AN ANALYSIS OF LEAST-COST RATIONS FOR POULTRY

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by
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CHAPTER ONE

INTRODUCTION

Shortages of meat accompanied by rapid price increases have aroused much concern in Ghana recently. These shortages may be attributed in part to a decline in the flow of livestock from neighbouring states which serve as our primary external sources of meat (Clottey, 1971). There is evidence to suggest that of recent local sources of meat have also lagged due to increased costs of production. These supply factors combined with a rising demand, resulting primarily from population growth, have caused these price increases. The result of the shortages is that Ghanaians have had little access to animal protein and have been unable to meet their protein needs.

In an attempt to meet the protein needs of the people, the government has sought, as a short term measure, to increase imports of meat. This approach involves expenditure of foreign exchange. Furthermore, the situation is aggravated by the fact that prices have risen to such levels that the amount of meat that must be imported, if Ghana is to meet domestic demand, will require large amounts of foreign exchange. Clottey (1971) has reported that in 1961, ¢8.7

million were expended on 21,000 tons of meat while ¢6.1 million were expended on only 6,600 tons of meat in 1968.[1] Apparently, supplies have declined in the face of rising prices. In the light of balance of payments constraints, the quantity that the country can import to satisfy domestic demand is limited by scarcity of foreign exchange. These difficulties suggest that efforts to expand local sources of meat should become increasingly attractive.

However, the problem with local livestock herds is that their rate of reproduction is very low. As a result, the extraction rates have exceeded the growth rate. Clottey (1971) has estimated that in 1967 the take off for slaughter and consumption was about 8 per cent which was more than double the growth rate. This state of affairs was typical of the sixties. Clottey has also observed that the present cattle herd of 600,000 has taken about 50 years to build, starting with a population of 70,000 in the early twenties. Looking into the future and making projections, he concluded: "... at the current growth rate of 4 per cent, we would require about 40 more years to build the herd to a level that will permit self-sufficient extractions" (1971, p.233). This con-

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[1] We refer here to meat equivalent converting live animals into dressed meat equivalent.

clusion paints a gloomy picture for satisfying consumption needs from local production of livestock. It appears, it will require a major break-through to achieve such a target in the near future.

Poultry also serves as a source of animal protein in Ghana and has many advantages over livestock. For instance, poultry has a shorter production cycle. The poultry industry in Ghana has witnessed a relatively rapid growth in the past few years. It has been transformed from the traditional way of rearing whereby the birds are allowed to fend for themselves to large scale commercial farming which involves confining the birds and providing them with feed and water. Growth in poultry production has been attributed to the poultry extension programme introduced in 1952 by the Department of Agriculture, (Gyasi, 1970).

The 1952 extension programme was accompanied by the importation of exotic poultry breeds which were quickly adopted along with the improved systems of management. These production factors together with favourable demand for the products stimulated the expansion of the industry. Prior to this period, various extension schemes had been tried without success.

In spite of past growth in the poultry industry, prices are currently increasing at a rapid rate. Various factors account for this situation. For instance, the demand for eggs and poultry meat has undoubtedly increased. Production costs, however, have also gone up. A combination of these demand and supply factors have led to the price rises that have been experienced. For poultry to continue to enjoy steady growth, production problems associated with the industry must be examined critically and solutions found to them.

Various factors enter into the production costs of poultry products. One of the major factors influencing the cost of producing meat and eggs is the feed bill. It has been estimated that the feed cost represents more than half the total variable costs of producing eggs and poultry meat in Ghana (Asare, 1971). The high feed cost component suggests the possibility of focusing efforts on reducing costs of production through reducing the cost of feed. Feed, however, plays such an important role in the production process that, as Cameron (1969) has argued, the feed used must satisfy the daily dietary requirements of the animal for protein, energy, vitamins and minerals, but their supply must also be regular. However, the poultry feed supply in Ghana is both irregular and the quality of feed poor.

The effect of irregular supply of feed is poor performance of the birds which consequently leads to high production costs. Dalton (1971) has reported that an interruption in the normal feed supply resulted in the reduction in the laying percentage from around 70 per cent down to 23 per cent on a poultry farm near Legon. Furthermore, Gyasi (1970) has recorded that in 1966 the Ministry of Agriculture reported that shortages of fish meal and groundnut cake caused a drastic reduction in the production of feed mixed by the mixing firms and consequently led to a reduction in the production of eggs.

The feed supplied to poultry farmers also too often does not contain sufficient amounts of nutrients required by the birds (Cameron, 1969). Comparing the nutrient contents of the various feeds analysed by Cameron with the feeding standards (Table 2), for example, reveals that while in some cases the minimum requirements are exceeded in others they fall short of the minimums. For instance, chick feed produced by State Farm contains 14.4 per cent crude protein which is less than the minimum of 20 per cent recommended, and the fat and fiber contents are exceedingly high. Chick starter whose protein content of 25 per cent surpasses the minimum requirement contains 4.14 per cent fiber, 1.7 per cent calcium and 0.85 per cent phosphorus, which are greater than the tolerance levels of 3.5 per cent, 1.0 per cent and 0.7 per cent, respectively. Such deficiencies can have deleterious effect on performance and encourage disease. Even though the analysis does not cover all the nutrients, such as vitamins, that must be considered in poultry feed mixing, it demonstrates clearly the kinds of feeds supplied to the poultry farmers in Ghana. Under such circumstances, the farmer stands to lose because he cannot get the best out of his birds.

The feed situation, since 1969, has been gloomy and has not witnessed any improvement. It appears that the feed mixing firms have practised trial and error methods in compounding feeds. The need, therefore, arises for investigating the possibility of improving the quality of poultry feed and concurrently reducing cost of feed.

In Ghana, white maize is the energy source used most extensively in poultry feed mixing. White maize is also consumed to a very large extent by most Ghanaians, particularly those living in the southern part of the country. This competition is of course reflected in the cost of maize and in turn the cost of feed and reinforces the need to examine the feed problem with a view to finding alternative feedstuffs for consideration in poultry feed mixing.

The irregular supply coupled with the poor quality of poultry feed led Dalton (1971) to suggest an investigation into the possibility of using Linear Programming to formulate least-cost rations based on local sources of feedstuffs. This approach will ensure the satisfaction of the nutrient specifications and at the same time indicate rations at least cost relative to others. Thus, the old outmoded trial and error feed formulation practices can be eliminated and hopefully more local feedstuffs used.

Objectives of the Study

This study looks at the problem of compounding least-cost rations for various size-classes of poultry in order to improve the quality of the feed at least cost. The essence of a least-cost ration is to produce a feed that provides all the nutrients required by the animal, satisfying minimum and tolerance levels at a minimum cost. Nutrient requirements can also be allowed to vary to achieve lower costs. This involves, for example, choosing low feed conversion rates and avoiding the use of high cost protein sources. Economic theory suggests that least-cost rations will be beneficial not only to the farmer but to the feed manufacturer, since demand for feed will be increased and to the consumer, since the cost of producing meat and eggs will be reduced.

Usually, in applying linear programming to least-cost feed formulation, market prices are used in the first instance. Market prices, however, do not necessarily represent social costs. In particular, foreign exchange is under-valued with the current exchange rate and, therefore, shadow prices for foreign exchange will be used to determine the effect upon least-cost rations. Thus, the competitiveness of imported with local feedstuffs in least-cost rations can be analysed. Also, market prices are not available for certain feedstuffs, such as cocoa shells. The value of such feedstuffs will be determined on the basis of their value as a substitute for other feedstuffs.

Specifically, the main objectives of the study are:

(i) to formulate least-cost rations for poultry, considering both local and imported feedstuffs;

(ii) to investigate the potential for depending primarily upon local feedstuffs for compounding poultry rations; and

(iii) to analyse the effect of shadow pricing foreign exchange upon the role of imported feedstuffs in least-cost rations.

Summary

The meat situation with accompanied price increases has been reviewed. The domestic production of livestock is seen as not being an area which can generate sufficient growth in the immediate future to provide sufficient amount of protein for Ghanaians unless a major break-through in production is achieved. For this reason, it is suggested that attention be focused on solving the problems impeding the growth of the poultry industry, since its growth in the recent past seems to emphasize its potential for providing protein. It is argued that one of the major problems facing the poultry industry is the poor quality and irregular supply of feed. The poultry feed problem forms the basis of this study.

CHAPTER TWO

M E T H O D O L O G Y

Animal nutritionists have established feeding standards for poultry and other classes of livestock to serve as a guide to feeding. Feeding standards are the amounts of nutrients that should be provided in the rations for farm animals in order to secure the best results. The determination of feeding standards is based on experiments designed to measure the effect of the particular nutrient on the performance of the animal. The level of the nutrient which stimulates maximum performance (maximum rate of gain) is considered to be the nutrient requirement of that size-class of animal (Dent and Casey, 1967).

It will be argued below that the poultry-man's profit maximizing problem can be viewed as a problem of minimizing the costs of feeding his birds with a ration that meets stated nutrient requirements. Similarly, the feed manufacturer must also produce a feed that meets the needs of the birds. The recommended nutrient requirements for various size-classes of poultry as well as the nutrient composition of the alternative feedstuffs will be outlined in the next chapter.

General Formulation of the Problem

Consider a poultry farmer who has the necessary labour, buildings and equipment to handle a given number of birds at one time. Assume that his production function relating quantities of both fixed and variable inputs to the level of production is given by

$$(1) \qquad Q = f(X_1, X_2, \ldots, X_N \mid X_{N+1}, \ldots, X_n),$$

where

Q = kilograms of poultry meat produced per unit time,

$X_1, \ldots, X_N$ = levels of various feedstuffs used per unit time,

$X_{N+1}, \ldots, X_n$ = number of birds and amounts of labour, buildings, equipment and other non-feed inputs available at a fixed level.

For the production function specified in (1), it is assumed that as the levels of the various feedstuffs are increased the kilograms of meat produced from the fixed flock and facility also increases but at a diminishing rate. Hence, the production function exhibits diminishing marginal returns.

Assume that the poultry-man's objective is to maximize profits from the fixed resources. A necessary condition for maximizing profits is that feed costs be minimized at the optimal level of output. Assume that the production function is continuous in its first and second derivatives. If output is constrained to Q* kilograms of poultry meat, equation (1) becomes:[1]

(2) $$Q^* = f(X_1, X_2 \mid X_3, \ldots, X_n).$$

The criterion to be minimized is defined by

(3) $$C = P_1X_1 + P_2X_2$$

where

P_1, P_2 = prices of kilogram of 2 feedstuffs, X_1 and X_2,

C = total cost of producing Q* kilograms of meat.

Minimizing the cost of producing Q* define the Lagrangian function

(4) $$L = P_1X_1 + P_2X_2 + \lambda\{Q^* - f(X_1, X_2 \mid X_3, \ldots, X_n)\}$$

which is minimized by setting the partial derivatives with respect to X_1, X_2 and λ equal to zero resulting in the following necessary conditions:

(5) $$\frac{\partial L}{\partial X_1} = P_1 - \lambda\frac{\partial Q}{\partial X_1} = 0,$$

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[1] We shall first consider 2 feedstuffs and later generalize the treatment for N feedstuffs.

(6) $$\frac{\partial L}{\partial X_2} = P_2 - \lambda \frac{\partial Q}{\partial X_2} = 0,$$

and

(7) $$\frac{\partial L}{\partial \lambda} = Q^* - f(X_1, X_2 \mid X_3, \ldots, X_n) = 0,$$

where

$\frac{\partial Q}{\partial X_1}$ and $\frac{\partial Q}{\partial X_2}$ are the marginal physical products of X_1 and X_2 ($MPPx_1$ and $MPPx_2$), respectively. They measure the marginal output from additional units of these factors. Equation (7) is merely the production constraint re-stated. Moving the price terms of (5) and (6) to the right and dividing (5) by (6), we get the following:

(8) $$\frac{\partial Q}{\partial X_1} / \frac{\partial Q}{\partial X_2} = \frac{P_1}{P_2}.$$

We note that the rate of technical substitution is defined as

(9) $$RTS = \frac{\partial Q}{\partial X_1} / \frac{\partial Q}{\partial X_2} = \frac{MPPx_1}{MPPx_2}.$$ [1]

From (8) and the definition of RTS, it follows that for cost minimization:

(10) $$RTS = \frac{MPPx_1}{MPPx_2} = \frac{P_1}{P_2}.$$

Relationship (10) states that the rate of technical substitu-

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[1] Totally differentiating $Q = f(X_1, X_2)$ and setting $dQ = 0$ results in the following:

$$dQ = \frac{\partial Q}{\partial X_1} \cdot dX_1 + \frac{\partial Q}{\partial X_2} \cdot dX_2 = 0$$

$$RTS = -\frac{dX_2}{dX_1} = \frac{\partial Q}{\partial X_1} / \frac{\partial Q}{\partial X_2}.$$

tion equals the inverse price ratio. Solving (7) and (10) simultaneously, the optimal values of X_1 and X_2 can be determined.

Since Q* is exogenously determined, it can be fixed at any level. Assume we have pre-determined Q* at three different levels, Q_1, Q_2 and Q_3, and considering the two feedstuffs, we want to minimize the cost of each level of output subject to (2). Our optimizing conditions (8) still hold. Presented in the form of (8) the necessary conditions for minimization can be explained in terms of isoquants and isocosts. The rate of technical substitution, for example, is the negative of the slope of an isoquant and it measures the rate at which X_2 substitutes for X_1, while still producing Q* kilograms of meat.

The isocost curve is the locus of feedstuff combinations that give rise to the same total cost and can be expressed as:

(11) $$C = P_1X_1 + P_2X_2.$$

Solving (11) for X_2 results in the following:

(12) $$X_2 = \frac{C}{P_2} - \frac{P_1}{P_2}X_1.$$

The price ratio, P_1/P_2, therefore is the negative of the slope of the isocost curve. The necessary conditions for minimizing the cost of producing Q_1, Q_2 and Q_3 are shown diagrammatically in Fig. 1 for any two feedstuffs.

In Fig. 1, different isoquants are represented by Q_1, Q_2 and Q_3. A family of isocost lines is represented by straight lines whose slope equals $- P_1/P_2$. For each specified output, cost is minimized at the point of tangency between the isoquant and the relevant isocost line. The slopes of the isoquant and isocost lines are equal at that point. Hence, for output Q_1, A is the least-cost point and Ox_{21} of X_2 and Ox_{11} of X_1 would be used. Similarly, to produce Q_2, Ox_{22} of X_2 and Ox_{12} of X_1 would be used. The curve joining the points A, B and C is the expansion path of the farmer. The expansion path tells us how the farmer's optimal input combination will vary for given relative prices of the two feedstuffs as his level of production increases. Since no assumption is made about the nature of the production function, it is possible that different mixes (i.e. different proportions of each feedstuff) would be used at each level of output due to the need to increase protein content or the level of vitamins and antibiotics, for example.

Sufficient Conditions

Having satisfied the necessary conditions for minimization, the second order conditions must be satisfied in order to ensure minimum cost. Sufficient conditions for our problem

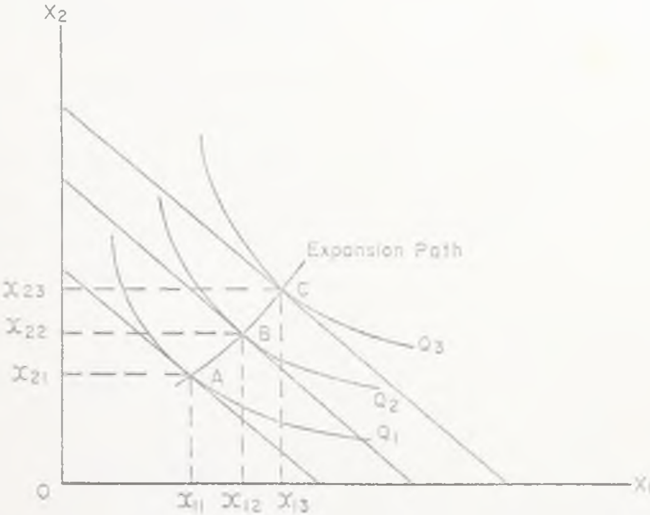

Figure I. COST MINIMIZATION AT DIFFERENT LEVELS OF OUTPUT are derived below.

