number of birds finished, density and mortality were calculated according to Costa et al. (2001).

The optimum dLys levels during grower and finisher phases and broiler performance were computed using Excel (Microsoft, Seattle, WA) and Solver nonlinear programming (Frontline System, Inc., 1999) under state variables of cut-up parts and whole carcass dock prices (P_i), DOA and field condemnation (DOA), price of dead on arrivals and field condemnation (PD), processing cost of whole carcass and cut-up parts (PC), catching and hauling cost (CH), annual interest rate. Control variables were feed ingredient prices which provided feed cost (r_{FC}), total fixed cost (TFC), profit (π), derived average price of a broiler (P_{BW}), live body weight (BW), feed consumed (FC), feed cost (r), interest cost (I), feeding time (d), live value of broilers that delivered to the processing plant (LV), number of birds finished per house on the delivered day (BF), average derived price depended on the targeted market (DP).

Data used for economic analysis were obtained from a confidential survey conducted with a poultry company and the Georgia Department of Agriculture. The information contained prices of ingredients, production costs and targeted market prices. The formulations used in this study were based on corn, SBM, meat and bone meal and synthetic amino acids to assure the dietary protein was balanced. An example of diets, which maximized profit for whole carcass market during grower and finisher phases, and their nutrient compositions were reported in this study.

4.2.3 Historical Prices of Major Feed Ingredients

Feed ingredient (corn and soybean meal, SBM) prices between January 2000 and April 2011 were obtained from Mundi (2009). For analysis the data were divided into the low volatile period, January 2006 through December 2005, and the high volatile period, January 2006 and December 2005. Descriptive statistics (mean, variance, minimum, maximum, standard deviation, skewness and kurtosis) for the two periods along with the total data set are provided in Table 1. The skewness indicated an asymmetry of the distribution compare to the mean. The positive value indicated that the distribution is skewed to the right while the negative value indicated visa versa. The kurtosis value indicated that the distribution is peakedness (too tall) or flatness (too flat). The positive value indicated a peakedness distribution while the negative value indicated a flatness distribution compared to a normal distribution. A normal distribution produces a skewness and kurtosis equal to zero (Mendenhall and Sincich, 2003).

The data of corn and SBM prices were used to evaluate profit maximization conditions and its distribution function using Excel (Microsoft, Seattle, WA). The Solver nonlinear programming (Frontline System, Inc., 1999) under Excel was used to estimate the optimum feeding levels (levels of dLys that maximized profit under fixed grow-out day at 49 days of age and output price at $1.42 per kg live bird at 76% carcass yield) in order to make a clear observation of volatile feed ingredient prices. The program was used to calculated revenue (cent per bird), total cost (TC, cent per bird), maximum profit (cent per bird), conventional profit (cent per bird), and cost of making wrong decision (maximum profit minus conventional profit, cent per bird), then using PROC MEANS of SAS (2004) to calculate their descriptive statistics. The conventional profits were calculated based on the recommended dLys levels of Ross 708 (Aviagen, 2007) at 1.10 % dLys during 11 to 24 days and 0.97% dLys during 25 days of age to market. PROC GLM of SAS (2004) was used to compare mean differences using a pairwise comparison procedure based on t-test: Least Significant Differences (LSD) when differences were found at the 5% significance level.

4.3 Results and Discussion

4.3.1 Production Functions

The Cobb-Douglas production functions based on Equations 11 to 13 were reported in Tables 1 and 2. The coefficient of determinations (R^2) of live BW, CFI and carcass weight production functions were 0.99, 0.97 and 0.91, respectively. The F values of the three production functions were found to be highly significance ($P < 0.0001$, Table 1). The production function of live BW suggested that BW increased significantly as birds were fed either higher dLys levels during both phases or consumed more feed. This BW response was expected from an increased dLys level or feed intake.

Amount of feed consumed was the major impact to live BW since its coefficient was the largest value among the coefficients. This meant a percentage increase in CFI improved BW by 0.867 percent. Noticeably, CFI production function suggested that feed consumption decreased significantly when birds are fed higher dLys level during finisher phase. Moreover, feed consumption increased significantly when increased number of days in the house. The number of days in the house had the biggest impact to CFI since a percentage increase in number of days in the house increased CFI by 1.735 percent.

Carcass weight production function suggested that carcass weight increased significantly with respect mainly to live BW since a percentage increase in BW improved carcass weight by 1.035 percent (Table 1). Table 2 showed the production functions of cut-up parts and the rest of carcass. All production functions depended mainly on live BW of broilers. The weights of skinless boneless breast meat, tenderloin, wings and the rest of carcass increased as birds BW and dLys levels during grower phase increased significantly. The estimated coefficients of Table 2 showed that only the GdLys coefficient was found to be significantly negative impact to the rest of carcass, which had low in market value. This suggested that feeding broilers at higher dLys levels improved broiler market value.

4.3.2 Profit Maximization of Broiler Production under Changes in Feed Ingredient and Broiler Market Prices

Table 3 compared the profitability of selling whole carcass at various carcass and feed ingredients (corn and SBM) prices. At the fixed feed ingredient prices, corn at $275 per MT and SBM at $400 per MT, while reduced carcass price from $1.87 to $1.65 per kg, the profitability analysis using Excel (Microsoft, Seattle, WA) estimated that the targeted carcass weight and feeding day declined. This result agreed with the study of Costa et al. (2001) that when carcass price declined, the solution was to raise smaller birds, which meant less feeding days. Moreover, the optimum dLys levels during grower and finisher phases, live BW, feed cost, derived price and profit were lower at low carcass price compared with high carcass price. The initiated number of birds at low carcass price was higher compared with high carcass price because of smaller birds with less floor space were expected to produced.

When both corn and SBM prices decreased (corn dropped from $275 to $236 per MT, SBM dropped from $400 to $350 per MT) while carcass price was fixed at $1.87 per kg, total profit increased due to low feed ingredient cost. Thus, the overall profit of lower feed ingredient costs per house per period increased about 371 thousand dollars. When corn and SBM prices were fixed at $236 per MT, SBM $350 per MT) while carcass prices increased from $1.87 to $2.09 per kg), the targeted carcass weight increased. The optimum dLys levels during grower and finisher phases, live BW, feed cost, derived price and profit also increased compared with the lower carcass price scenario.