Differentiating (5), (6) and (7) further with respect to X_1, X_2 and λ respectively, we get

(13) $$\frac{\partial^2 L}{\partial X_1^2} = -\lambda f_{11} - \lambda f_{12},$$

(14) $$\frac{\partial^2 L}{\partial X_2^2} = -\lambda f_{21} - \lambda f_{22},$$

(15) $$\frac{\partial^2 L}{\partial \lambda^2} = 0 ,$$

(16) $$\frac{\partial^2 L}{\partial \lambda \partial X_1} = - f_1 ,$$

and

(17) $$\frac{\partial^2 L}{\partial \lambda \partial X_2} = - f_2 ,$$

where

$$f_{ij} = \frac{\partial^2 Q}{\partial X_i \partial X_j}$$

Putting equations (13) through (17) in the border Hessian determinant form, the second order conditions require the relevant determinant to be negative (Henderson and Quandt, (1958):

(18) $$D = \begin{vmatrix} -\lambda f_{11} & -\lambda f_{12} & - f_1 \\ -\lambda f_{21} & -\lambda f_{22} & - f_2 \\ - f_1 & - f_2 & 0 \end{vmatrix} < 0$$

or

$$D = \lambda(f_{11}f_2^2 - 2f_{12}f_1f_2 + f_{22}f_1^2) < 0$$

Since from (5) and (6)

$$\lambda = \frac{\partial X_1}{\partial Q} P_1 = \frac{\partial X_2}{\partial Q} P_2 ,$$

λ can be interpreted as the cost of producing an additional unit of output at the margin, i.e. the marginal cost of Q using a least-cost ration. Therefore, $\lambda > 0$ and the term in parenthesis in (18) must be negative. Hence, $\frac{d^2X_2}{dX_1^2}$ must be positive, implying that the isoquants must be convex from below.[1]

In summary, therefore, equations (5), (6), (7) and (18) constitute necessary and sufficient conditions for a minimum cost, feed made up of 2 feedstuffs.

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[1] From footnote 1 on page 13, we have

(1.1) $$-\frac{dX_2}{dX_1} = \frac{f_1}{f_2}$$

where $$f_1 = \frac{\partial Q}{\partial X_1} \text{ and } f_2 = \frac{\partial Q}{\partial X_2}$$

Further differentiation of (1.1) gives

(1.2) $$\frac{d^2X_2}{dX_1^2} = -\frac{1}{f_2^3}(f_{11}f_2^2 - 2f_{12}f_1f_2 + f_{22}f_1^2).$$

Equation (18) ensures that the bracketed term in (1.2) is negative.

Hence, $\frac{d^2X_2}{dX_1^2}$ is positive.

N-feedstuff Case

Up to this point, the cost minimization approach has been treated for only two feedstuffs. Now the treatment will be extended to N-feedstuffs using equation (1). From (1) form an isoquant and assume it to be first and second derivative continuous. Equation (1) becomes

(19) $$Q^* = f(X_1, X_2, \ldots, X_N \mid X_{N+1}, \ldots, X_n).$$

The feed cost associated with producing Q* kilograms of poultry meat is given by

(20) $$C = \Sigma_j P_j X_j \qquad j = 1, 2, \ldots, N,$$

where

P_j = the price per kilogram of the j^{th} feedstuff,

X_j = kilograms of the j^{th} feedstuff,

C = the total cost of Q*.

Minimizing cost define the Lagrangian function

(21) $$J = \sum_{j=1}^{N} P_j X_j + \lambda\{Q^* - f(X_1, X_2, \ldots, X_N \mid X_{N+1}, \ldots, X_n)\}$$

where

J = the constrained objective function,

λ = the Lagrange multiplier associated with the constraint that Q* is being produced.

Differentiating equation (21) partially with respect to X_j and λ and setting the partial derivatives to zero, results in the following necessary conditions:

(22) $$\frac{\partial J}{\partial X_1} = P_1 - \lambda \frac{\partial Q}{\partial X_1} = 0 ,$$

(23) $$\frac{\partial J}{\partial X_2} = P_2 - \lambda \frac{\partial Q}{\partial X_2} = 0 ,$$

$$\vdots \qquad \vdots \qquad \vdots$$

(24) $$\frac{\partial J}{\partial X_N} = P_N - \lambda \frac{\partial Q}{\partial X_N} = 0 ,$$

and

(25) $$\frac{\partial J}{\partial \lambda} = Q^* - f(X_1, X_2, \ldots, X_N \mid X_{N+1}, \ldots, X_n) = 0.$$

Moving price terms of (22) through (24) to the right and selecting any two feedstuffs and dividing one into the other, we get the following:

(26) $$\frac{\partial Q}{\partial X_i} / \frac{\partial Q}{\partial X_j} = \frac{P_i}{P_j} .$$

The following is also true:

(27) $$\frac{MPPx_1}{P_1} = \frac{MPPx_2}{P_2} = \ldots = \frac{MPPx_N}{P_N}$$ [1]

Solving (26) and (25) simultaneously, the equilibrium values of $X_1, X_2, \ldots, X_N$ can be determined.

The second order conditions will be assumed to be satisfied.[2] These conditions together with the necessary conditions, (22) through (25), constitute the necessary and sufficient conditions for the N feedstuffs for a minimum cost.

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[1] From (26), for example, $\frac{\partial Q/\partial X_i}{P_i} = \frac{\partial Q/\partial X_j}{P_j}$.

[2] In other words, the determinant of the relevant bordered Hessian has the correct sign, (See Henderson & Quandt, p.74).

The Linear Programming Model

A modified version of the least-cost combination problem can be formulated as a linear programming problem in which the smooth isoquant which is assumed to be continuous and differentiable is replaced by a kinked isoquant. We shall demonstrate first how the problem formulated above can be linearized so that linear programming can be applied to analyse it.

If output is constrained to Q* kilograms of meat produced per unit time (1) for N = 2 becomes: [1]

(28) $Q^* = f(X_1, X_2)$.

Let the isoquant associated with producing the output Q* be approximated by a constraint set made up of certain minimum nutrient requirements and tolerance levels for the production of Q*. The constraint set is represented mathematically, for example, by (29), (30) and (31), which express the relationships between the nutrient contents of the feedstuffs and the minimum protein and energy requirements and the fiber tolerance level, respectively.

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[1] The treatment that follows will be for 2 feedstuffs but is applicable to N-feedstuffs. Later it is generalized for N-feedstuffs.

(29) $a_{11}X_1 + a_{12}X_2 \geq P,$

(30) $a_{21}X_1 + a_{22}X_2 \geq E,$

(31) $a_{31}X_1 + a_{32}X_2 \leq F,$

where

a_{ij} = the level of the $_i$th nutrient in the $_j$th feedstuff, i = 1,2,3 and j = 1,2;

P = minimum protein requirement for producing Q*;

E = minimum energy requirement for producing Q*;

F = tolerance (maximum) level of fiber for producing Q*.

Dividing (29), (30) and (31) through by Q*, we get

(32) $a_{11}(X_1/Q^*) + a_{12}(X_2/Q^*) \geq P/Q^*,$

(33) $a_{21}(X_1/Q^*) + a_{22}(X_2/Q^*) \geq E/Q^*,$

(34) $a_{31}(X_1/Q^*) + a_{32}(X_2/Q^*) \leq F/Q^*.$

Solving (32), (33) and (34) for X_2/Q^* results in the following, respectively:

(35) $X_2/Q^* \geq 1/a_{12}(P/Q^*) - a_{11}/a_{12}(X_1/Q^*)$,

(36) $X_2/Q^* \geq 1/a_{22}(E/Q^*) - a_{21}/a_{22}(X_1/Q^*)$,

(37) $X_2/Q^* \leq 1/a_{32}(F/Q^*) - a_{31}/a_{32}(X_1/Q^*)$.

Equations (35), (36) and (37) can be viewed as linear approximations to the smooth unit isoquant[1] as in Fig. 2, where these constraints actually define a region in the X_2/Q^*, X_1/Q^* space.

Assumptions

A.1 Assume that it is the handling and feeding system which determines the rate of intake of any feed mixture as long as the latter satisfies the constraint set.

This assumption implies that if the minimum nutrient requirements and tolerance level specified by equations (29), (30) and (31) are met, consumption for the flock is at a predetermined rate of intake of feed, say X^* kilograms per unit time. Thus, let

(38) $X_1 + X_2 = X^*$

Dividing (38) by Q^*, we have

(39) $X_1/Q^* + X_2/Q^* = X^*/Q^*$.

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[1] By unit isoquant we refer to the locus of points of the various combinations of X_1 and X_2 required per unit of output at the level of output Q^*.

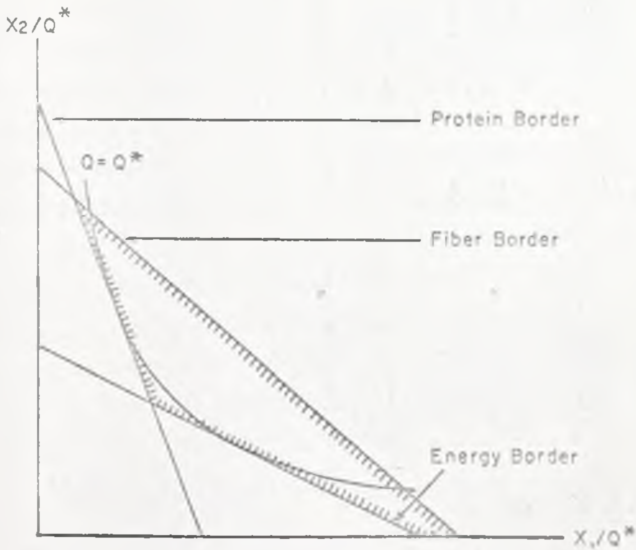

Figure 2. LINEARIZATION OF UNIT ISOQUANT

Fig. 3 shows the minimum nutrient requirements and tolerance level for our example, taking into account the constrained rate of feed intake. The admissible region in Fig. 2 has now been reduced to the heavy line shown in Fig. 3 and this line now becomes our approximation of the unit isoquant in Fig. 2.

A.2 Alternatively, let us assume that the total weight of feedstuffs requiredto produce the amount Q* is independent of the feed mix used as long as the minimum nutrient requirements and tolerance levels are observed.

Under this latter assumption the level of production can be expressed in terms of kilograms of meat produced or total kilograms of feed used, i.e., we can talk about the mixing of two feedstuffs to produce X* kilograms of feed or Q* kilograms of meat, assuming a constant feed conversion ratio. Hence, Q* can be replaced by αX^* where α = kilograms of meat per kilogram of feed when producing Q*.[1] Equations (39), (32), (33) and (34), respectively, become:

(40) $$X_1/\alpha X^* + X_2/\alpha X^* = X^*/\alpha X^*$$

(41) $$a_{11}(X_1/\alpha X^*) + a_{12}(X_2/\alpha X^*) \geq P/\alpha X^*$$

[1] In other words, A.2 implies a constant feed conversion ratio for the production of Q* per unit time regardless of the feed mixture (as long as it satisfies the constraints specified).

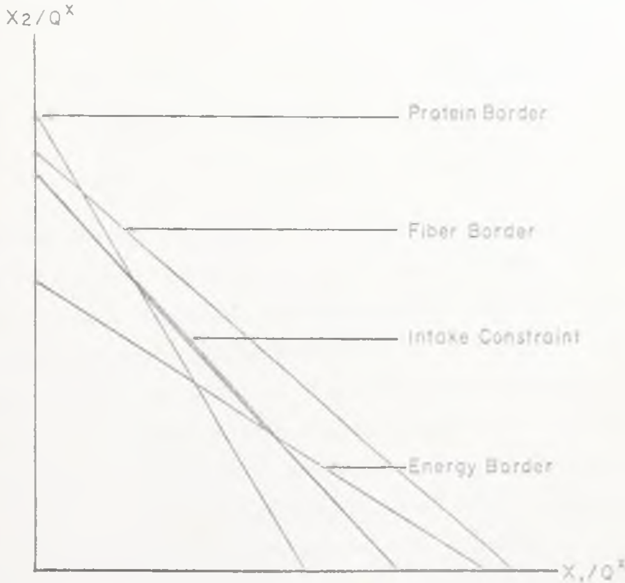

Figure 3. NUTRIENT REQUIREMENTS AND RATE OF FEED INTAKE

(42) $a_{21}(X_1/\alpha X^*) + a_{22}(X_2/\alpha X^*) \geq E/\alpha X^*,$

(43) $a_{31}(X_1/\alpha X^*) + a_{32}(X_2/\alpha X^*) \leq F/\alpha X^*.$

Multiplying (40), (41), (42) and (43) by α results in

(44) $X_1/X^* + X_2/X^* = 1,$

(45) $a_{11}(X_1/X^*) + a_{12}(X_2/X^*) \geq P/X^*,$

(46) $a_{21}(X_1/X^*) + a_{22}(X_2/X^*) \geq E/X^*,$

(47) $a_{31}(X_1/X^*) + a_{32}(X_2/X^*) \leq F/X^*.$

A.3 Assume further that the feed conversion ratio is independent of Q*, the level of production per unit time.

This latter assumption combined with A.2 implies that Q* can be replaced by αX^* for all levels of Q* where α = kilograms of meat per kilogram of feed for producing Q*. Assumption A.3 together with A.1 or A.2 results in the above equations (44) to (47), which are represented graphically in Fig. 4 where Q* in Fig. 3 has been replaced by X*. Consequently, the feed produced is constrained to 1 kilogram.

A.4 Finally, let us assume that the rate of gain is at maximum as long as the minimum nutrient requirements are satisfied and the tolerance levels are observed, i.e., as long as the constraint set is satisfied.

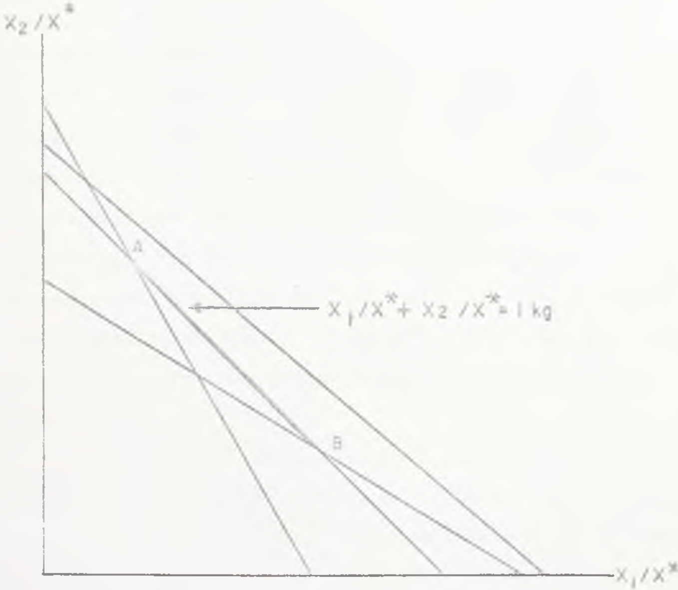

Figure 4. CONSTRAINTS OF EQUIVALENT LINEAR PROGRAMMING PROBLEM, CONSTANT FEED CONVERSION RATIO.

As noted above, A.3 combined with A.1 or A.2 implies that the feed conversion ratio is invariant with exceeding the minimum nutrient requirements and observing tolerance levels. Assumption A.4 implies that a maximum of Q* can be produced from the fixed facility per unit of time, i.e., exceeding the minimum nutrient requirements will not increase the number of birds that can be marketed per unit time.[1] Furthermore, it implies that if the nutrient requirements and tolerance levels are to be satisfied, profits are maximized if assumptions A.4 and A.3 or A.1 are satisfied and feed costs are minimized. For profit maximization, we therefore have a linear programming problem to solve which consists of minimizing the cost of producing 1 kilogram of feed subject to the satisfaction of certain minimum nutrient requirements and tolerance levels.

At this stage the problem has been revised so that 1 kilogram of feed is to be produced at minimum cost.[2] In Fig.4 the feasible line including the extreme points A and B constitute possible choices open to the poultry farmer or feed manufacturer. However, the optimal choice depends upon the relative prices of the two feedstuffs.

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[1] It is possible that by violating one or more of the constraints feed cost could be reduced more than the reduction in the value of production. This possibility will not be considered here.

[2] Since 1 kilogram of feed is to be produced, it implies that X* = 1 kg and X* can now be dropped.

The production function is now discontinuous in its first derivatives. To minimize feed costs at point B, the slope of the isocost lines must be greater than or equal to the slope of the feasible line AB. In Fig. 5, AB represents the feasible line with various isocost lines [1] whose slope equals - P_1/P_2. At point B, where the slope of the isocost lines is greater than the slope of AB, the optimal ration is B and the feed cost is C_2.

Sensitivity Analysis

One of the assumptions underlying the linear programming model which has not been explicitly stated is that the nutrient requirements, nutrient contents and the prices of the feedstuffs remain unchanged. However, there is some variability in these parameters. Feedstuff nutrient contents are greatly affected by the environment in which they are cultivated and by the way they are processed. Feedstuff prices also tend to vary with seasonal supply so that when relative prices change the feed manufacturer and farmer may have an incentive to change their ingredients used for mixing their feed. This variability suggests that our model should incorporate it so as to give the farmer or the feed manufacturer a least-cost feed in various situations. The most important parameter singled out here for consideration in the

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[1] $C = P_1X_1 + P_2X_2$.

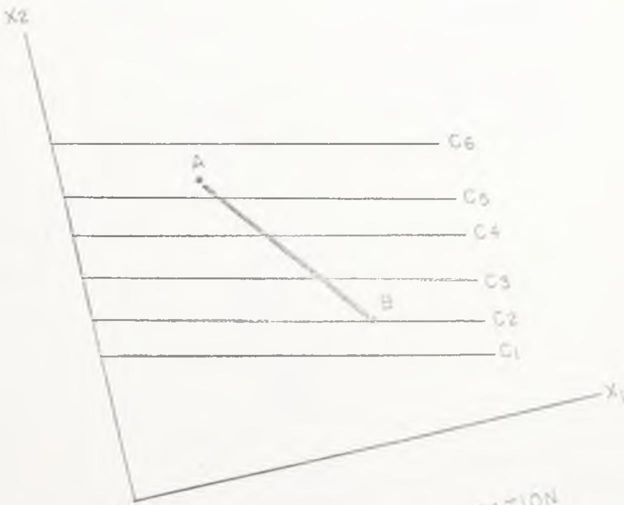

Figure 5. OPTIMAL RATION

sensitivity analysis is the prices of the feedstuffs.

In Fig. 5, the optimal ration is B where a certain amount of X_2 combines with that of X_1. If the relative prices were to change such that the slope of the isocost line consequently changes, another ration could result. Figs. 6a and 6b show diagrammatically the effect of price changes upon the optimal rations. For each price ratio the optimal ration can be determined. For the farmer to shift from ration B to ration A, the following condition should hold:

Save cost increase

(48) $$- \Delta X_1 P_1 \geq \Delta X_2 P_2$$

or

$$- \frac{P_1}{P_2} \leq \frac{\Delta X_2}{\Delta X_1}$$

This latter expression implies that as an incentive to shift from ration B to ration A, the savings from the reduction of X_1 must be greater than or equal to the increase in cost as a result of using more of X_2. Moreover, if he were to stay with ration B, then the following condition should hold:

Save

(49) $$- \Delta X_1 P_1 \leq \Delta X_2 P_2$$

or

$$- \frac{P_1}{P_2} \geq \frac{\Delta X_2}{\Delta X_1}$$

Now assume that the optimal ration occurs at A. For the farmer to stick with ration A, the following should hold:

Save

(50) $$- \Delta X_2 P_2 \leq \Delta X_1 P_1$$

or

$$\frac{\Delta X_2}{\Delta X_1} \geq - \frac{P_1}{P_2}$$

To shift from ration A to ration B, the following condition should prevail:

Save

(51) $$- \Delta X_2 P_2 \geq \Delta X_1 P_1$$

or

$$\frac{\Delta X_2}{\Delta X_1} \leq - \frac{P_1}{P_2}$$

Hence, if

(i) $\frac{dX_2}{dX_1} < - \frac{P_1}{P_2}$ the optimal ration is B;

(ii) $\frac{dX_2}{dX_1} > - \frac{P_1}{P_2}$ the optimal ration is A;

(iii) $\frac{dX_2}{dX_1} = - \frac{P_1}{P_2}$ the optimal ration is A or B.

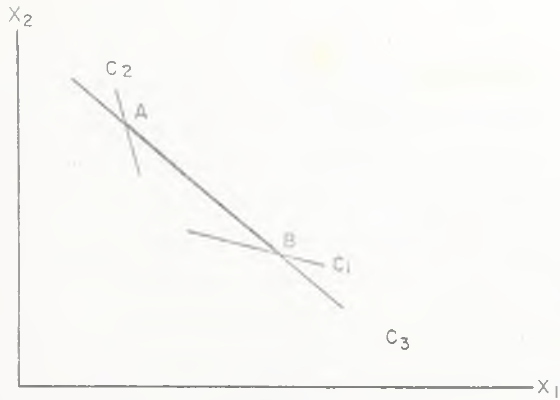

Figure 6a

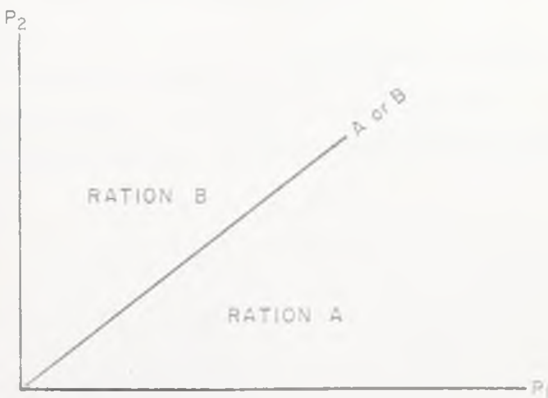

Figure 6b

EFFECT OF PRICE CHANGES ON RATIONS

These conditions imply that if the slope of the isocost line is less than the slope of AB, the optimal ration will be A in which case the cost of the feed will be C_2 as shown in Fig. 6a. If on the other hand, the relative prices of the feedstuffs change such that the slope of the isocost line is greater than that of AB, the optimal ration will be B and the cost of the feed will be C_1. When the slope of the isocost line is equal to the slope of AB the farmer or the feed manufacturer is indifferent between rations A and B, and rations in between on the line AB. Thus, using the slope of the isocost lines, the optimal rations can be determined.

Now let us consider three feedstuffs in formulating a least-cost ration. Equations (44) to (47) modified to include X_3, a third feedstuff, result in the following, respectively:[1]

(52) $$X_1 + X_2 + X_3 = 1$$

(53) $$a_{11}X_1 + a_{12}X_2 + a_{13}X_3 \geq P$$

(54) $$a_{21}X_1 + a_{22}X_2 + a_{23}X_3 \geq E$$

(55) $$a_{31}X_1 + a_{32}X_2 + a_{33}X_3 \leq F$$

[1] Note that X* = 1.

Equations (52) to (55) define a feasible plane in three-space. This plane can be represented in two-space by setting $X_3 = 1 - X_1 - X_2$. The feasible region is delineated in two-space in Fig.7a by the shaded polygon ABCDEF.

The new cost function for the three feedstuffs is given by

(56) $$C = P_1X_1 + P_2X_2 + P_3X_3.$$

Dividing (56) through by P_3, we have

(57) $$C/P_3 = (P_1/P_3)X_1 + (P_2/P_3)X_2 + X_3$$

Solving for X_3 in (52) and substituting into (57), we get

(58) $$\begin{aligned} C/P_3 &= (P_1/P_3)X_1 + (P_2/P_3)X_2 + 1 - X_1 - X_2 \\ &= (\frac{P_1}{P_3} - 1)X_1 + (\frac{P_2}{P_3} - 1)X_2 + 1 \end{aligned}$$

Solving for X_2 in (58), we have

(59) $$X_2 = (\frac{C}{P_3} - 1)/(\frac{P_2}{P_3} - 1) - \{(\frac{P_1}{P_3} - 1)/(\frac{P_2}{P_3} - 1)\}X_1$$

To know the relationship between the intercept of equation (59) and cost of the ration, C, differentiate (59) with respect to C to have

(60) $$\frac{dX_2}{dC} = \frac{1/P_3}{(\frac{P_2}{P_3} - 1)}$$

The sign of $\frac{dX_2}{dC}$ together with the nature of the slope of

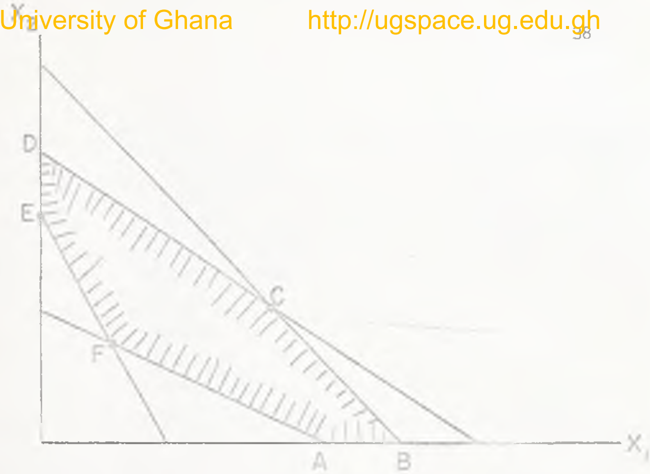

FIG. 7a.

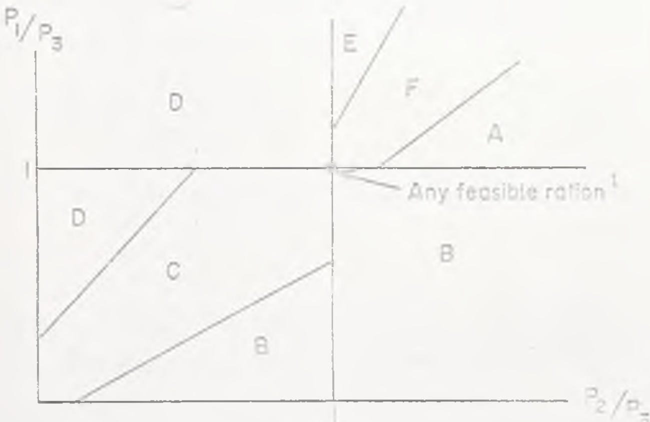

FIG. 7b.

Sensitivity of Least-[illegible] rations to Price changes with Three Feedstuffs and Four Constraints (including [illegible] constraint).

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[1] Any ration in the shaded region in Figure 7a.

the isocost curve will help us illustrate the optimal rations for three feedstuffs for various price combinations.

If $(\frac{P_1}{P_3} - 1)/(\frac{P_2}{P_3} - 1) > 0$, i.e., if the slope of the isocost curve is negative, and

$$\frac{dX_2}{dC} = \frac{1/P_3}{(\frac{P_2}{P_3} - 1)} > 0,$$

then E, F, or A in Fig. 7a is the optimal ration, i.e., if $\frac{P_2}{P_3} - 1 > 0$ and $\frac{P_1}{P_3} - 1 > 0$; it is also possible for the change in cost of the negatively sloping isocost curve to result in a decrease in the intercept; hence

$$\frac{dX_2}{dC} = \frac{1/P_3}{(\frac{P_2}{P_3} - 1)} < 0,$$

then D, C or B is the optimal ration, i.e., if $\frac{P_2}{P_3} - 1 < 0$ and $\frac{P_1}{P_3} - 1 < 0$.

Secondly, it is possible in the 3 feedstuffs case to have a positively sloping isocost curve. This together with the sign of $\frac{dX_2}{dC}$ gives rise to specific rations. Consequently, if $(\frac{P_1}{P_3} - 1)/(\frac{P_2}{P_3} - 1) < 0$, i.e., if the slope of the isocost curve is positive, and

$$\frac{dX_2}{dC} = \frac{^1/P_3}{(\frac{P_2}{P_3} - 1)} > 0,$$

then B is the optimal ration, i.e., if $\frac{P_2}{P_3} - 1 > 0$ and $\frac{P_1}{P_3} - 1 < 0$ or $\frac{dX_2}{dC} = \frac{1/P_3}{(\frac{P_2}{P_3} - 1)} < 0,$

then D is the optimal ration, i.e., if $\frac{P_2}{P_3} - 1 < 0$ and $\frac{P_1}{P_3} - 1 > 0.$

These results are presented in Fig. 7b. To determine the specific price ratios, for example, for which rations B and C are appropriate, consider the range of prices where $^{P_1}/P_3 < 1$ and $^{P_2}/P_3 < 1$, then set the slope of the isocost curve to a constant, k, where k is the slope of the line BC in Fig. 7a. Thus,

(61) $$(\frac{P_1}{P_3} - 1)/(\frac{P_2}{P_3} - 1) = \text{constant} = k.$$

Solving for $\frac{P_1}{P_3}$ in (61), we have

(62) $$^{P_1}/P_3 = k(^{P_2}/P_3) + 1 - k.$$

Equation (62) is graphed in Fig. 7b as a straight line with slope k and intercept 1 - k. This result implies that when the slope of the isocost is -k the farmer or the feed manufacturer is indifferent between rations B and C. Similarly, the indifference between the other rations can be shown.

These results demonstrate that depending upon the nature of the isocost curve and the constraint set, the various optimal rations can be determined. Note, however, that when all the prices of the three feedstuffs are equal to 1, any ration in the shaded area in Fig. 7a is a possible choice.

Mathematical Formulation of the Model

The problem for two and three feedstuffs was treated graphically on pages 21 - 41. The problem will now be extended to N feedstuffs and treated mathematically. Mathematically, the N feedstuffs equivalent of the objective function presented in equation (56) is:

$$(63) \qquad C = \sum_{j=1}^{N} c_j X_j,$$

and the N feedstuffs equivalent of the constraint equations (52) to (55) is:

$$(64) \qquad \sum_{j=1}^{N} a_j X_j = 1 \text{ kg},$$

$$(65) \qquad \sum_{j=1}^{N} a_{ij} X_j \geq B_i \qquad i = 1,2,\ldots,m,$$

$$(66) \qquad \sum_{j=1}^{N} a_{ij} X_j \leq B_i \qquad i = m+1,\ldots,M$$

where

C = the total cost of 1 kilogram of ration,

c_j = the cost (price) per kilogram of the jth feedstuff,

a_{ij} = the level of the ith nutrient in the jth feedstuff,

X_j = the amount of the jth feedstuff in the ration,

B_i = the minimum requirement of the ith nutrient (65) or tolerance level of the ith nutrient (66),

a_j = the number of kilogram per unit of the jth feedstuff.

The addition of the following non-negative constraint to (63) - (66) specifies a conventional linear programming problem.[1]

(67) $X_j \geq 0 \qquad j = 1,2,\ldots,N.$

The non-negativity constraint expresses the mathematical requirement that only non-negative amounts of a feedstuff are allowable. Although the above formulation is general enough to specify all linear constraints desired, the handling of the calcium-phosphorus ratio requires special attention. It is assumed here that the calcium content of the rations should be

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[1] A linear objective function, alternative methods or processes and linear restrictions constitute a linear programming problem, (see Heady and Candler, 1958).

at least 1.5 times the phosphorus content and less than 2.5 times the phosphorus content. The minimum calcium-phosphorus ratio requirement is handled by two equations, (68) which expresses a minimum constraint for the calcium, and (69) which represents a maximum constraint on the phosphorus.

(68) $$- \sum_{j=1}^{N} a_{ij}X_j + 1.5X_k \le 0 \qquad i = M+1,\ k = N+1,$$

(69) $$\sum_{j=1}^{N} a_{ij}X_j - 1.0X_k \le 0 \qquad i = M+2,\ k = N+1,$$

where

$a_{M+1,j}$ = the calcium content of the jth feedstuff,

$a_{M+2,j}$ = the phosphorus content of the jth feedstuff,

X_k = a transfer activity, $k = N+1$

X_k X_j = the amount of the jth feedstuff in the ration.