The profitability of selling cut-up parts (breast meat, tenderloin, leg quarters and wings) at various carcass and feed ingredients (corn and SBM) prices were shown in Tables 4 to 7, respectively. The results under these scenarios suggested that the most profitable strategy of producing broilers was to target selling cut-up parts which shown higher profit compared with targeted selling whole carcass. The programming using Excel then formulated grower and finisher phase diets based on optimum dLys levels which maximized profit. An example of the diets that maximize profit for targeted whole carcass market based on corn, SBM and carcass prices at $275 and $400 per MT, and $1.87 per kg, respectively, was shown in Tables 8 and 9. These diets were formulated using DBP concept to ensure the dietary protein was balanced.

The summarized result of profitability analysis based on targeted market of selling whole carcass and cut-up parts (Tables 3 to 7) was shown in Table 10. The changes in price of carcass and cut-up parts (P_c) to the change in variables in column (y) that greater than zero explained a positive relationship between the price changes and variables in the column, in order to maximized profit. Therefore, as prices of carcass and cut-up parts increased, the optimum profit solution was to increase targeted weight of carcass and cut-up parts. As prices of feed ingredients increased, the optimum profit solution was to increase or retain the targeted weight of carcass and cut-up parts (Table 10). As prices of carcass, cut-up parts and feed ingredients increased, the optimum profit solution was to increase the dLys level during grower and finisher phases; unless the level was at the maximum constraint then it can be retained. The other variables can be explained in the same manner.

4.3.3 Profit Maximization under Low and High Volatility of Feed Ingredient Prices

Comparison of corn and SBM prices between January 2000 and December 2005, which represented a low volatile period, and between January 2006 and April 2011, which represented a high volatile period was shown in Table 11 and Figure 1. The means of corn and SBM prices during high volatile period ($179.43 and $309.35 per MT, respectively) were significantly higher than low volatile period ($98.76 and $204.90 per MT, respectively, Table 12) at 5% level. The spread (the difference between SBM and corn prices) of high volatile period was also significantly higher compared with low volatile period ($106.14 vs. $129.92 per MT).

The skewness and kurtosis of corn, spread and total cost were positive values, which indicated that the distribution was skewed to the right and peakedness. The skewness of maximum profit during low volatile period showed a negative value while the kurtosis showed a positive value. This indicated that the distribution of maximum profit during low volatile skewed to the left and too tall compared with the high volatile (Figure 2). The skewness and kurtosis of maximum profit during high volatile were closer to zero compared with low volatile period. The results indicated that the distribution of maximum profit during high volatile period was similar to a normal distribution.

The means of maximum profit (calculated from the optimum dLys levels) and conventional profit (calculated from the breeder recommended dLys levels) of low volatile period was significantly higher compared with high volatile period (Table 12). These were mainly due to lower feed cost during low volatile period. The average cost of making wrong decision (when using breeder recommendation instead of optimum dLys levels) was higher during high volatile period compared with low volatile period, even though they are not significantly difference. This result suggested that during high volatile period, the optimum dLys levels which maximized profit should be considered because of the large variance of feed ingredient prices. Thus, feeding the optimum dLys levels that maximized profit was a better decision to gain more profit compared with using the breeder recommended feeding levels.

4.4 Conclusions

1. By using the optimal relative to the conventional, mean profits increase 1% in the high volatile period compared to 0.8% in low volatile period. Using the optimal relative to conventional is more valuable given volatile prices.

2. However, the optimal method was not able to greatly reduce the variance in profit during the high volatile period. If the producers are risk averse, some other method of risk management may be required. Only 1.9% in variance reduction occurred.

3. The optimal method did reduce the variance by 16% over the conventional in low volatile period.

4. The conventional method does surprisingly about the same will relative to the optimal in terms risk reduction during the high volatile period, but not as well during the low volatile period.

Table 4.1 Cobb-Douglas function results for broiler live production: live body weight (BW), cumulative feed intake (CFI) and carcass weight.[a]

Variable	Body Weight	Cumulative Feed Intake	Carcass Weight
Intercept (A)	-0.226***	-4.889***	-0.314***
	0.019	*0.129*	*0.045*
CFI	0.867***		
	0.011		
GdLys[b]	0.059***	0.010	0.012
	0.009	*0.015*	*0.025*
FdLys[c]	0.078***	-0.067***	0.013
	0.009	*0.015*	*0.025*
Day		1.735***	
		0.034	
BW			1.035***
			0.035
R^2	0.985	0.967	0.906
F value	2024.29	886.38	293.76
Pr > F	<0.0001	<0.0001	<0.0001
N	96	96	96

Standard errors are in italics.
** Statistically significant at the 0.05 level.
*** Statistically significant at the 0.01 level.
Body weight, CFI and carcass weight functions are estimated in kg.
[a] Cobb-Douglas Production Function of estimated Body Weight = $e^{A} * CFI^{\alpha} * \text{GdLys}^{\beta} * \text{FdLys}^{\gamma}$; CFI = $e^{A} * \text{GdLys}^{\delta} * \text{FdLys}^{\rho} * Day^{\theta}$; Carcass Weight = $e^{A} * BW^{\eta} * \text{GdLys}^{\varphi} * \text{FdLys}^{\lambda}$, where $A, \alpha, \beta, \gamma, \delta, \rho, \theta, \eta, \varphi$ and λ were regression coefficients.
[b] Digestible lysine level during grower phase (%).
[c] Digestible lysine level during finisher phase (%).