From (68), we get

(70) $$\Sigma a_{M+1,j}X_j \ge 1.5X_k$$

and from (69), we have

(71) $$X_k \ge \Sigma a_{M+2,j}X_j.$$

Combining (71) and (70), we can derive

(72) $$\Sigma a_{M+1,j}X_j \ge 1.5X_k \ge 1.5\ \Sigma a_{M+2,j}X_j$$

Hence,

$$\frac{Ca}{P} = \frac{\Sigma a_{M+1,j}X_j}{\Sigma a_{M+2,j}X_j} \geq 1.5.$$

This latter relationship implies that for every unit of phosphorus brought into the ration at least 1.5 units of calcium must be supplied. An additional activity which is designated as a transfer activity (X_k) has been added to (68) and (69). With the two additional constraint equations, it is ensured that the ration satisfies the minimum ratio of calcium to phosphorus requirement as demonstrated above. Equations (68) and (69) specify a minimum calcium-phosphorus ratio and allow for excess when a disposal is added. However, nutrition requirements specify that the calcium-phosphorus ratio should not exceed 2.5. The upper limit can be incorporated in the system by introducing another transfer activity and two other constraint equations, (73) which is a maximum constraint on the calcium and (74) which is a minimum constraint on phosphorus:

(73) $$\sum_{j=1}^{N} a_{ij}X_j - 2.5X_k \leq 0 \qquad i = M+3,\ k = N+2.$$

(74) $$-\sum_{j=1}^{N} a_{ij}X_j + 1.0X_k \leq 0 \qquad i = M+4,\ k = N+2.$$

where

$a_{M+3,j}$ = the calcium content of the j^{th} feedstuff,[1]

[1] Note: $a_{M+1,j} = a_{M+3,j}$ and $a_{M+2,j} = a_{M+4,j}$ for all j.

$a_{M+4,j}$ = the phosphorus content of the jth feedstuff,

X_k = a transfer activity, $k = N+2$.

From (73), we get

(75) $$\Sigma a_{M+3,j}X_j \leq 2.5X_k$$

From (74), we have

(76) $$X_k \leq \Sigma a_{M+4,j}X_j.$$

Combining (76) and (75), we get

(77) $$\Sigma a_{M+3,j}X_j \leq 2.5X_k \leq 2.5\Sigma a_{M+4,j}X_j.$$

Hence,

$$\frac{Ca}{P} = \frac{\Sigma a_{M+3,j}X_j}{\Sigma a_{M+4,j}X_j} \leq 2.5$$

Thus, by incorporating (73) and (74) in the system the upper limit on the calcium-phosphorus ratio is satisfied.

Morrison (1961) has suggested that as long as the minimum methionine requirement of chickens is satisfied, cystine will replace part of methionine. To incorporate this substitutability, three equations are required. One equation is required to satisfy the minimum methionine requirements; another equation for deriving the level of cystine; and a third equation to limit the level of cystine that can be used to replace methionine. Equations (78), (79) and (80) specify the minimum methionine constraint, the cystine used to raise the level of methionine and the maximum level of cystine that can be used, respectively. Thus, we have

(78) $$\sum_{j=1}^{N} a_{ij}X_j + 1.0X_k \geq B_i \qquad i = M+7,\ k = N+5,$$

(79) $$-\sum_{j=1}^{N} a_{ij}X_j + 1.0X_k \leq 0 \qquad i = M+8,\ k = N+5,$$

(80) $$1.0X_k \leq B_i \qquad i = M+8,\ k = N+5,$$

where

$a_{M+7,j}$ = the level of methionine in the jth feedstuff,

$a_{M+8,j}$ = the level of cystine in the jth feedstuff,

B_{M+7} = the minimum methionine requirement,

B_{M+8} = the maximum cystine that can be used,

X_{N+5} = transfer activity.

All three equations include a transfer activity (X_k) whose coefficient is 1. The transfer activity ensures that the level of methionine in the rations can be raised through the supply of cystine in the rations.

Apart from these equations which play special roles, other constraint equations express the restrictions imposed on the levels of the other nutrients. Such conditions ordinarily will be maximum or minimum requirements. In the case of minimum requirements, disposals are added to ensure that the minimum requirements can be exceeded while for maximums (tolerance levels), disposals are added to allow for lower levels of the nutrient. Thus, for equations such as (66) which specify maximum constraints, disposal activities will be added to get

(81) $$\sum_{j=1}^{N} a_{ij}X_j + 1.0X_{N+i} = B_i \qquad i = m+1,\ldots,M.$$

The minimum requirements can be handled in two ways. One method is to subtract disposals and add artificial activities. In this case, equations such as (65) become

(82) $$\sum_{j=1}^{N} a_{ij}X_j - 1.0X_{N+i} + 1.0X_{N+m+i} = B_i \quad i = 1,2,\ldots,m,$$

where

X_{N+i} = the disposal activities,

X_{N+m+i} = the artificial activities.

Another approach is to multiply the original minimum constraint through by -1 so that it becomes a maximum constraint and add only disposals to permit excess of the minimum nutrients. In such a situation, (65) becomes

(83) $$-\sum_{j=1}^{N} a_{ij}X_j + 1.0X_{N+i} = -B_i \qquad i = 1,2,\ldots,m,$$

where

X_{N+i} = the disposal activities.

An artificial activity must also be added to (64), the bulk constraint, so as to ensure a starting basis. In fact, artificial activities added to the minimum constraints ensure a starting basis. Equation (64) is modified to include the artificial activity, thus:

$$(84) \qquad \sum_{j=1}^{N} a_j X_j + 1.0 X_{N+M+1} = 1 \text{ kg.}$$

where

X_{N+M+1} = the artificial activity.

As a result of addition of artificial activities, the cost function must include high penalties upon the artificial activities to ensure that they do not come into the optimal programme. Hence, (63) results in

$$(85) \qquad C = \sum_{j=1}^{N} c_j X_j + \Phi X_{N+M+1},$$

where

Φ = very high cost, i.e., penalty on the artificial.

Having made the necessary modifications to the basic equations, we have a linear programming problem consisting of minimizing the cost of feed subject to certain specifications to solve.

Sensitivity Analysis for N-feedstuffs

As indicated elsewhere, nutrient contents of feedstuffs as well as feedstuff prices tend to vary under different situations. Because of this problem the linear programming model fails to yield a satisfactory result applicable in all situations, using single estimates of nutrient contents and prices of feedstuffs. One way to deal with this problem is to do sensitivity analysis; in other words, to see what would happen if other values of the data were substituted.

Earlier on pages 30 - 41 graphical presentation of sensitivity analysis involving price changes of two feedstuffs and later three feedstuffs was made. It was assumed that the prices of other feedstuffs remained fixed at certain levels. Now, the sensitivity analysis is extended to N feedstuffs and treated mathematically. When an optimal solution which specifies the amounts of the different feedstuffs to be used in the rations is achieved, different prices and in particular, the observed maximum and minimum price sets of the feedstuffs would be used to see the effect of price changes upon the least-cost rations. Essentially, a new cost and a new mix of feedstuffs would be determined. Hence, the cost function expressed by (85) is modified to account for the price changes. The new cost function is given by

(86) $$C = \sum_{j=1}^{N} \bar{c}_j X_j + \Phi X_{N+M+1},$$

where

$$\bar{c}_j = c_j + dc_j \qquad j = 1,2,\ldots,N,$$

$\bar{c}_j$ = the new cost (price) per kilogram of the jth feedstuff.

When $dc_j = 0$, $\bar{c}_j = c_j$. For some feedstuffs, this latter relationship will hold, implying that the prices of those feedstuffs have not changed. The nutrient contents of the feedstuffs and nutrient requirements will remain unchanged while the price changes are analysed. Hence, only the cost function to be minimized will change while the constraint set remains constant. The sensitivity analysis will be considered for only laying hens ration.

One of the results provided by linear programming is the shadow prices of the activities. At the optimum, the value of the local feedstuffs excluded from the programme will be provided. Such information will enable us to know the extent to which their prices have to be altered for them to be selected for feed mixing.

Using the linear programming model developed above, least-cost rations will be formulated for the following size-classes of poultry and sensitivity analysis considered for laying hens ration:

(i) chicks 0 - 8 weeks,

(ii) broilers at 6 weeks,

(iii) growing chickens 8 - 18 weeks,

(iv) laying hens, and

(v) breeding hens.

Summary

The poultry farmer's profit-maximizing problem is viewed as a problem of minimizing the costs of feeding his birds with a ration that meets stated nutrient requirements. A unit isoquant derived from a continuous and differentiable production function is approximated by a constraint set. By linearizing the unit isoquant, a linear programming model has been developed from the least-cost combination approach. It has been assumed that the farmer seeks to minimize the cost of feed subject to producing 1 kilogram of feed which meets the nutrient specifications of the birds. First, a graphic solution to the linear programming problem has been presented for two and three feedstuffs. Later, the solution is generalized for N feedstuffs by developing the mathematical formulation of the model. Sensitivity analysis involving price changes is finally considered. The linear programming

model developed here will be employed to identify least-cost rations.

CHAPTER THREE

NUTRIENT COMPOSITION OF FEEDSTUFFS AND NUTRIENT REQUIREMENTS OF POULTRY

The data requirements of the linear programming problem formulated in the preceding chapter include nutrient requirements, the nutrient composition of feedstuffs and the prices of the feedstuffs. In this chapter, the discussion will centre on the data that will be used to formulate the linear programming problem.

Sources of Data

Feeding Standards

The data on feeding standards is taken from "Nutrient Requirements of Poultry", (National Academy of Sciences, 1966). The feeding standards are estimates of nutrients recommended for poultry for maximum performance in the United States of America. These estimates are comparable to those given by Morrison (1961). They are being used for lack of equivalent data in Ghana. Table 2 presents the required nutrient composition of one kilogram of feed.

Nutrient Composition of Feedstuffs

Information relating to nutrient contents of the feedstuffs is obtained primarily from secondary sources; the sources are as follows:

(i) Animal Science Department, Legon,
Chemical Analysis of Feedstuffs, (unpublished);

(ii) National Academy of Sciences (1966)
Nutrient Requirements of Domestic Animals;

(iii) Morrison, F.B. (1961), Feeds and Feeding,
The Morrison Publishing Company, U.S.A.;

(iv) Oyenuga, V.A. (1959), Nigeria's Feeding-Stuffs
Their Composition and Nutritive Value,
Ibadan University Press, Nigeria, 2nd Edition.

Chemical analysis done on feedstuffs at the Animal Science Department at Legon does not cover all the nutrients or feedstuffs considered here. For this reason, other sources are resorted to for data on nutrient contents of the feed ingredients. In generating the basic data for the ration formulation, either the mode or the mean has been used after compiling the data available from the four sources. The reason for using the mode in some cases is that the estimated nutrient content given by one source is extremely high. When the estimates happen not to deviate too much from each other, the mean of the estimates is used. The nutrient contents of the feedstuffs used are presented in Appendix Table 1.

Prices of the Feedstuffs

The price information on the feedstuffs is gathered from secondary sources such as the "Food Situation Report", published by the Economics and Marketing Division of the Ministry of Agriculture. If not available from that source, the price data has been collected from both the feedstuff dealers and feed manufacturers. This is particularly so with imported feedstuffs and some local industrial by-products. The prices used in the analysis are those that prevailed in December, 1973, when the study was started. All the prices are Accra prices.

After formulating the rations the prices of the feedstuffs have been modified to analyse the effect of price changes upon the least-cost ration for laying hens. Maximum and minimum prices recorded in Accra from 1953-1973 for the feedstuffs have been used. Where such price estimates do not exist, the shadow prices of those feedstuffs are studied to how much the prices of the feedstuffs would have varied to be included in the least-cost rations.

Feedstuffs

Thirty feedstuffs are considered for the analysis. Of these, twenty one are obtained locally and the rest are imported. Some of the feedstuffs available locally are also imported to supplement local supply. For example, groundnut cake and fish meal are imported as well as produced locally. In addition, the list of feedstuffs includes one vitamin premix and one mineral premix, both of which are imported. Table 1 shows the list of the kinds of feedstuffs considered. These feedstuffs have been selected for consideration because they are currently being used in compounding poultry rations, have been tried experimentally in Ghana or have been tried elsewhere, and are available locally, suggesting that they are potential feedstuffs that can be used in poultry feeds.

Nutrient Contents of Feedstuffs

In formulating rations feedstuffs are given consideration with respect to the nutrients they contain and supply. In our problem, as set out in Chapter two, both the prices and the nutrient contents of the feedstuffs are taken into account simultaneously so that the rations eventually produced provide the important nutrients at minimum cost.

The nutrients which the birds should be supplied through

Table 1: List of Feedstuffs.

LOCAL FEEDSTUFF		IMPORTED FEEDSTUFF	
Current Use	Potential Use	Current Use	Potential Use
Copra nut cake	Brewers' grains, dried	Bone meal steamed	Bone meal cooked
Fish meal	Brewers' yeast, dried	Fish meal	Alfalfa meal, dehydrated
Groundnut cake	Cassava, unpeeled	Soybean meal	Blood meal
Guinea corn [1]	Cocoa meal	Vetrivit	Manganous sulphate
Maize, white	Cocoa shells, coarse	Groundnut cake	Meat and bone meal
Maize, yellow	Cocoa shells, fine		Skimmilk
Millet [1]	Cotton seed meal		
Oyster shell	Kokonte		
Wheat bran	Palm kernel cake		
	Pineapple pulp		
	Rice, polished		
	Rice bran		

[1] Used mainly in the North.

the rations may be classified as protein, energy, minerals and vitamins. In this regard, feedstuffs are grouped on the basis of the nutrients which they furnish most in excess of the requirements of the birds. Thus, the feedstuffs may be grouped into protein, energy, mineral and vitamin sources. However, it should be noted that feedstuffs can be classified according as to whether they are animal or plant source. A more useful classification for our purpose is the one based on the nutrients that they supply.

Protein Sources

Under this group, feedstuffs which qualify are those which at least supply the minimum amount of protein required by chicks. Fifteen feedstuffs furnish at least 20 per cent protein and, therefore, qualify. Appendix Table 1 shows the feedstuffs and their nutrient contents. Table 2 shows the nutrient requirements of chickens. Blood meal is the richest source of crude protein, containing 82 per cent, while fish meal, meat and bone meal, soybean meal and groundnut cake contain 60 per cent, 50 per cent, 44 per cent and 42 per cent, respectively. These are also the feedstuffs used largely as protein supplement in poultry rations.

Amino acid contents of fish meal, blood meal, meat and bone meal, groundnut cake and soybean meal are appreciable.

Fish meal supplies 3.9 per cent arginine, 6.5 per cent lysine, 1.8 per cent methionine, 0.8 per cent cystine and 0.7 per cent tryptophan. Similarly, blood meal furnishes 3.5 per cent arginine, 6.9 per cent lysine, 0.9 per cent methionine, 1.4 per cent cystine and 1.1 per cent tryptophan. Meat and bone meal, groundnut cake and soybean meal furnish at least the minimum amino acids required by chicks. Information on amino acid content of palm kernel cake is unavailable, making it difficult to analyse its contribution of amino acids in the rations. Thus, fifteen feedstuffs are likely to be used as sources of protein but those with at least 40 per cent protein may override those with smaller amounts in the selection of feedstuffs, using protein content as the criterion of selection.

As far as amino acids are concerned, blood meal, fish meal, groundnut cake, meat and bone meal, soybean meal, brewers' yeast and cotton-seed meal may be selected because they meet the amino acid requirements of chicks. Considering both protein and amino acids together as basis of selection, five feedstuffs consisting of blood meal, fish meal, groundnut cake, meat and bone meal and soybean meal will be combined to produce the rations. However, protein and amino acids are not the only nutrients that must be made available in the rations for chickens. They require other nutrients such as energy, vitamins and minerals.

Energy Sources

Energy is supplied by seventeen feedstuffs, including cereals, considering feedstuffs for which data on energy is available. The largest amount of energy of 6000 kilocalories is supplied by coarse and fine cocoa shells and groundnut cake. This amount exceeds the minimums required by chickens. Cotton-seed meal and brewers' grains are next with 5100 kilocalories. Palm kernel cake contains 4800 kilocalories of energy. The by-products from oil processing tend to have large energy value probably as a result of their fairly high fat content. Similarly, cocoa beans by-products have large oil content which may have biased their energy value upwards. Since chicks feed should have small amounts of fat, these feedstuffs which have extremely high energy value will be less suitable for chicks but may be considered on energy grounds for inclusion in broiler rations. In particular, cocoa beans by-products are not currently being used in Ghana but have been tried elsewhere, suggesting their potential for poultry rations. On the other hand, cassava, soybean meal, cereals and their by-products and pineapple pulp contain over 3500 kilocalories of energy. Hence on the basis of energy and fat only these feedstuffs will be selected for compounding the rations.

Vitamin Sources

Apart from the vitamin premix, vetrivit, which contains excessive amounts of the vitamins except biotin and pyridoxine, other good sources of vitamins among the feedstuffs are soybean meal, wheat bran, rice bran, fish meal, cotton-seed meal, brewers' yeast, alfalfa meal and skimmilk. The thiamine content of brewers' yeast surpasses all the feedstuffs and it contains 91 milligrams of thiamine. Thiamine is also largely present in rice bran at the level of 22.44 milligrams, followed by wheat bran which contains 7.92 milligrams. Maize, cotton-seed meal, guinea corn, brewers' grains, millet and soybean meal contain amounts which are at least equal to the minimum required by chicks. Hence, the cereals and their by-products are good sources of thiamine. Brewers' yeast again contains the largest amount of riboflavin at the level of about 35 milligrams, followed by alfalfa meal with about 15 milligrams, while copra nut cake contains 13 milligrams and fish meal furnishes about 17 milligrams. In all, eight feedstuffs are fairly good sources of riboflavin. In the case of pantothenic acid, the largest amount is present in vetrivit furnishing 770 milligrams, followed by dried brewers' yeast with 109 milligrams. Groundnut cake supplies 51.7 mg. followed by alfalfa meal and skimmilk, each supplying 33 milligrams. Wheat bran which is next contains 29 milligrams of pantothenic acid;

rice bran follows with 23 milligrams. Ten feedstuffs, including the vitamin premix, furnish pantothenic acid. Rice bran and wheat bran are extremely rich in niacin and contain 303 milligrams and 209 milligrams, respectively.

Furthermore, brewers' yeast, rice bran and wheat bran contain large amounts of pyridoxine and the largest is supplied by brewers' yeast at the level of 44 milligrams as against 29 milligrams and 24 milligrams supplied by rice bran and wheat bran, respectively. Yellow maize, fish meal, skimmilk, and brewers' grains are the other feedstuffs which contain pyridoxine. Biotin is available in only five feedstuffs with rice bran and soybean meal excelling in amounts. Choline is also present in only seven feedstuffs of which some are fish meal, meat and bone meal, soybean meal and vetrivit. All this shows that very few of the feedstuffs will be selected when vitamins are viewed as the criterion for selection. In this regard, vetrivit, fish meal, brewers' yeast, cotton-seed meal, rice bran, wheat bran, soybean meal and alfalfa meal, which supply at least four kinds of vitamins in amounts satisfying the minimum requirements for chicks, will be selected for the chicks ration. It is, therefore, important to consider vitamin premix in formulating rations, particularly, for chicks. However, if, for example, growing chickens ration is considered, there is the likelihood that the spectrum of feedstuffs qualifying for selection will be wider. It must be pointed out that the information on vitamins of some feedstuffs are unavailable and this might have given rise to a situation of having to consider a few feedstuffs.

Mineral Sources

Three kinds of minerals are included as nutrients which must be provided by the rations. They are calcium, phosphorus and manganese. With regard to calcium, oyster shell, steamed and cooked bone meals supply the largest amount of over 30 per cent. Nineteen other feedstuffs contain calcium. Since the amount of calcium in the ration must not exceed 1 per cent in the case of rations for chicks, broilers and growing chickens, any feedstuff containing more than the tolerance level would be disqualified on the basis of calcium alone. As the tolerance level is increased to 2.75 per cent for laying and breeding hens, the spectrum of feedstuffs qualified for consideration in layers and breeding hens' rations widens. This is not to say that those feedstuffs with considerable amounts of calcium are unsuitable for poultry rations. For instance, oyster shell is used extensively as calcium supplement in poultry feeds.

Very good sources of phosphorus are cooked and steamed bone meals. They furnish more than 10 per cent phosphorus. Sixteen feedstuffs fall within the tolerance level of 0.7 per cent of phosphorus. They include cocoa shells, copra nut cake, yellow maize, groundnut cake, soybean meal and brewers' grains.

Apart from the mineral premix, manganous sulphate, the richest source of manganese, is rice bran which provides 417 milligrams of manganese, followed by wheat bran with about 115 milligrams. Palm kernel cake has more than the minimum required by chicks. Hence in terms of manganese, palm kernel cake, rice bran and wheat bran are the only feedstuffs that qualify to be used in breeding hens and chicks rations. Thus, it may be necessary to consider manganous sulphate for formulating rations for chicks and breeding hens.

From the foregoing, it is clear that no single feedstuff can be used alone as poultry ration. None of the feedstuffs contains all the nutrients and if they supply the nutrients, the nutrient levels may fall short of the minimum requirements or exceed the tolerance levels. Nevertheless, soybean meal is the only feedstuff which furnishes most of the nutrients at the desirable minimum requirements. Brewers' yeast satisfies 15 nutrient requirements while cotton-seed meal, wheat bran, fish meal and rice bran respectively satisfy 12, 11 and 10 nutrient requirements. This state of affairs emphasises the importance of combining feedstuffs in the right proportions to produce balanced rations which provide all the nutrients at the desirable levels. It suggests further that the choice of feedstuffs must be based primarily on their nutrient contents and availability. If a feedstuff is a potential candidate for ration formulation but there is no complete information on its nutrients, it is possible that it may not be selected at all.

Nutrient Requirements of Chickens

Chickens have need for nutrients for maintenance and growth. The nutrients must be supplied by the rations fed the birds. Any feed formulated for poultry must be based primarily on the birds need for nutrients regardless of the system of feeding practised so as to obtain the best performance from them. Moreover, deficiencies of the nutrients have deleterious effect upon the performance of the chickens and lead to diseases. For instance, a chick feed deficient in manganese may cause perosis in chicks. Table 2 presents the nutrient requirements recommended for various kinds of chickens. The requirements relate to one kilogram of the feed.

Table 2: Nutrient Requirements of Chickens*

Nutrient	Starting Chickens 0-8 weeks	Broilers 6 weeks	Growing Chickens 8-18 weeks	Laying Hens	Breeding Hens
Crude Protein %	20.0	18.0	16.0	15.0	15.0
Fat (max.) %	5.0	5.0			
Fiber (max.) %	3.5	3.5			
Calcium (max.) %	1.0	1.0	1.0	2.75	2.75
Phosphorus (max.) %	0.7	0.7	0.6	0.6	0.6
Gross Energy kcl	2640.0	2860.0	2640.0	2640.0	2640.0
Manganese mg	55.0	55.0			33.0
Arginine %	1.2	1.2	1.6	0.8	0.8
Lysine %	1.1	1.1	1.5	0.5	0.5
Methionine %	0.7	0.7	0.87	0.53	0.53
Cystine %	0.3	0.3	0.35	0.25	0.25
Tryptophan %	0.2	0.2	0.26	0.15	0.15
Vitamin A U.S.P. units	2000.0	2000.0	2000.0	4000.0	4000.0
Vitamin B_{12} mg	0.009	0.009			0.003
Thiamine mg	1.8	1.8			
Riboflavin mg	3.6	3.6	1.8	2.2	3.8
Pantothenic Acid mg	10.0	10.0	10.0	2.2	10.0
Niacin mg	27.0	27.0	11.0		
Pyridoxine mg	3.0	3.0		3.0	4.5
Biotin mg	0.09	0.09			0.15
Choline mg	1300.0	1300.0			
Folic Acid mg	1.2	1.2		0.25	0.35

* in percentage or Amount per kg of Ration.

Source: National Academy of Sciences (1966)
Nutrient Requirements of Domestic Animals, No.1.

The birds need for crude protein depends upon the age and the function it performs. The older the bird, the less the crude protein level required. Chicks must be provided with at least 20 per cent crude protein in the ration. Growing chickens especially pullets between the ages of eight and eighteen weeks require 16 per cent crude protein. Broilers are to be provided with 18 per cent crude protein and 15 per cent has been recommended for breeding and laying hens.

The amino acid requirements of poultry, like protein, vary with the age and function of the bird. The requirements suggest that young birds have greater demand for amino acids than older chickens. They are the same for breeding and laying hens on one hand and chicks and broilers on the other hand but differ for chicks and growing chickens. Growing chickens demand the greatest amount of amino acids among all classes of chickens. For example, chicks and broilers require in their rations 1.2 per cent arginine while growing chickens must be provided with 1.6 per cent, and both breeding and laying hens rations must supply 0.8 per cent arginine.

As Table 2 shows, chicks and broilers are the only classes of chickens for which fat and fiber levels have been recommended. The fat content recommended for chicks and broilers must not exceed 5 per cent of the ration and the fiber level should also not be greater than 3.5 per cent of the ration.

Again Table 2 shows that 1 per cent calcium is recommended in the rations for chicks, broilers and growing chickens and 2.75 per cent in rations for laying and breeding hens. The large calcium requirement for both laying and breeding hens is due to the fact that calcium is used by these birds in forming shells of eggs. These requirements are the maximum amounts that must be provided.

The birds need for phosphorus is lower than for calcium. While the chicks and broilers calcium tolerance level is lower than that of other chickens, their phosphorus tolerance level is higher than that of other chickens. Chicks and broilers must be provided with a maximum of 0.7 per cent phosphorus in the rations whereas growing chickens, laying and breeding hens require 0.6 per cent phosphorus in their rations. Another mineral on which recommendation has been made is manganese. Fifty-five milligrams of manganese is recommended for chicks and broilers as opposed to 33 milligrams for breeding hens.

Recommendations have been made in respect of vitamins, as shown in Table 2, but do not cover all the vitamins in the case of growing chickens, laying and breeding hens. Chicks and broilers make the greatest demand for vitamins while growing chickens make the least demand. Choline is recommended for only chicks and broilers at the level of 1300 milli-

Table 3: Prices of Feedstuffs*

Feedstuff	Current Price Estimate per kg ¢	Observed Minimum Price Estimate per kg ¢	Observed Maximum Price Estimate per kg ¢
Alfalfa meal	0.70	n.a.	n.a.
Bone meal, cooked	0.70	0.66	n.a.
Bone meal, steamed	0.39	0.39	0.66
Blood meal	0.70	n.a.	n.a.
Brewers' grains, dried	0.70	n.a.	n.a.
Brewers' yeast, dried	0.70	n.a.	n.a.
Cassava, unpeeled	0.08	0.04	0.09
Cocoa meal	0.70	n.a.	0.79
Cocoa shells, coarse	0.70	n.a.	0.79
Cocoa shells, fine	0.70	n.a.	0.79
Copra nut cake	0.31	n.a.	n.a.
Cottonseed meal	0.70	n.a.	n.a.
Fish meal	0.66	0.66	0.70
Groundnut cake	0.22	0.22	0.36
Guinea corn	0.26	0.07	0.28
Kokonte	0.19	0.07	0.20
Maize, white	0.23	0.04	0.30
Maize, yellow	0.20	0.04	0.30
Manganous sulphate	4.40	n.a.	n.a.
Meat & bone meal	0.70	n.a.	n.a.
Millet	0.29	0.07	0.29
Oyster shell	0.05	0.05	n.a.
Palm kernel cake	0.70	n.a.	n.a.
Pineapple pulp	0.70	n.a.	n.a.
Rice, polished	0.79	0.12	0.79
Rice bran	0.04	n.a.	n.a.
Skimmilk	0.70	n.a.	1.25
Soybean meal	0.60	0.51	0.60
Vetrivit	2.42	n.a.	n.a.
Wheat bran	0.07	0.07	0.08

* Accra Prices for December, 1973.

n.a. - not available.

grams whereas thiamine, vitamin B_{12} and biotin have been recommended for chicks, broilers and laying hens but at different levels. Vitamin D is derived from sun rays so that in Ghana where the birds are exposed to sun rays, the problem of vitamin D deficiency does not arise.

Prices of Feedstuffs

Table 3 shows the prices of the feedstuffs per kilogram. The current price estimate is the price prevailing at the time of the study in December, 1973, and is the price used in the first instance of the analysis. For some feedstuffs, price information has been recorded over a number of years. Those feedstuffs have maximum and minimum prices and these prices will be used to do sensitivity analysis. The prices of some of the feedstuffs are unavailable. Prices have been assumed for those feedstuffs. For instance, the price of alfalfa meal which is unavailable is assumed to be ¢0.70 per kilogram. The shadow prices of those local feedstuffs with unavailable prices will be studied to see how their prices have to be for them to be used in the rations. If such feedstuffs are selected, their assumed prices will be considered appropriate but lowering their prices will lead to more of them being used.

Summary

The discussion has centred mainly on the generation of the basic data for solving the linear programming problem formulated in Chapter two. In this regard, the sources of data, the nutrient composition and the prices of the feedstuffs and the nutrient requirements of poultry have been discussed, pointing out the relevance of combining feedstuffs to produce poultry rations.

CHAPTER FOUR

LEAST-COST RATIONS FOR POULTRY

The linear programming model considers the cost and the nutrient contents of the feedstuffs simultaneously, and in the light of these selects, the mixture of feedstuffs for producing least-cost rations that meet the constraint set. The optimal solution yields information on the composition of the rations, their costs and also the shadow prices or marginal value products of both the excluded feedstuffs and the limiting nutrients. The data and methodology described in earlier chapters are used here to solve least-cost feed mix problems for poultry. The problem consists of minimizing the costs of the feeds considering thirty alternative feedstuffs and thirty constraints. The problem was solved using the IBM 1130 computer at the University of Ghana.

Least-cost Ration for Chicks

Twelve feedstuffs out of the possible thirty feedstuffs were selected at different levels for compounding the ration for chicks. Of these, seven are locally available: cocoa meal, oyster shell, unpeeled cassava, yellow maize, fish meal, groundnut cake, and wheat bran. Table 4 shows the amounts of feedstuffs in the ration and also the cost of the ration. Soybean

Table 4: Least-cost Feed Mix for Chicks

Feedstuff	Assumed Price Cedis per kg.		Feed Cost Cedis per ton
Soybean meal	0.60	26.78	160.68
Cassava, unpeeled	0.08	23.75	19.00
Cocoa meal	0.70	17.85	124.95
Fish meal	0.66	11.71	77.29
Skimmilk	0.70	7.62	53.34
Maize, yellow	0.20	5.60	11.20
Groundnut cake	0.22	2.62	5.76
Wheat bran	0.07	2.34	1.64
Blood meal	0.70	1.41	9.87
Oyster shell	0.05	0.25	0.13
Manganous sulphate	4.40	0.05	2.20
Vetrivit	2.42	0.02	0.48
Total		100.00	466.54

meal which is the largest single feedstuff in the ration contributes about 27 per cent of the ration. It is closely followed by unpeeled cassava which contributes about 24 per cent of the ration. The main protein sources of the ration are soybean meal and fish meal while the major energy sources are unpeeled cassava and cocoa meal. The chicks ration contains a mineral premix, manganous sulphate, at the level of 0.05 per cent and vitamin premix at the level of 0.02 per cent of the ration. These premixes are selected because of the high manganese and vitamin requirements of chicks. Chicks are the only class of poultry which has this great demand for vitamins as well as manganese in their ration. The cost of the chicks' ration is about 47 pesewas per kilogram or ¢466.54 per metric ton.