Table 4.2 Cobb-Douglas function results for broiler processing: breast meat, tenderloin, leg quarters, wings and rest of carcass.[a]

Variable	Breast Meat	Tenderloin	Leg Quarters	Wings	Rest of Carcass
Intercept (A)	-1.756***	-3.220***	-1.489***	-2.384***	-1.599***
	0.060	*0.066*	*0.051*	*0.044*	*0.058*
BW	1.131***	1.028***	1.043***	0.891***	0.985***
	0.047	*0.052*	*0.040*	*0.034*	*0.045*
GdLys	0.085**	0.123**	-0.018	0.040*	-0.058*
	0.033	*0.036*	*0.028*	*0.024*	*0.032*
FdLys	0.042	0.055	0.028	0.018	-0.039
	0.033	*0.036*	*0.028*	*0.024*	*0.032*
R^2	0.868	0.824	0.882	0.883	0.839
F value	202.26	143.32	229.12	231.98	159.90
Pr > F	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
N	96	96	96	96	96

Standard errors are in italic.
* Statistically significant at the 0.10 level.
** Statistically significant at the 0.05 level.
*** Statistically significant at the 0.01 level.
Body weight, CFI and carcass weight functions are estimated in kg.
[a] Cobb-Douglas Production Function of estimated Breast Meat, Tenderloin, Leg Quarters, Wings and Rest of Carcass = $e^{A} * BW^{\eta} * \text{GdLys}^{\varphi} * \text{FdLys}^{\lambda}$, where A, η, φand λ were regression coefficients.
[b] Digestible lysine level during grower phase (%).
[c] Digestible lysine level during finisher phase (%).

Table 4.3 Scenarios used to analyze the profitability, dLys levels and feeding days which maximize profit at various feed ingredient and carcass prices.

Variable	Unit	Scenarios			
Corn	$/MT	275	275	236	236
SBM	$/MT	400	400	350	350
Carcass Price	$/kg	1.87	1.65	1.87	2.09
Profitability analysis based on targeted market of selling whole carcass					
Carcass Target Weight	Kg	3.02	2.59	3.02	3.08
Grower dLys Level	%	0.89	0.74	0.92	1.11
Finisher dLys Level	%	0.73	0.70	0.71	0.79
Feeding Time	Days	49	45	49	49
Body Weight	Kg	3.96	3.42	3.97	4.02
Feed Consume	kg/bird	6.58	5.66	6.60	6.56
Feed per Gain	kg/kg	1.66	1.65	1.66	1.63
Feed Cost	$/bird	2.11	1.76	1.89	1.97
Derived Price[a]	$/kg live bird	1.13	0.96	1.13	1.31
Profit	$/bird	1.43	0.74	1.67	2.31
Birds Initiated[b]	Birds/house	16,546	19,427	16,506	16,202
Broiler House Profit	$/house/period	2,293,018	1,395,627	2,664,072	3,617,790

[a] The price per kg depended on the targeted market times the dock price of each processed part i and subtracted the processing cost, and catching and hauling cost.
[b] Number of birds settle per house at the beginning of grow-out period.

Table 4.4 Scenarios used to analyze the profitability, dLys levels and feeding days which maximize profit at various feed ingredient and breast meat prices.

Variable	Unit	Scenarios			
Corn	$/MT	275	275	236	236
SBM	$/MT	400	400	350	350
Breast Meat Price	$/kg	3.04	2.76	3.04	3.97
Profitability analysis based on targeted market of selling breast meat					
Breast Meat Target Weight	kg	0.87	0.86	0.87	0.87
Grower dLys Level	%	1.25	1.25	1.25	1.25
Finisher dLys Level	%	1.05	1.00	1.04	1.19
Feeding Time	Days	49	49	49	49
Targeted Body Weight	kg	4.083	4.080	4.082	4.094
Feed Consume	kg/bird	6.447	6.465	6.452	6.393
Feed per Gain	kg/kg	1.58	1.58	1.58	1.56
Feed Cost	$/bird	2.32	2.31	2.08	2.12
Derived Price[a]	$/kg live bird	1.348	1.285	1.347	1.550
Profit	$/bird	2.191	1.955	2.428	3.194
Birds Initiated[b]	Birds/house	15,905	15,924	15,910	15,850
Broiler House Profit	$/house/period	3,370,476	3,011,296	3,737,155	4,897,238

[a] The price per kg depended on the targeted market times the dock price of each processed part i and subtracted the processing cost, and catching and hauling cost.
[b] Number of birds settle per house at the beginning of grow-out period.

Table 4.5 Scenarios used to analyze the profitability, dLys levels and feeding days which maximize profit at various feed ingredient and tenderloin prices.

Variable	Unit	Scenarios			
Corn	$/MT	275	275	236	236
SBM	$/MT	400	400	350	350
Tenderloin Price	$/kg	3.75	3.31	3.75	4.41
Profitability analysis based on targeted market of selling tenderloin					
Tenderloin Target Weight	kg	0.175	0.175	0.175	0.175
Grower dLys Level	%	1.25	1.25	1.25	1.25
Finisher dLys Level	%	1.05	1.03	1.04	1.06
Feeding Time	Days	49	49	49	49
Targeted Body Weight	kg	4.083	4.082	4.082	4.084
Feed Consume	kg/bird	6.447	6.453	6.452	6.442
Feed per Gain	kg/kg	1.58	1.58	1.58	1.58
Feed Cost	$/bird	2.32	2.31	2.08	2.08
Derived Price[a]	$/kg live bird	1.348	1.328	1.347	1.377
Profit	$/bird	2.191	2.117	2.428	2.538
Birds Initiated[b]	Birds/house	15,905	15,911	15,910	15,900
Broiler House Profit	$/house/period	3,370,476	3,259,013	3,737,155	3,904,009

[a] The price per kg depended on the targeted market times the dock price of each processed part i and subtracted the processing cost, and catching and hauling cost.
[b] Number of birds settle per house at the beginning of grow-out period.

Table 4.6 Scenarios used to analyze the profitability, dLys levels and feeding days which maximize profit at various feed ingredient and leg quarters prices.