The computer formulated chicks' ration in all cases meets the constraint set and in some cases exceeds the minimum nutrient requirements and falls short of the tolerance levels. The levels of the nutrients in the ration for chicks are presented in Table 5. The crude protein content of the chicks' ration exceeds the minimum requirement of 20 per cent by about 9 per cent and the digestible protein level is about 24 per cent. The gross energy level is exactly met and the digestible energy content of the feed is 1139 kilocalories. The low digestible energy content may be attributable in part to the

Table 5: Nutrient Levels in Least-Cost Chicks' Ration

No.	CONSTRAINT		AMOUNT SPECIFIED	AMOUNT IN RATION	SHADOW PRICE ¢ PER TON FEED
1.	Crude Protein	%	20.0	29.46	0.0
2.	Digestible Protein	%	0.0	24.13	0.0
3.	Fat [1]	%	5.0	5.00	2.45
4.	Fiber [1]	%	3.5	3.50	35.02
5.	Calcium [1]	%	1.0	1.00	242.27
6.	Phosphorus [1]	%	0.7	0.67	0.0
7.	Gross Energy	kcal	2640.0	2640.0	0.0
8.	Digestible Energy	kcal	0.0	1139.00	0.0
9.	Manganese	mg	55.0	55.00	0.08
10.	Arginine	%	1.2	1.49	0.0
11.	Lysine	%	1.1	1.89	0.0
12.	Methionine	%	0.7	0.70	0.0
13.	Cystine	%	0.30	0.29	0.0
14.	Tryptophan	%	0.2	0.31	0.0
15.	Vitamin A	U.S.P.	2000.0	3013.46	0.0
16.	Vitamin B_{12}	mg	0.009	0.406	0.0
17.	Thiamine	mg	1.8	2.96	0.0
18.	Riboflavin	mg	3.6	3.60	0.0
19.	Pantothenic Acid	mg	10.0	10.00	24.75
20.	Niacin	mg	27.0	27.00	0.0
21.	Pyridoxine	mg	3.0	3.00	8.92
22.	Biotin	mg	0.09	0.11	0.0
23.	Choline	mg	1300.0	1300.00	28.87
24.	Folic Acid	mg	1.2	2.74	0.0
25.	Weight	kg	1.0	1.00	0.0
26.	Calcium Ratio		1.5	1.50	219.85
27.	Calcium Ratio [1]		2.5	1.50	0.0

[1] Maximum constraints.

fact that no digestible energy data is available for unpeeled cassava which forms the major energy source in the ration. The minimum vitamin A requirement of 2,000 U.S.P. units is exceeded by more than 1,000 U.S.P. units.

In addition to providing information on the choice of feedstuffs, the model also provides information on the marginal value products or the shadow prices of the excluded feedstuffs and the constraining nutrients. The shadow price means that if the excluded feedstuff were to be included in the ration, the cost of the feed would increase by that amount. The shadow prices of the local feedstuffs excluded from the ration for chicks are presented in Table 6. Some of the local feedstuffs have shadow prices which are greater than their assumed market prices. For example, the market price of millet is 29 pesewas per kilogram whereas its shadow price is 77 pesewas per kilogram. The interpretation of this shadow price is that introducing millet into the ration will increase the cost of the feed mix by 77 pesewas per kilogram used, i.e., if millet were 29 pesewas per kilogram, the user would have to be subsidized an amount of 48 pesewas per kilogram. Those excluded feedstuffs whose shadow prices are less than their market prices would be selected if prices were to be lowered to the shadow prices of those feedstuffs. For example, if the price of kokonte were reduced to 13 pesewas per kilogram, it

Table 6: Shadow Prices of Local Feedstuffs Excluded from Least-Cost Chicks' Ration.

Feedstuff	Assumed Price ¢ per kg.	Shadow Price ¢ per kg.
Brewers' grains	0.70	0.94
Brewers' yeast	0.70	0.82
Cocoa shells, coarse	0.70	1.43
Cocoa shells, fine	0.70	1.36
Copra-nut cake	0.31	0.63
Cotton-seed meal	0.70	0.77
Guinea corn	0.26	0.12
Kokonte	0.19	0.13
Maize, white	0.23	0.24
Millet	0.29	0.77
Palm kernel cake	0.70	1.36
Pineapple pulp	0.70	1.19
Rice, polished	0.79	0.62
Rice bran	0.04	0.51

would be included in the least-cost ration.

These results arise from the constraint set of the problem. The most limiting constraint of the problem is the calcium constraint and consequently the minimum calcium-phosphorus ratio constraint of the feed. The marginal value product of calcium is ¢242.27 per percentage unit. This means that for a 1 per cent increase in the quantity of calcium in the feed, the cost of the feed would decrease by ¢242.27 per ton of the least-cost ration. Because of the restrictive nature of the calcium constraint the minimum calcium-phosphorus ratio constraint becomes difficult to satisfy and therefore is the second most limiting constraint of the chicks feed problem.

Least-Cost Ration for Broilers

Broilers and chicks are similar in nutrient requirments except for the levels of crude protein and gross energy. Because broilers are fattened for the market, their ration is required to contain a higher level of energy and a lower level of protein than the chicks' ration. Consequently, chickens destined for broiler production are switched to broilers ration after eight weeks to finish them off for the market.

The least-cost mix for broilers consists of eleven feedstuffs of which seven feedstuffs are locally produced.

Table 7: Least-Cost Feed Mix for Broilers

Feedstuff	Assumed Price ¢ per kg.	%	Feed Cost ¢ per ton
Cassava, unpeeled	0.08	33.05	26.44
Soybean meal	0.60	27.79	166.74
Cocoa meal	0.70	13.22	92.54
Fish meal	0.66	11.05	72.93
Skimmilk	0.70	8.56	59.92
Wheat bran	0.07	4.27	2.99
Groundnut cake	0.22	1.62	3.56
Oyster shell	0.05	0.33	0.17
Copra-nut cake	0.31	0.04	0.12
Manganous sulphate	4.40	0.04	1.76
Alfalfa meal	0.70	0.03	0.21
Total		100.00	427.38

Table 7 presents the composition of the least-cost broilers ration. Alfalfa meal and copra-nut cake have replaced yellow maize, vetrivit and blood meal in the chicks ration. The major protein sources of the broilers ration are soybean meal and fish meal, and the major energy sources are unpeeled cassava and cocoa meal. Because of the lower protein requirement and higher energy requirements of broilers, unpeeled cassava which furnishes largely energy, forms the largest amount of the ration (33 per cent) and soybean meal, the next largest (28 per cent). The level of cocoa meal has gone down while the level of fish meal has remained almost the same. Furthermore, the cost of broilers ration is about 43 pesewas per kilogram or about 4 pesewas per kilogram lower than that of chicks ration. The cost differences may be attributed partly to the lower level of crude protein whose sources tend to be expensive and to the fact that a larger amount of the ration is unpeeled cassava which is relatively cheaper.

The nutrient levels in the least-cost broilers ration and the corresponding shadow prices are presented in Table 8. The crude protein level is 27 per cent and the digestible protein level is about 23 per cent which are lower than those contained in the chicks ration. The level of fat in the broilers ration is also lower than that in the chicks ration

Table 8: Nutrient Levels in Least-Cost Broilers Ration

No.	CONSTRAINT		Amount Specified	Amount in Ration	Shadow Price ¢ per ton
1.	Crude Protein	%	18.0	27.04	0.0
2.	Digestible Protein	%	0.0	22.66	0.0
3.	Fat [1]	%	5.0	3.95	0.0
4.	Fiber [1]	%	3.5	3.50	3.57
5.	Calcium [1]	%	1.0	1.00	128.20
6.	Phosphorus [1]	%	0.7	0.67	0.0
7.	Gross Energy	kcal	2860.0	2860.00	0.0
8.	Digestible Energy	kcal	0.0	1000.00	0.0
9.	Manganese	mg	55.0	55.00	0.08
10.	Arginine	%	1.2	1.39	0.0
11.	Lysine	%	1.1	1.79	0.0
12.	Methionine	%	0.7	0.74	0.0
13.	Cystine	%	0.30	0.30	0.0
14.	Tryptophan	%	0.2	0.30	0.0
15.	Vitamin A	U.S.P.	2000.0	2000.00	0.38
16.	Vitamin B_{12}	mg	0.009	0.025	0.00
17.	Thiamine	mg	1.8	2.85	0.0
18.	Riboflavin	mg	3.6	3.60	0.0
19.	Pantothenic Acid	mg	10.0	10.00	12.00
20.	Niacin	mg	27.0	27.18	0.0
21.	Pyridoxine	mg	3.0	3.00	0.0
22.	Biotin	mg	0.09	0.12	0.0
23.	Choline	mg	1300.0	1300.00	21.55
24.	Folic Acid	mg	1.2	2.65	0.0
25.	Weight	kg	1.0	1.00	0.0
26.	Calcium Ratio		1.5	1.5	110.78
27.	Calcium Ratio [1]		2.5	1.5	0.0

[1] Maximum constraints.

presumably, because cocoa meal which contains much fat is smaller in broilers ration than in chicks ration. The vitamin A requirement of 2,000 U.S.P. units is exactly met. The digestible energy level in broilers ration is 1,000 kilocalories which is lower than that in chicks ration. It must be noted that some of the minimum requirements are exceeded while others are exactly met.

The marginal value product of the calcium constraint is the largest, implying that calcium is still the most limiting constraint on the problem. It is ¢128.20 per percentage unit.

The solution to the broilers ration formulation problem yielded information on shadow prices of the excluded feedstuffs. Table 9 presents the values of the local feed ingredients not selected for the broilers ration formulation. The values of kokonte, white maize, yellow maize, cotton-seed meal and rice are 7 pesewas, 18 pesewas, 9 pesewas, 34 pesewas and 66 pesewas, respectively. The market prices of these commodities must be equal to their shadow prices for them to be used in the broilers ration.

Table 9: Shadow Prices of Local Feedstuffs Excluded from Least-Cost Broilers Ration.

Feedstuff	Assumed Price ¢ per kg.	Shadow Price ¢ per kg.
Brewers' grains	0.70	0.51
Brewers' yeast	0.70	0.70
Cocoa shells, coarse	0.70	1.01
Cocoa shells, fine	0.70	1.01
Cotton-seed meal	0.70	0.34
Guinea corn	0.26	0.08
Kokonte	0.19	0.07
Maize, white	0.23	0.18
Maize, yellow	0.20	0.09
Millet	0.29	0.37
Palm kernel cake	0.70	0.86
Pineapple pulp	0.70	0.74
Rice, polished	0.79	0.66
Rice bran	0.04	0.05

Least-Cost Ration for Growing Chickens

Chickens destined for breeding and egg laying must be switched to a different feed after eight weeks. Such chickens have different nutrient requirements. The least-cost mix for growing chickens is presented in Table 10.

Eight feedstuffs of which six are locally produced are chosen for compounding the growing chickens ration. The major protein sources are blood meal and groundnut cake at the levels of 38 per cent and 17 per cent of the ration, respectively. The high blood meal level in the ration may be due in part to its high amino acid contents which are also greatly demanded by growing chickens. Unpeeled cassava forms the major source of energy and contributes 34 per cent of the ration. The level of fish meal in the growing chickens ration has gone down tremendously as compared with its level in both broilers and chicks rations. Meat and bone meal is selected at a very low level while soybean meal is excluded from the growing chickens ration. Cocoa meal is also replaced by fine cocoa shells but cocoa shells form a small percentage of the ration. The level of oyster shell has gone up appreciably because of the greater demand for calcium by growing chickens. The cost of the growing chickens ration is 39 pesewas per kilogram or ¢392.28 per metric ton.

Table 10: Least-Cost Feed Mix for Growing Chickens

Feedstuff	Assumed Price ¢ per kg.	%	Feed Cost ¢ per ton
Blood meal	0.70	38.08	266.56
Cassava, unpeeled	0.08	34.48	27.58
Groundnut cake	0.22	17.50	38.50
Fish meal	0.66	5.84	38.54
Pineapple pulp	0.70	1.71	11.97
Oyster shell	0.05	1.17	0.59
Cocoa shells, fine	0.70	1.07	7.49
Meat and Bone meal	0.70	0.15	1.05
Total		100.00	392.28

Table 11 presents the nutrient levels in the growing chickens ration as calculated from the programme. The level of protein is extremely high and is more than twice the minimum protein requirement of 16 per cent for growing chickens. Consequently, the digestible protein in the ration is also high at the level of 33 per cent. The zero digestible energy results from the fact that there is no information on the digestible energy for unpeeled cassava which is the main energy source. In spite of the high protein content of the feed, the cost of the growing chickens ration is less than those of chicks and broilers rations. This may be due partly to the fewer vitamins required by growing chickens than by both chicks and broilers.

Table 11 also shows that the most limiting constraint of the growing chickens ration is methionine whose marginal value product is ¢323.67. Thus, if the methionine content in the growing chickens ration were reduced by 1 per cent, the cost of the least-cost ration for growing chickens would decrease by ¢323.67 per metric ton of the feed.

The shadow prices of the excluded local feedstuffs are presented in Table 12. The shadow prices of palm kernel cake and rice are 42 pesewas per kilogram and 12 pesewas per kilogram, respectively. Furthermore, the shadow prices of some

Table 11: Nutrient Levels in Least-Cost Growing Chickens Ration

No.	CONSTRAINT		Amount Specified	Amount in Ration	Shadow Price ¢ per ton
1.	Crude Protein	%	16.0	43.16	0.0
2.	Digestible Protein	%	0.0	33.63	0.0
3.	Fat [1]	%	-	3.57	0.0
4.	Fiber [1]	%	-	2.20	0.0
5.	Calcium [2]	%	1.0	1.00	0.0
6.	Phosphorus [2]	%	0.6	0.40	0.0
7.	Gross Energy	kcal	2640.0	2640.00	32.82
8.	Digestible Energy	kcal	0.0	0.00	0.0
9.	Manganese	mg	0.0	2.60	0.00
10.	Arginine	%	1.6	2.60	0.00
11.	Lysine	%	1.5	3.41	0.0
12.	Methionine	%	0.87	0.87	323.67
13.	Cystine	%	0.35	0.35	32.37
14.	Tryptophan	%	0.26	0.54	0.0
15.	Vitamin A	U.S.P.	2000.0	2000.00	5.18
16.	Vitamin B_{12}	mg	0.0	0.001	0.0
17.	Thiamine	mg	0.0	1.27	0.0
18.	Riboflavin	mg	1.8	1.80	0.0
19.	Pantothenic Acid	mg	10.0	10.00	21.67
20.	Niacin	mg	11.0	46.09	0.0
21.	Pyridoxine	mg	0.0	0.86	0.0
22.	Biotin	mg	0.0	0.00	0.00
23.	Choline	mg	0.0	252.64	0.0
24.	Folic Acid	mg	0.0	0.00	0.0
25.	Weight	kg	1.0	1.00	0.0

1 No recommendations of fat and fiber are made for growing chickens. 100% was specified to have a soluble problem.

2 Maximum constraints.

Table 12: Shadow Prices of Local Feedstuffs Excluded from Least-Cost Growing Chickens Ration.

Feedstuff	Assumed Price ¢ per kg.	Shadow Price ¢ per kg.
Brewers' yeast	0.70	22.07
Cocoa meal	0.70	1.96
Cocoa shells, coarse	0.70	0.01
Copra-nut cake	0.31	8.84
Cotton-seed meal	0.70	2.17
Guinea corn	0.26	0.87
Kokonte	0.19	0.21
Maize, white	0.23	0.80
Maize, yellow	0.20	0.48
Millet	0.29	2.58
Palm kernel cake	0.70	0.42
Rice	0.79	0.12
Rice bran	0.04	1.29
Wheat bran	0.07	0.80

of the local feedstuffs, for example, white maize, exceed their market prices. Those feedstuffs would only be used if the feed manufacturer or the poultryman is offered rewards equivalent to the differences between the shadow prices and the market prices.

Least-Cost Ration for Laying Hens

Pullets that enter the laying flock must be given a different ration because they will require different levels of the various nutrients in order for them to achieve maximum performance. Table 13 shows the feedstuffs that must be combined to produce rations for laying hens. Eleven feedstuffs of which six are locally produced are chosen to compound the least-cost layers mix. Fish meal forms the major source of protein and contributes about 17 per cent of the ration. Unpeeled cassava which forms more than half the ration is the major source of energy. Soybean meal is excluded from the least-cost ration. The vitamin premix is chosen at the level of 0.09 per cent of the ration. The laying hens ration costs about 31 pesewas per kilogram or ¢305.34 per metric ton.

The levels of nutrients in the laying hens ration are presented in Table 14. The crude protein content is 17 per cent while the digestible protein level is 12 per cent. The gross energy requirement is exactly met while the digestible energy level is 200 kilocalories. The low digestible energy

Table 13: Least-Cost Feed Mix for Laying Hens

Feedstuff	Assumed Price ¢ per kg.	%	Feed Cost ¢ per ton
Cassava, unpeeled	0.08	57.74	46.19
Fish meal	0.66	17.57	115.96
Cocoa meal	0.70	14.47	101.29
Maize, yellow	0.20	4.94	9.88
Blood meal	0.70	1.48	10.36
Skimmilk	0.70	1.30	9.10
Oyster shell	0.05	0.89	0.44
Alfalfa meal	0.70	0.75	5.25
Meat and Bone meal	0.70	0.59	4.13
Copra-nut cake	0.31	0.18	0.56
Vetrivit	2.42	0.09	2.18
Total		100.00	305.34

Table 14: Nutrient Levels in Least-Cost Laying Hens Ration.

No.	CONSTRAINT		Amount Specified	Amount in Ration	Shadow Price ¢ per ton
1.	Crude Protein	%	15.0	17.52	0.0
2.	Digestible Protein	%	0.0	12.67	0.0
3.	Fat [1]	%	-	4.30	0.0
4.	Fiber [1]	%	-	2.02	0.0
5.	Calcium [2]	%	2.75	1.50	0.0
6.	Phosphorus [2]	%	0.6	0.60	11.05
7.	Gross Energy	kcal	2640.0	2640.00	0.0
8.	Digestible Energy	kcal	0.0	200.00	0.0
9.	Manganese	mg	0.0	2.16	0.0
10.	Arginine	%	0.8	0.80	0.0
11.	Lysine	%	0.5	1.31	0.0
12.	Methionine	%	0.53	0.53	57.68
13.	Cystine	%	0.25	0.18	0.0
14.	Tryptophan	%	0.15	0.15	0.0
15.	Vitamin A	U.S.P.	4000.0	4000.00	0.85
16.	Vitamin B_{12}	mg	0.0	1.829	0.0
17.	Thiamine	mg	0.0	0.90	0.0
18.	Riboflavin	mg	2.2	2.20	0.0
19.	Pantothenic Acid	mg	2.2	3.28	0.0
20.	Niacin	mg	0.0	15.48	0.0
21.	Pyridoxine	mg	3.0	3.00	0.0
22.	Biotin	mg	0.0	0.007	0.0
23.	Choline	mg	0.0	740.66	0.0
24.	Folic Acid	mg	0.25	0.25	60.17
25.	Weight	kg	1.0	1.00	0.0

[1] No recommendations of fat and fiber made for laying hens. 100% was specified to have a soluble problem.

[2] Maximum constraints.

level is attributable in part to the lack of digestible energy data for unpeeled cassava. Some of the minimum requirements are exceeded while others are exactly satisfied. The most constraining nutrient is folic acid whose marginal value product is ¢60.17, followed by methionine with marginal value product of ¢57.68.

The values of the excluded local feedstuffs are presented in Table 15. Some of the shadow prices exceed the market prices while others are less than the market prices. For example, kokonte and white maize, whose shadow prices are 6 pesewas and 21 pesewas, respectively, have market prices which are 19 pesewas and 23 pesewas, respectively.

Least-Cost Ration for Breeding Hens

The final ration to be considered is the breeding hens ration. Such a ration is fed to hens which are in the breeding flock and produce eggs for hatching. The least-cost mix for breeding hens is presented in Table 16. Twelve feedstuffs of which nine are available locally are selected for breeding hens ration for mulation. The greatest proportion of the ration is guinea corn at 20 per cent. The next largest is yellow maize with a proportion of 17 per cent. These together with unpeeled cassava form the major energy sources of the ration. The major protein sources are skimmilk and blood meal at the respective levels of about 13 per cent and 8 per cent.

Table 15: Shadow Prices of Local Feedstuffs Excluded from Least-Cost Laying Hens Ration.

Feedstuff	Assumed Price ¢ per kg.	Shadow Price ¢ per kg.
Brewers' grains	0.70	0.49
Brewers' yeast	0.70	0.21
Cocoa shells, coarse	0.70	0.94
Cocoa shells, fine	0.70	0.95
Cotton-seed meal	0.70	1.28
Groundnut cake	0.22	1.26
Guinea corn	0.26	0.17
Kokonte	0.19	0.06
Maize, white	0.23	0.21
Millet	0.29	0.27
Palm kernel cake	0.70	0.77
Pineapple pulp	0.70	0.65
Rice, polished	0.79	0.61
Rice bran	0.04	0.26
Wheat bran	0.07	0.57

Table 16: Least-Cost Feed Mix for Breeding Hens.

Feedstuff	Assumed Price ¢ per. kg.	%	Feed Cost ¢ per ton
Guinea corn	0.26	20.62	53.61
Maize, yellow	0.20	17.63	35.26
Skimmilk	0.70	12.90	90.30
Cassava, unpeeled	0.08	11.05	8.84
Blood meal	0.70	8.29	58.03
Cocoa meal	0.70	8.15	57.05
Brewers' grains	0.70	7.11	49.77
Rice bran	0.04	6.45	2.58
Fish meal	0.66	3.87	25.54
Oyster shell	0.05	1.58	0.79
Bone meal, steamed	0.39	1.45	5.65
Wheat bran	0.07	0.90	0.63
Total		100.00	388.05

The level of oyster shell in the ration has increased to 1.58 per cent which is the largest amount for all the rations. No premix is included in the least-cost breeding hens ration. The cost of the breeding hens ration is about 39 pesewas per kilogram or ¢388.05 per metric ton.

Nutrient levels in the breeding hens ration have been calculated and shown in Table 17. The crude protein content in the ration is about 30 per cent while the digestible protein level is 16 per cent. The gross energy requirement is exactly satisfied while the level of digestible energy is 1590 kilocalories. Some of the minimum requirements are exactly satisfied and others are exceeded. Except for phosphorus which is exactly satisfied, the maximum constraints are within the tolerance levels. The most limiting nutrient is methionine with a marginal value product of ¢129.09. The cost of the feed would reduce by ¢129.09 if the methionine content were decreased by 1 per cent.

The shadow prices of the local feedstuffs not chosen for the breeding hens ration are presented in Table 18. The shadow prices of kokonte, white maize and rice are 6 pesewas, 14 pesewas and 59 pesewas, respectively. These are lower than their corresponding market prices.

In solving the least-cost feed mix problem for the various classes of poultry, the only variation considered

Table 17: Nutrient Levels in Least-Cost Breeding Hens Ration.

No.	CONSTRAINT	Amount Specified	Amount in Ration	Shadow Price ¢ per ton
1.	Crude Protein %	15.0	22.90	0.0
2.	Digestible Protein %	0.0	16.53	0.0
3.	Fat [1] %	-	4.03	0.0
4.	Fiber [1] %	-	4.69	0.0
5.	Calcium [2] %	2.75	1.50.	0.0
6.	Phosphorus [2] %	0.6	0.60	1.89
7.	Gross Energy kcal	2640.0	2640.00	0.0
8.	Digestible Energy kcal	0.0	1590.00	0.0
9.	Manganese mg	33.0	33.00	0.0
10.	Arginine %	0.8	0.80	0.0
11.	Lysine %	0.5	1.31	0.0
12.	Methionine %	0.53	0.53	129.09
13.	Cystine %	0.25	0.24	0.0
14.	Tryptophan %	0.15	0.22	0.0
15.	Vitamin A U.S.P.	4000.0	4000.00	0.0
16.	Vitamin B_{12} mg	0.003	0.013	0.0
17.	Thiamine mg	0.0	4.20	0.0
18.	Riboflavin mg	3.8	3.80	0.0
19.	Pantothenic Acid mg	10.0	10.00	35.34
20.	Niacin mg	0.0	28.26	0.0
21.	Pyridoxine mg	4.5	4.50	25.32
22.	Biotin mg	0.15	0.15	13.49
23.	Choline mg	0.0	525.10	0.0
24.	Folic Acid mg	0.35	1.32	0.0
25.	Weight kg	1.0	1.00	0.0

[1] No recommendations of fat and fiber are made for breeding hens. 100% was specified to have a soluble problem.

[2] Maximum constraints.

Table 18: Shadow Prices of Local Feedstuffs Excluded from Least-Cost Breeding Hens Ration.

Feedstuff	Assumed Price ¢ per kg.	Shadow Price ¢ per kg.
Brewers' yeast	0.70	2.05
Cocoa shells, coarse	0.70	0.90
Cocoa shells, fine	0.70	0.90
Copra-nut cake	0.31	2.38
Cotton-seed meal	0.70	1.53
Groundnut cake	0.22	3.39
Kokonte	0.19	0.07
Maize, white	0.23	0.14
Millet	0.29	0.66
Palm kernel cake	0.70	1.11
Pineapple pulp	0.70	1.09
Rice, polished	0.79	0.59

is the nutrient requirements of the birds because nutrient requirements differ from one class of poultry to another. The prices of the feedstuffs and the nutrient contents are assumed to remain unchanged. As a result, different combinations of feed ingredients are chosen to compound the various rations. Some of the feedstuffs are chosen consistently for all the five rations. Unpeeled cassava, fish meal and oyster shell are the three feedstuffs that are used in all the five least-cost rations. The largest amount of unpeeled cassava is used in laying hens ration at the level of about 58 per cent. The levels of oyster shell in the various rations increase as the calcium tolerance levels of the birds increase. Fish meal, on the other hand, is used largely in laying hens ration. Furthermore, fish meal and unpeeled cassava provide the major sources of protein and energy respectively in laying hens ration. These three feedstuffs which are used in all the least-cost rations are also locally produced. The feasibility of using them to the extent required in the rations will depend upon their availability.

Only three feedstuffs are selected for compounding four rations; they are skimmilk, blood meal and cocoa meal. Blood meal and cocoa meal can, however, be produced locally. Table 19 shows the distribution of feedstuffs in the least-

Table 19: Distribution of Feedstuffs in Least-Cost Rations.

Feedstuff	Chicks Ration	Broilers Ration	Growing Chickens Ration	Laying Hens Ration	Breeding Hens Ration	Rations Containing Feedstuff
Cassava, unpeeled	x	x	x	x	x	5
Fish meal	x	x	x	x	x	5
Oyster shell	x	x	x	x	x	5
Blood meal	x		x	x	x	4
Cocoa meal	x	x		x	x	4
Skimmilk	x	x		x	x	4
Groundnut cake	x	x	x			3
Maize, yellow	x			x	x	3
Wheat bran	x	x			x	3
Alfalfa meal		x		x		2
Copra-nut cake		x		x		2
Manganous sulphate	x	x				2
Meat and Bone meal			x	x		2
Soybean meal	x	x				2
Vetrivit	x			x		2
Bone meal, steamed					x	1
Brewers' grains					x	1
Cocoa shells, fine			x			1
Guinea corn					x	1
Pineapple pulp			x			1
Rice bran					x	1
No. of Feedstuffs	12	11	8	11	12	

x's refer to rations containing the feedstuffs.

cost rations. In all twenty-one feedstuffs of which thirteen are available locally are chosen to compound one or more of the five rations. Some of the local feedstuffs excluded from the rations are white maize, kokonte, millet and rice. White maize, which is not selected, is currently being used in poultry rations. However, the results suggest that if poultry farmers were faced with the prices and other information on feedstuffs assumed in the model, they ought to exclude white maize from poultry rations. White maize can be replaced in poultry rations by unpeeled cassava and yellow maize so that white maize can be restricted to human consumption.

On the other hand, local feedstuffs which are selected but are not currently being used in poultry rations are brewers' grains, fine cocoa shells, guinea corn, pineapple pulp and rice bran. These feedstuffs could replace part of the imported feedstuffs. For instance, growing chickens ration consists of six local feedstuffs and two imported feedstuffs, while breeding hens ration is composed of nine local feedstuffs and three imported feedstuffs. It is also possible that if the assumed price situation were to change in favour of the local feedstuffs, some of the imported feedstuffs would be forced out of the least-cost rations. In general, relative price changes can lead to entirely different mix of feeds.

Sensitivity Analysis

As discussed in Chapter two, sensitivity analysis will be considered with regard to price changes. In particular, sensitivity analysis is considered here for only the laying hens ration to demonstrate the effect of price changes upon least-cost rations.

In doing the sensitivity analysis, the minimum and maximum observed prices are substituted for the current price estimates (Table 3) of the feedstuffs portraying such prices and the programme re-run for laying hens. The resulting least-cost ration for laying hens under minimum price situation is presented in Table 20. The first recognizable aspect about the ration is that considering the minimum observed prices, the cost of 1 kilogram of laying hens ration has been reduced to about 27 pesewas as compared with the original least-cost laying hens ration under current price situation.[1] Vetrivit has been forced out of the ration and is replaced by polished rice at the level of 2.46 per cent. It is interesting to note that the level of yellow maize has gone up. Furthermore, except vetrivit which has been replaced by rice essentially the same feedstuffs are to be used but at different levels.

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[1] All comparisons are made with reference to the original laying hens ration presented in Table 13.

Table 20: Least-Cost Laying Hens Ration under Minimum Prices Situation.

Feedstuff	Assumed Price ¢ per kg.	%	Feed Cost ¢ per ton
Cassava, unpeeled	0.04	53.06	21.22
Fish meal	0.66	15.77	104.08
Cocoa meal	0.70	12.83	89.81
Maize, yellow	0.04	7.43	2.97
Skimmilk	0.70	3.45	24.15
Rice, polished	0.12	2.46	2.95
Blood meal	0.70	1.27	8.89
Alfalfa meal	0.70	1.04	7.28
Oyster shell	0.05	0.98	0.49
Meat and Bone meal	0.70	0.95	6.65
Copra-nut cake	0.31	0.76	2.36
Total		100.00	270.85

When the programme is re-run with maximum prices for laying hens, the number of feedstuffs reduces to ten instead of eleven for the original laying hens ration. Skimmilk is forced out of the ration. The levels of unpeeled cassava, fish meal and cocoa meal go up while the level of yellow maize falls in the ration. Moreover, the cost of the ration goes up to 33 pesewas per kilogram or ¢334.99 per metric ton as opposed to 30 pesewas per kilogram or ¢305.34 per metric ton. These results are presented in Table 21.

Another method adopted is to increase the prices of selected protein and energy sources to see what the least-cost laying hens ration would be. Thus, the prices of some feedstuffs such as blood meal, meat and bone meal, cocoa meal, white maize and guinea corn have been increased to omit them from the least-cost laying hens ration. Table 22 shows the feedstuffs omitted from the least-cost ration and the least-cost ration. The least-cost ration for laying hens under this situation costs 34 pesewas per kilogram or ¢343.84 per metric ton. The high cost of the ration is due to the fact that in seeking a least-cost ration, relatively more expensive feedstuffs have been selected. An entirely different set of feedstuffs is chosen to feed the laying hens under this situation. Cocoa meal is forced out of the least-cost ration and is replaced by rice at the level of 10.38 per cent.

Table 21: Least-Cost Laying Hens Ration under Maximum Prices Situation.

Feedstuff	Assumed Price ¢ per kg.	%	Feed Cost ¢ per ton
Cassava, unpeeled	0.09	58.65	52.78
Fish meal	0.70	18.41	128.87
Cocoa meal	0.79	15.07	119.05
Maize, yellow	0.30	3.95	11.85
Blood meal	0.70	1.48	10.36
Oyster shell	0.05	0.85	0.43
Alfalfa meal	0.70	0.62	4.34
Copra-nut cake	0.31	0.44	1.36
Meat and Bone meal	0.70	0.40	2.80
Vetrivit	2.42	0.13	3.15
Total		100.00	334.99

Table 22: Price Changes and Least-Cost Laying Hens Ration : 11 Feedstuffs.

Feedstuff	The Least-Cost Ration		
	Price ¢ per kg.	%	Cost ¢ per ton
Cassava, unpeeled	0.08	51.12	40.90
Fish meal	0.66	15.56	102.70
Rice, polished	0.79	10.38	82.00
Palm kernel cake	0.70	6.26	43.82
Maize, yellow	0.20	5.68	11.36
Skimmilk	0.70	4.68	32.76
Pineapple pulp	0.70	3.42	23.94
Oyster shell	0.05	1.26	0.63
Groundnut cake	0.22	0.52	1.14
Rice bran	0.04	0.38	0.15
Total		100.00	339.40

Feedstuffs Omitted from Feedstuff Set

Alfalfa meal	Blood Meal	Brewers' grains
Cocoa meal	Cocoa shells, coarse	Cocoa shells, fine
Guinea corn	Kokonte	Maize, white
Meat and Bone meal	Millet	

Table 23: Price Changes and Least-Cost Laying Hens Ration : 2 Feedstuffs.