Variable	Unit	Scenarios			
Corn	$/MT	275	275	236	236
SBM	$/MT	400	400	350	350
Leg Quarters Price	$/kg	0.85	0.80	0.85	0.90
Profitability analysis based on targeted market of selling leg quarters					
Leg Quarters Target Weight	Kg	0.976	0.976	0.975	0.976
Grower dLys Level	%	1.25	1.25	1.25	1.25
Finisher dLys Level	%	1.05	1.04	1.04	1.04
Feeding Time	Days	49	49	49	49
Targeted Body Weight	Kg	4.083	4.083	4.082	4.083
Feed Consume	kg/bird	6.447	6.449	6.452	6.449
Feed per Gain	kg/kg	1.58	1.58	1.58	1.58
Feed Cost	$/bird	2.32	2.32	2.08	2.08
Derived Price[a]	$/kg live bird	1.348	1.337	1.347	1.361
Profit	$/bird	2.191	2.150	2.428	2.479
Birds Initiated[b]	Birds/house	15,905	15,907	15,910	15,907
Broiler House Profit	$/house/period	3,370,476	3,308,042	3,737,155	3,815,062

[a] The price per kg depended on the targeted market times the dock price of each processed part i and subtracted the processing cost, and catching and hauling cost.
[b] Number of birds settle per house at the beginning of grow-out period.

Table 4.7 Scenarios used to analyze the profitability, dLys levels and feeding days which maximize profit at various feed ingredient and wings prices.

Variable	Unit	Scenarios			
Corn	$/MT	275	275	236	236
SBM	$/MT	400	400	350	350
Wings Price	$/kg	2.39	2.09	2.39	3.97
Profitability analysis based on targeted market of selling wings					
Wings Target Weight	Kg	0.326	0.326	0.326	0.327
Grower dLys Level	%	1.250	1.250	1.250	1.250
Finisher dLys Level	%	1.049	1.033	1.035	1.090
Feeding Time	Days	49	49	49	49
Targeted Body Weight	Kg	4.083	4.082	4.082	4.087
Feed Consume	kg/bird	6.447	6.453	6.452	6.430
Feed per Gain	kg/kg	1.58	1.58	1.58	1.57
Feed Cost	$/bird	2.32	2.31	2.08	2.09
Derived Price[a]	$/kg live bird	1.348	1.313	1.347	1.475
Profit	$/bird	2.191	2.057	2.428	2.918
Birds Initiated[b]	Birds/house	15,905	15,911	15,910	15,888
Broiler House Profit	$/house/period	3,370,476	3,166,787	3,737,155	4,484,138

[a] The price per kg depended on the targeted market times the dock price of each processed part i and subtracted the processing cost, and catching and hauling cost.

[b] Number of birds settle per house at the beginning of grow-out period.

Table 4.8 Composition of the diets during grower and finisher phases which maximize profit for carcass market where corn, SBM and carcass prices were $275 and 400 per MT, and $1.87 per kg, respectively.

Ingredients	Grower Diet	Finisher Diet
Corn	69.47	76.79
Soybean Meal	22.63	16.40
Meat & Bone Meal	3.00	3.00
Poultry Fat	2.19	1.09
L-LysineHCl	0.17	0.16
DL-Methionine	0.27	0.19
L-Threonine	0.07	0.05
Limestone	1.05	1.06
Defluorinated P	0.18	0.23
Salt	0.42	0.27
UGA Vitamin PMX	0.25	0.25
UGA Mineral PMX	0.08	0.08
Choline Chloride	0.05	0.07
S-Carb	0.00	0.19
Copper Sulfate	0.04	0.04
Quantum 2,500	0.02	0.02
BMD-50	0.05	0.05
Coban 90	0.06	0.06
Total	100.00	100.00
Feed cost, $/ MT	367.1	346.8

Table 4.9 Nutrient composition of the diets during grower and finisher phases which maximize profit for the carcass market where corn, SBM and carcass prices were $275 and 400 per MT, and $1.87 per kg, respectively.

Composition	Grower Diet	Finisher Diet
Nutrients (% and Ratios)		
Crude Protein, %	17.45	14.86
ME Mcal / kg	3.16	3.16
Digestible Lys, %	0.89	0.73
Dig Met / Dig Lys	54	52
Dig M+C / Dig Lys	77	77
Dig Thr / Dig Lys	67	67
Dig Trp / Dig Lys	19	19
Dig Ile / Dig Lys	68	68
Dig Val / Dig Lys	79	81
Dig Arg / Dig Lys	116	117
Tot Gly / Dig Lys	93	100
Calcium, %	0.93	0.93
Avaliable P., %	0.46	0.46
Ca / Available P	2.00	2.00
Sodium, %	0.22	0.22
Digestible Amino Acids (%)		
Lysine	0.89	0.73
Methionine	0.48	0.38
Met + Cys	0.68	0.56
Threonine	0.59	0.49
Tryptophan	0.17	0.14
Isoleucine	0.60	0.49
Valine	0.70	0.59
Arginine	1.03	0.85
Leucine	1.27	1.12
Histidine	0.37	0.31
Alanine	0.77	0.68
Glutamic Acid	2.52	2.11
Aspartic Acid	1.36	1.10
Phenylalanine	0.73	0.61
Proline	0.91	0.81
Serine	0.70	0.59
Tyrosine	0.33	0.28
Total Glycine	0.71	0.61
Dig. Essential Amino Acids (DEAA)	6.83	5.69
Dig. Non-essential Amino Acids (DNEAA)	7.50	6.37
Sum of the Dig. AA (DAA)	14.33	12.07
DEAA / DAA	47.65	47.17
DNEAA / DAA	52.35	52.83
DAA / CP	82.15	81.22

Table 4.10 Summary of the scenarios changed to the dLys levels and feeding days which maximize profit at various feed ingredient and cut-up part prices.

Variables (y)	Unit	Profitability analysis based on targeted market of selling cut-up parts				
		Carcass	Breast meat	Tenderloin	Leg quarters	Wings
Cut-Up Part Target Weight	Kg	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} < 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$
Grower dLys Level	%	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} < 0$	$\frac{\partial y}{\partial P_c} = 0, \frac{\partial y}{\partial P_f} = 0$	$\frac{\partial y}{\partial P_c} = 0, \frac{\partial y}{\partial P_f} = 0$	$\frac{\partial y}{\partial P_c} = 0, \frac{\partial y}{\partial P_f} = 0$	$\frac{\partial y}{\partial P_c} = 0, \frac{\partial y}{\partial P_f} = 0$
Finisher dLys Level	%	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$
Feeding Time	Days	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} = 0$	$\frac{\partial y}{\partial P_c} = 0, \frac{\partial y}{\partial P_f} = 0$	$\frac{\partial y}{\partial P_c} = 0, \frac{\partial y}{\partial P_f} = 0$	$\frac{\partial y}{\partial P_c} = 0, \frac{\partial y}{\partial P_f} = 0$	$\frac{\partial y}{\partial P_c} = 0, \frac{\partial y}{\partial P_f} = 0$
Targeted Body Weight	Kg	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$
Feed Consume	Kg/bird	$\frac{\partial y}{\partial P_c} > or < 0, \frac{\partial y}{\partial P_f} < 0$	$\frac{\partial y}{\partial P_c} > or < 0, \frac{\partial y}{\partial P_f} < 0$	$\frac{\partial y}{\partial P_c} < 0, \frac{\partial y}{\partial P_f} < 0$	$\frac{\partial y}{\partial P_c} < 0, \frac{\partial y}{\partial P_f} < 0$	$\frac{\partial y}{\partial P_c} < 0, \frac{\partial y}{\partial P_f} < 0$
Feed Cost	$/bird	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$
Profit	$/bird	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} < 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} < 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} < 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} < 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} < 0$

P_c is the price of cut-up part; P_f is the price of feed ingredients.

Table 4.11 Descriptive statistics of the corn and soybean meal (SBM) prices and their spread (SBM minus corn prices) between low volatile period (January 2000 to December 2005) and high volatile period (January 2006 to April 2011).

Descriptive Statistics	Corn $/MT	SBM $/MT	Spread $/MT
Descriptive Statistics between January 2000 and December 2005			
Mean	98.76[b]	204.90[b]	106.14[b]
Variance	135.52	1691.60	1063.54
Minimum	75.06	165.45	74.19
Maximum	133.39	343.71	210.32
Skewness	0.79	1.92	1.76
Kurtosis	1.09	3.25	2.62
Standard Deviation	11.64	41.13	32.61
N	72	72	72
Descriptive Statistics between January 2006 and April 2011			
Mean	179.43[a]	309.35[a]	129.92[a]
Variance	2539.46	5918.71	2430.86
Minimum	102.70	175.91	45.03
Maximum	318.45	452.19	262.95
Skewness	0.85	-0.21	0.36
Kurtosis	0.31	-1.05	0.02
Standard Deviation	50.39	76.93	49.30
N	64	64	64

[1] The difference between feeding the dLys levels that maximized profit (Maximum profit) and the dLys levels that recommended by the breeder (Conventional profit).

Means in a column with different letters (LSD multiple range test) differ significantly ($P < 0.05$).

Table 4.12 Descriptive statistics of dLys levels that maximized profit during grower and finisher phases, revenue, total cost, maximum profit, conventional profit and cost of making wrong decision between low volatile period (January 2000 to December 2005) and high volatile period (January 2006 to April 2011).

Descriptive Statistics	Grower dLys level %	Finisher dLys level %	Revenue Cent/bird	Total cost Cent/bird	Maximum profit Cent/bird	Conventional profit Cent/bird	Cost of making wrong decision[1] Cent/bird
Descriptive Statistics between January 2000 and December 2005							
Mean	1.25[a]	0.78	571.08[a]	211.40[b]	359.68[a]	356.93[a]	2.75
Variance	0.02	0.004	28.39	81.57	189.08	224.85	−35.77
Minimum	0.78	0.71	552.25	194.97	315.79	307.10	8.69
Maximum	1.30	0.95	575.34	236.46	378.72	376.41	2.31
Skewness	-2.52	0.63	-2.43	0.86	-1.61	-1.79	
Kurtosis	5.06	-0.18	4.92	0.60	2.41	2.99	
Standard Deviation	0.13	0.06	5.33	9.03	13.75	15.00	
N	72	72	72	72	72	72	
Descriptive Statistics between January 2006 and April 2011							
Mean	1.09[b]	0.77	565.27[b]	263.20[a]	302.07[b]	299.14[b]	2.93
Variance	0.03	0.01	56.82	1009.12	1316.84	1342.07	−25.23
Minimum	0.77	0.71	551.75	213.21	222.99	222.69	0.29
Maximum	1.30	1.05	576.69	349.35	359.63	357.55	2.07
Skewness	-0.06	1.74	0.0002	0.64	-0.36	-0.31	
Kurtosis	-1.40	2.00	-1.27	0.12	-0.42	-0.50	
Standard Deviation	0.18	0.10	7.54	31.77	36.29	36.63	
N	64	64	64	64	64	64	

[1] The difference between feeding the dLys levels that maximized profit (Maximum profit) and the dLys levels recommended by the breeder (Conventional profit).

Means in a column with different letters (LSD multiple range test) differ significantly ($P < 0.05$).

Figure 4.1 Historical corn and soybean meal prices and their spread (soybean meal price minus corn price) between January 2000 and April 2011

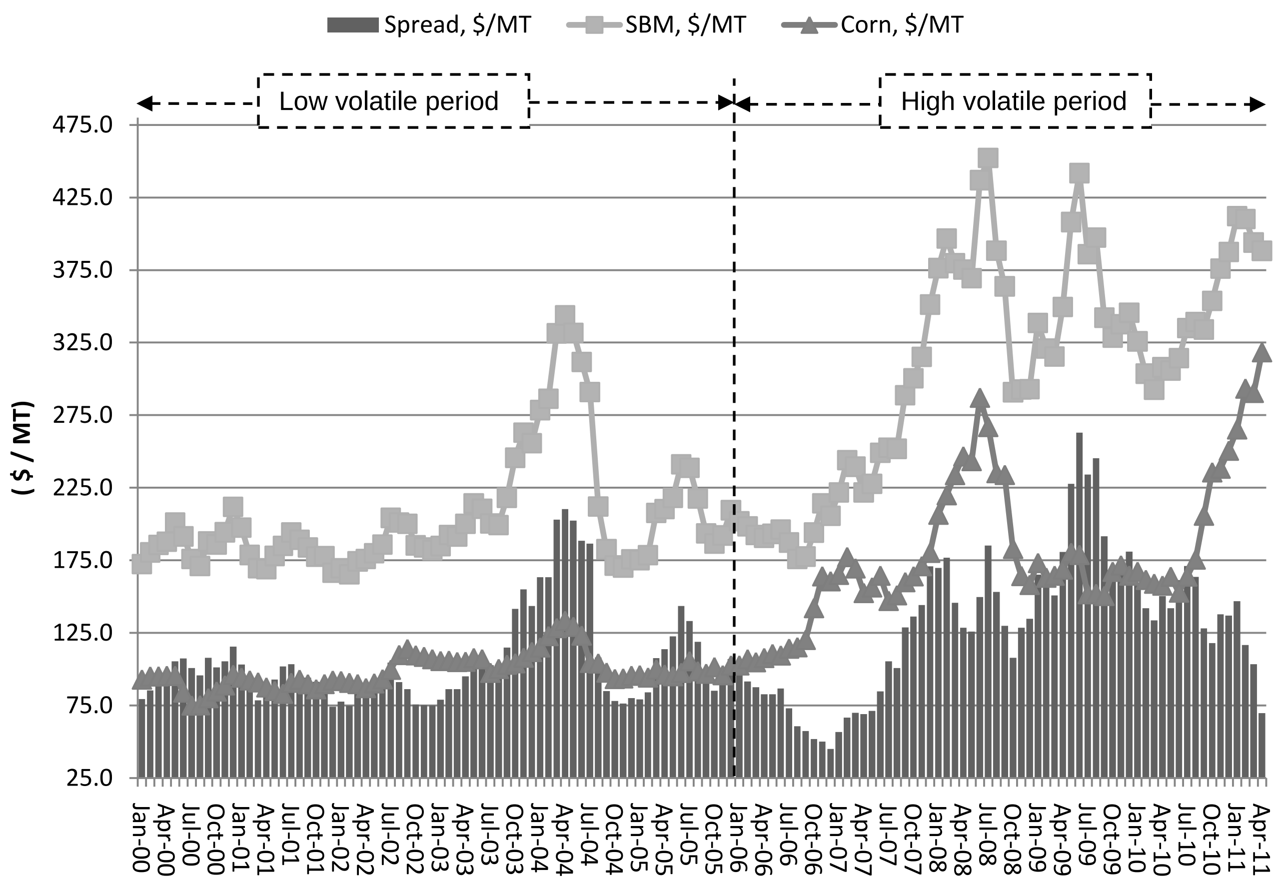
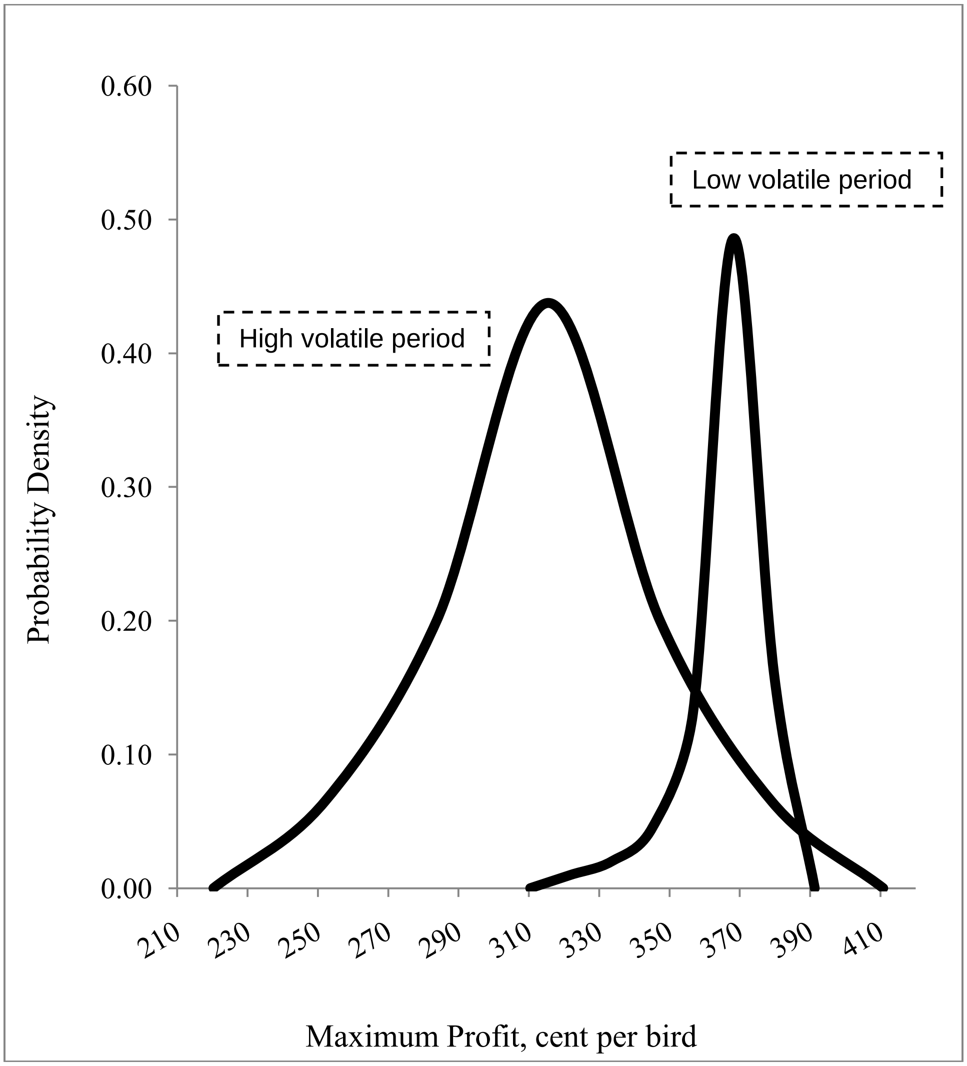


Figure 4.2 Probability distributions of maximum profit conditions during low (January 2000 to December 2005) and high (January 2006 to April 2011) volatile periods



CHAPTER 7

CONCLUSIONS

The objective of this research was to demonstrate that the broiler production decision, based on the targeted market for selling whole carcass or cut-up parts, can be evaluated using broiler growth performance information and a profit function. Nonlinear models of production functions, using broiler growth performance information, were used in the profit function to evaluate a profit-maximization condition that operated under Microsoft Excel spreadsheet. The spreadsheets make the analysis accessible to chicken producers and integrators. The profit model can determine the optimum conditions where a producer utilizes its production, inputs, and processing plant to obtain the maximum profit. This research showed that growth responses can vary depending on the maximum profit of feeding the formulated diet to broilers under various feed ingredient and broiler market prices. At constant output prices, increasing input costs decreases the size of bird that maximizes profits. Similarly, at constant input costs, increasing output prices increases the size of bird that maximizes profits. The marginal product of input (feed consumption) is the change in output (liveweight) as the change in feed consumption goes to zero. To maximize profit, the marginal product of feed consumption must be equal to the price of the feed consumed divided by the liveweight price. Profitability can be improved when revenue and costs are both considered in the formulation of broiler diets. Broiler growth and feed intake are two key components in determining the profit, which are not considered in traditional least-cost feed formulation.

In this research, an experiment was conducted to obtain the data necessary to evaluate the broiler production responses (body weight and feed intake) of dietary balanced protein (based on digestible lysine (dLys) level). The broiler diets used in this research were based on corn, soybean meal, meat and bone meal and synthetic amino acids to assure the dietary protein was balanced. The data collected from the experiment were used to estimate the production functions. Data used for economic analysis were obtained from a confidential survey conducted with a poultry company and the Georgia Department of Agriculture. The information contained prices of ingredients, production costs and targeted market prices.

The Cobb-Douglas (CD) production functions were adopted. The coefficients of the CD can be used to explain the elasticity among the variables. Results indicated that body weight of broilers increased about 0.87 percent for every one percent increased in feed intake. Analysis showed that broiler fed with one percent higher in dLys increased broilers' body weight by 0.06 and 0.08 percents during grower and finisher phases, respectively. Feed intake was analyzed as a function of time (number of grow-out day) and dLys levels during grower and finisher phases.

Results showed that feed intake increased about 1.74 percent for every one percent increase in the number of grow-out days. Analysis showed that broilers fed with one percent higher digestible lysine level (dLys) increased feed consumption by 0.01 during grower phase while decreasing feed consumption by 0.07 percent during finisher phases. Carcass and cut-up part weights were determined as functions of live body weight and dLys levels during grower and finisher phases. Results showed that carcass and cut-up part weights, except leg quarters and rest of carcass, increased as live body weight and the level of dLys in the diets increased. Thus, carcass and cut-up part weight can be improved by feeding higher level of dLys. This suggested that feeding broilers at higher dLys levels improved broiler market value.

The estimated production functions were used in the profit maximization analysis of the programming model. The optimum feeding levels of dLys were determined based on input costs, output prices and other fixed and variable costs of broiler production. The optimum broiler weight, number of grow-out day, feed consumption and feed formulation that provided the maximum profit was estimated. The profit function was defined as average price of a broiler (P_{BW}) times live body weight (BW), minus total cost (TC). The TC is the calculation of least-cost feed (r_{FC}) plus feed delivery cost (DEL) times feed consumed and interest (future cost accounted for feed consumption at d); plus the sum of grower cost (GRO) and field DOA and condemnation cost (FDOA) times broiler weight and interest (future value of chicken at d); plus fixed cost (TFC) such as chick cost, vaccination, supervising, and miscellaneous costs. The interest cost (I) was the calculation of $(1+\frac{i}{365})^{d}$, where d is feeding days and i is the annual interest rate of the grower.

The programming model provided alternative options on targeted market of broilers either selling a whole carcass or cut-up parts. Moreover, the model also formulated the diets that maximized profit of broiler production. For all the scenarios studied here, the most profitable strategy of a broiler company was to target the market of selling cut-up parts. At constant output prices (broiler market prices), increasing input costs (feed cost) decreases the size of bird that maximizes profits. Likewise, at constant input costs, increasing output prices increases the size of bird that maximizes profits. These results agreed with previous published article by Pesti et al. (2009a and 2009b).

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APPENDIX A

Table A 1.1 Production costs used in the profit maximization analysis

Variables	Abbreviation	Values	Unit
Interest Cost	I	1.01	%
Feed Cost	r_{FC}	29.85	Cent/lb
Chick Costs	TFC	29.79	Cent/chick
Vaccination, Supervising, Miscellaneous	TFC	1.61	Cent/chick
Grower Costs	GRO	6.06	Cent/lb
Milling and Delivery Cost	DEL	1.50	Cent/lb
DOA and Field Condemnation Cost	FDOA	0.33	Cent/lb
Cost of Catching and Hauling	CH	1.45	Cent/lb
Processing Cost	PC		
Step 1: Including all fixed overhead		7.50	Cent/lb
Step 2: Cutting and Packaging		9.75	Cent/lb
Total Cost		386.07	Cents / bird

APPENDIX B

Table B 1.1 Corn and soybean meal prices and their spread (soybean meal minus corn)

Month / Year	Corn, $/MT	SBM, $/MT	Spread, $/MT
Jan-00	92.95	172.43	79.48
Feb-00	95.08	180.47	85.39
Mar-00	95.17	185.63	90.46
Apr-00	95.54	187.86	92.32
May-00	95.53	200.98	105.45
Jun-00	84.04	191.49	107.45
Jul-00	75.06	175.93	100.87
Aug-00	75.24	171.07	95.83
Sep-00	80.15	188.03	107.88
Oct-00	84.71	186.00	101.29
Nov-00	88.94	194.33	105.39
Dec-00	96.22	211.81	115.59
Jan-01	94.30	197.59	103.29
Feb-01	92.38	178.71	86.33
Mar-01	91.01	169.52	78.51
Apr-01	87.55	169.02	81.47
May-01	85.08	178.07	92.99
Jun-01	83.16	185.04	101.88
Jul-01	90.75	194.23	103.48
Aug-01	92.88	189.10	96.22
Sep-01	89.74	183.94	94.20
Oct-01	86.27	177.63	91.36
Nov-01	89.88	177.99	88.11
Dec-01	92.31	166.50	74.19
Jan-02	91.97	169.58	77.61
Feb-02	90.73	165.45	74.72
Mar-02	89.86	174.29	84.43
Apr-02	87.11	175.93	88.82
May-02	90.33	179.90	89.57
Jun-02	93.17	185.83	92.66
Jul-02	99.70	204.24	104.54
Aug-02	109.89	201.12	91.23
Sep-02	113.94	200.25	86.31
Oct-02	109.65	185.35	75.70
Nov-02	108.65	183.88	75.23
Dec-02	107.01	181.98	74.97
Jan-03	105.75	184.87	79.12
Feb-03	106.04	192.42	86.38
Mar-03	105.06	191.36	86.30
Apr-03	105.25	200.26	95.01

Month / Year	Corn, $/MT	SBM, $/MT	Spread, $/MT
May-03	107.82	214.18	106.36
Jun-03	106.99	210.61	103.62
Jul-03	97.61	200.44	102.83
Aug-03	100.31	199.30	98.99
Sep-03	103.22	218.14	114.92
Oct-03	104.17	245.71	141.54
Nov-03	108.03	262.96	154.93
Dec-03	111.98	255.64	143.66
Jan-04	115.09	278.48	163.39
Feb-04	122.91	286.39	163.48
Mar-04	128.43	331.41	202.98
Apr-04	133.39	343.71	210.32
May-04	129.30	331.65	202.35
Jun-04	123.23	311.68	188.45
Jul-04	104.48	291.01	186.53
Aug-04	104.04	212.15	108.11
Sep-04	97.76	182.69	84.93
Oct-04	93.37	171.44	78.07
Nov-04	93.75	170.13	76.38
Dec-04	95.59	175.72	80.13
Jan-05	95.98	175.18	79.20
Feb-05	94.36	178.55	84.19
Mar-05	99.94	207.64	107.70
Apr-05	96.39	210.27	113.88
May-05	95.27	218.01	122.74
Jun-05	97.56	241.22	143.66
Jul-05	105.60	238.80	133.20
Aug-05	98.64	217.60	118.96
Sep-05	96.99	193.57	96.58
Oct-05	101.50	186.58	85.08
Nov-05	95.97	192.15	96.18
Dec-05	102.66	209.58	106.92
Jan-06	102.70	201.96	99.26
Feb-06	106.92	198.43	91.51
Mar-06	104.89	192.43	87.54
Apr-06	107.82	190.55	82.73
May-06	110.57	193.25	82.68
Jun-06	109.55	196.26	86.71
Jul-06	114.24	187.27	73.03
Aug-06	115.21	175.91	60.70

Month / Year	Corn, $/MT	SBM, $/MT	Spread, $/MT
Sep-06	120.26	177.59	57.33
Oct-06	142.17	194.12	51.95
Nov-06	164.08	214.23	50.15
Dec-06	160.66	205.69	45.03
Jan-07	165.10	221.79	56.69
Feb-07	177.35	244.10	66.75
Mar-07	169.52	239.53	70.01
Apr-07	152.58	221.75	69.17
May-07	156.44	227.67	71.23
Jun-07	164.50	249.16	84.66
Jul-07	147.13	252.57	105.44
Aug-07	151.01	251.83	100.82
Sep-07	160.05	288.78	128.73
Oct-07	164.09	300.43	136.34
Nov-07	171.06	315.25	144.19
Dec-07	180.25	351.22	170.97
Jan-08	206.53	376.33	169.80
Feb-08	219.95	396.71	176.76
Mar-08	233.85	379.70	145.85
Apr-08	246.67	375.32	128.65
May-08	243.46	369.37	125.91
Jun-08	287.11	436.91	149.80
Jul-08	266.94	452.19	185.25
Aug-08	235.16	388.40	153.24
Sep-08	233.91	363.78	129.87
Oct-08	182.96	290.84	107.88
Nov-08	164.27	292.76	128.49
Dec-08	158.16	292.94	134.78
Jan-09	173.24	338.50	165.26
Feb-09	163.13	320.89	157.76
Mar-09	164.52	315.37	150.85
Apr-09	168.72	349.57	180.85
May-09	180.31	408.05	227.74
Jun-09	178.83	441.78	262.95
Jul-09	151.76	385.85	234.09
Aug-09	152.01	397.30	245.29
Sep-09	150.57	342.18	191.61
Oct-09	167.22	328.54	161.32
Nov-09	171.61	337.63	166.02
Dec-09	164.58	345.58	181.00
Jan-10	167.21	325.85	158.64
Feb-10	161.63	303.66	142.03
Mar-10	159.01	292.60	133.59
Apr-10	157.66	308.05	150.39
May-10	163.77	305.74	141.97
Jun-10	152.87	314.32	161.45
Jul-10	163.92	335.09	171.17
Aug-10	175.60	339.14	163.54

Month / Year	Corn, $/MT	SBM, $/MT	Spread, $/MT
Sep-10	205.84	334.06	128.22
Oct-10	235.70	353.75	118.05
Nov-10	238.24	376.04	137.80
Dec-10	250.63	387.51	136.88
Jan-11	265.29	412.07	146.78
Feb-11	293.40	410.16	116.76
Mar-11	290.43	393.93	103.50
Apr-11	318.45	388.22	69.77