Feedstuff	The Least-Cost Ration		
	Price ¢ per kg.	%	Cost ¢ per ton
Cassava, unpeeled	0.08	61.24	48.99
Blood meal	0.70	12.14	84.98
Fish meal	0.66	8.18	53.99
Cocoa meal	0.70	6.91	48.37
Rice bran	0.04	2.46	0.98
Brewers' yeast	0.70	2.43	17.01
Copra-nut cake	0.31	1.97	6.11
Alfalfa meal	0.70	1.73	12.11
Bone meal, steamed	0.39	1.66	6.47
Oyster shell	0.05	1.13	0.57
Brewers' grains	0.70	0.15	1.05
Total		100.00	280.63

Feedstuffs Omitted from the Feedstuff Set

Maize, yellow	Rice, polished

Fish meal and unpeeled cassava continue to be the major protein and energy sources respectively. It is interesting to note that skimmilk and soybean meal are the only two imported feedstuffs used in the ration. Nine local feedstuffs are selected when the prices of some selected feedstuffs are raised by ¢5.00.

Finally, yellow maize and polished rice are omitted from the laying hens least-cost ration by raising their prices by 10 pesewas and 9 pesewas per kilogram respectively. The resulting least-cost laying hens ration costs 28 pesewas per kilogram or ¢280.63, and an entirely different feed mix is obtained. Table 23 presents the least-cost ration and the two feedstuffs omitted. Here, three imported and eight local feedstuffs are selected. The imported feedstuffs are blood meal, steamed bone meal and alfalfa meal. Unpeeled cassava forms the bulk of the ration contributing 61 per cent. Blood meal and fish meal are the major protein sources. Yellow maize and rice are not selected. Thus, if the price of yellow maize goes up from 20 pesewas per kilogram to 30 pesewas per kilogram and the price of rice also rises by 9 pesewas per kilogram, <u>ceteris paribus</u>, the least-cost laying hens ration would exclude yellow maize and rice, and consequently, achieve a lower cost of laying hens ration.

The sensitivity analysis involving price variations clearly demonstrates that under different price situations, which result in different price ratios of the feedstuffs, different feed mixes are obtained. Further, the cost of the feed also changes. Hence, the optimal choice of feedstuffs depends upon the relative prices of the feedstuffs, all things being equal.

Limitations of the Study

The results of the study follow from the data used in running the programme. In the absence of the actual prices, prices were assumed for certain feedstuffs. Thus, any divergence from the assumed prices may invalidate the results. Furthermore, price variations of the feedstuffs resulting in different price ratios may also give rise to different feed mixes. Sensitivity analysis was carried out for laying hens ration to see the effect of price variations upon the least-cost ration. The data on nutrient contents of some of the feedstuffs is also incomplete, making it difficult to analyse their role in the least-cost rations. A zero nutrient level has been assumed for those feedstuffs for which there is no information.

Another limitation of the study is the assumption that the other parameters, such as the nutrient contents of the feedstuffs, remain unchanged. This assumption is untenable in a situation where feedstuff nutrient contents tend to vary under different environments. The solution to this type of problem is to run the programme several times to see how it behaves under different nutrient contents of the feedstuffs. Alternatively, a method of linear programming approximation of least-cost feed mixes with probability restrictions suggested by Rahman and Bender (1971) may be used.

Summary

The results of this study are discussed in this chapter. Five least-cost rations have been determined for the five size-classes of poultry using December 1973 Accra prices. In each case, the composition and cost of the ration, the levels of the nutrients in the ration and the values of the excluded local feedstuffs from the rations have been discussed. It has been found that in satisfying the various nutrient requirements of the birds, different costs of the rations are obtained. The least expensive ration is the laying hens ration, costing about 31 pesewas per kilogram, while the most expensive ration is the chicks ration, costing about 47 pesewas per kilogram. The shadow prices of some of the excluded feedstuffs exceed their assumed market prices, suggesting that to use such feedstuffs the poultry farmer must be paid.

In all, twenty-one feedstuffs out of the possible thirty feedstuffs considered for formulating the five rations are selected for one or more of the five least-cost rations. Thirteen of the selected feedstuffs are available locally. Fish meal, unpeeled cassava and oyster shell are the only three local feedstuffs used in all the five rations.

Finally, sensitivity analysis involving price changes has been carried out for laying hens ration to demonstrate the effect of price changes upon least-cost rations. It has been established that, all things being equal, changes in the relative prices of the feedstuffs result in different feed mixes for laying hens.

CHAPTER FIVE

CONCLUSIONS AND FURTHER RESEARCH NEEDED

The restricted meat supply in Ghana has resulted from the decline in the supply of meat from our neighbouring countries due to the high prices of meat constraining the amount that the country can import. Domestic cattle production does not show promise using existing production techniques as a means of providing the necessary amount of protein for Ghanaians. A major breakthrough in production will be required to achieve a self-sufficient rate of extraction from local cattle sources in the near future. For this reason, it is argued that attention must be diverted towards solving the problems hindering the growth of the poultry industry whose growth in the recent past seems to emphasise its potential for providing protein. Poor quality and irregular supplies of feed are identified as one of the problems facing the industry. The poultry feed problem forms the theme of this study.

The poultryman is assumed to maximize profits. A necessary condition for maximizing profits is that feed costs be minimized. From this premise, the necessary and sufficient conditions for a minimum-cost feed mix are derived. The poultry farmer optimizes by equating the rate of technical substitution to the inverse feedstuff price ratio to determine the equilibrium values of the feedstuffs.

A unit isoquant derived from the production function of the poultry farmer is approximated by a constraint set comprising nutrient requirements of the birds. The linear programming model is developed from the least-cost combination approach by linearizing the unit isoquant. Graphical solution of the linear programming problem is presented for two and three feedstuffs. The treatment is generalized for N feedstuffs by developing the mathematical formulation of the model. Sensitivity analysis involving price changes has been considered graphically for two and three feedstuffs and mathematically for N feedstuffs. The model is employed to solve the least-cost ration problem of the poultry farmer.

Five different kinds of rations have been formulated. The rations are for chicks, broilers, growing chickens, laying hens and breeding hens. The cheapest ration is the laying hens ration which costs about 31 pesewas per kilogram or ¢305.34 per metric ton and the most expensive ration is the chicks ration costing ¢466.54 per metric ton. The costs of the broilers ration, growing chickens and breeding hens rations are ¢427.38, ¢392.28 and ¢388.05 per metric ton, respectively. The high cost of the chicks ration may be attributable to the larger number of nutrients required by chicks so that in seeking to satisfy all of them, costs are increased.

The crude protein content of the rations shows that growing chickens ration contains the highest amount (43 per cent) and the smallest amount is in laying hens ration (17 per cent). The crude protein levels in chicks ration, broilers ration and breeding hens ration are 29 per cent, 27 per cent, and 22 per cent, respectively. The high protein content of growing chickens ration may be attributed to the high demand for amino acids by growing chickens. The fat and fiber levels in all the rations are within the tolerance levels of 5 per cent fat and 3.5 per cent fiber. The chicks and broilers rations are the most fibrous rations, having a fiber level of 3.5 per cent and the laying hens ration is the least fibrous with 2.02 per cent fiber.

In formulating all the five rations, 21 feedstuffs of which thirteen are locally available are selected, considering the current price estimates. The most important among the local feedstuffs are unpeeled cassava, fish meal and oyster shell, which are chosen for compounding all the five rations. Unpeeled cassava forms the largest percentage of the broilers and laying hens rations at 35 per cent and 57 per cent of the rations, respectively. Compared with other rations, the amount of unpeeled cassava in breeding hens ration is the smallest. Fish meal is present most largely in laying hens ration at the level of 17 per cent of the ration.

Currently, in Ghana, unpeeled cassava is not used in poultry rations while white maize is most extensively used. The results show that white maize should be excluded from any of the five rations in order for the farmer to minimize feed costs and consequently maximize profits. This implies that unpeeled cassava can replace white maize in poultry rations, so that white maize can be restricted to human consumption. Experiments have proved that unpeeled cassava can replace white maize in poultry rations (Larsen and Obuobi, 1974). However, fish meal and oyster shell are currently being used in poultry rations.

Three feedstuffs; blood meal, cocoa meal and skimmilk are selected for four rations. Only skimmilk cannot be produced locally in the country at the moment. Moreover, these feedstuffs are not currently being used in poultry rations. Another three local feedstuffs are used in three different rations. They are groundnut cake, yellow maize, and wheat bran, which are currently being used in poultry rations.

The soybean meal levels in chicks and broilers rations imply that, to remove soybean meal from the programme, a very high cost would have to be charged. In so doing, the costs of the rations would consequently rise. Even shadow pricing foreign exchange might lead to a smaller amount of soybean meal being used but not complete elimination of it. Similarly, it is difficult to force blood meal out of growing chickens ration because of its high amino acid contents, which are greatly demanded by growing chickens. Alfalfa meal in broilers and laying hens least-cost rations can be eliminated by raising its price. For instance, the sensitivity analysis for laying hens ration in which prices of certain feedstuffs, including alfalfa meal, have been raised, forced alfalfa meal out of the least-cost laying hens ration (Table 22). The resulting least-cost ration consists of only two imported feedstuffs, skimmilk and soybean meal, and nine local feedstuffs. The sensitivity analysis produced results which demonstrate that variations in relative prices of the feedstuffs can give rise to different feed mixes and feed costs.

The potential for using primarily local feedstuffs exists and pricing of the feedstuffs may help to increase the potential greatly. In particular, unpeeled cassava, which is not currently being used in poultry rations, is selected for compounding all the five rations. Because the prices of some of the local feedstuffs are unavailable and prices have been assumed for them, they are selected on the basis of the assumed prices. This situation might have excluded some of the local feedstuffs such as brewers' grains and pineapple pulp from the programme. However, the question that must be answered is whether the local feedstuffs are available in quantities that can provide regular supply. The answer to this question is critical to the implications of this study.

In formulating the rations, using the linear programming model, some of the feedstuffs considered are not currently being used but are selected for compounding the rations. Because of this problem and the likelihood that the levels of the feedstuffs selected may be different from what are used, there is the need to test the least-cost rations against what is currently being used to ascertain the performance of the birds on the least-cost feed mixes. For instance, cocoa meal has been selected for four different rations, demonstrating its potential in poultry rations. It may be that the specified levels of cocoa meal have deleterious effect on the birds. In that case, the maximum amount of cocoa that the birds can tolerate may be found and incorporated in the model.

There is also the need to determine the nutrient requirements of the birds under Ghanaian conditions so that these will serve as the appropriate constraints of the problem. Moreover, information on some of the feedstuffs with regard to their nutrient contents is unavailable. Such information is important in least-cost ration formulation. Hence, analysis of the nutrient contents of the local feedstuffs such as unpeeled cassava, kokonte, cocoa shells and cocoa meal, needs to be made so that as more data becomes increasingly available better rations can be formulated.

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APPENDIX

Table 1: Nutrient Composition of Feedstuffs

Feedstuff / Nutrient		Alfalfa meal, dehydrated	Bone meal, cooked	Bone meal, steamed	Blood meal	Brewers' grains, dried	Brewers' yeast, dried
Crude Protein	%	17.7	25.7	7.5	85.5	26.2	44.9
Digestible Protein	%	12.4	17.39	n.a.	58.4	21.3	38.6
Fat	%	2.5	5.1	1.2	1.5	6.32	0.7
Fiber	%	17.5	1.0	1.5	0.9	15.5	2.7
Calcium	%	1.6	30.75	30.14	0.32	0.28	0.13
Phosphorus	%	0.26	10.17	14.53	0.25	0.53	1.68
Ca / P Ratio		6.15	3.02	2.07	1.28	0.53	0.08
Gross Energy	kcal	n.a.	2700.0	n.a.	n.a.	5100.0	n.a.
Digestible Energy	kcal	n.a.	836.0	n.a.	n.a.	1892.0	n.a.
Manganese	mg		30.36	30.36	5.28	37.62	5.72
Arginine	%	n.a.			3.5	1.3	2.2
Lysine	%	n.a.			6.9	0.9	3.0
Methionine	%	n.a.			0.9	0.4	0.7
Cystine	%	n.a.			1.4		0.5
Tryptophan	%	n.a.			1.1	0.4	0.5
Vitamin A	U.S.P. Units	230,632.6					
Vitamin B_{12}	mg						
Thiamine	mg	5.5	0.44	0.44		6.6	91.74
Riboflavin	mg	15.18	0.88	0.88	1.54	1.54	34.98
Pantothenic Acid	mg	33.66	2.42	2.42	1.10	8.58	109.78
Niacin	mg	39.6	4.18	4.18	31.46	43.34	447.48
Pyridoxine	mg					0.66	44.34
Biotin	mg					0.96	0.968
Choline	mg					1584.0	3885.2
Folic Acid	mg					9.68	9.68

n.a. = not available.

Table 1 continued Nutrient Composition of Feedstuffs

Feedstuff / Nutrient		Cassava unpeeled	Cocoa meal	Cocoa shells, coarse	Cocoa shells, fine	Copra nut cake	Cotton seed meal
Crude Protein	%	1.35	24.3	21.1	17.6	21.5	20.3
Digestible Protein	%		9.0	n.a.	n.a.	18.1	n.a.
Fat	%	0.3	17.1	33.0	39.8	6.3	9.2
Fiber	%	1.44	5.1	7.5	4.9	12.7	14.4
Calcium	%			0.3	0.5	0.171	0.4
Phosphorus	%	0.04		0.5	0.5	0.61	0.6
Ca / P Ratio		0.00		0.60	1.00	0.28	0.67
Gross Energy	kcal	4100.0	n.a.	6000.0	6000.0	n.a.	5100.0
Digestible Energy	kcal	n.a.	n.a.	n.a.	n.a.	3212.0	n.a.
Manganese	mg						20.46
Arginine	%		n.a.	n.a.		2.2	3.3
Lysine	%		n.a.	n.a.	n.a.	0.5	1.6
Methionine	%		n.a.	n.a.	n.a.	0.3	0.5
Cystine	%		n.a.	n.a.	n.a.		1.0
Tryptophan	%		n.a.	n.a.	n.a.	0.2	0.5
Vitamin A	U.S.P. units						167.0
Vitamin B_{12}	mg					0.88	6.38
Thiamine	mg					13.2	5.94
Riboflavin	mg					5.72	12.10
Pantothenic Acid	mg						35.86
Niacin	mg						
Pyridoxine	mg						
Biotin	mg						
Choline	mg						
Folic Acid	mg						

Table 1 continued Nutrient Composition of Feedstuffs

Feedstuff / Nutrient		Fish meal	Ground-nut cake	Guinea corn	Kokon-te	Maize white	Maize yellow
Crude Protein	%	60.45	42.8	15.03	5.4	9.1	9.33
Digestible Protein	%	53.6	42.78	9.17	n.a.	n.a.	6.7
Fat	%	7.5	10.28	3.25		4.0	3.94
Fiber	%	0.95	5.77	2.94	4.1	2.5	2.0
Calcium	%	6.08	0.3				0.025
Phosphorus	%	2.91	0.6				0.27
Ca / P Ratio		2.09	0.50				0.09
Gross Energy	kcal	400.0	6050.0	3941.9	3800.0	4400.0	4098.2
Digestible Energy	kcal	n.a.	n.a.	2921.0	n.a.	n.a.	3520.0
Manganese	mg	9.9				n.a.	2.4
Arginine	%	3.9	5.9			n.a.	0.4
Lysine	%	6.4	2.3				0.2
Methionine	%	1.8	0.4			n.a.	0.1
Cystine	%	0.8	0.7			n.a.	0.1
Tryptophan	%	0.7	0.5			n.a.	0.08
Vitamin A	U.S.P. units		367.4				2167.0
Vitamin B_{12}	mg	0.1914					
Thiamine	mg	1.32	6.82	5.28		4.84	3.74
Riboflavin	mg	6.82	4.62	1.32		1.32	1.32
Pantothenic Acid	mg	9.02	51.7	9.02		3.74	5.28
Niacin	mg	63.36	173.36	64.68		15.62	21.56
Pyridoxine	mg	14.74					7.26
Biotin	mg					0.066	
Choline	mg	3658.6	205.7				
Folic Acid	mg						

Table 1 continued Nutrient Composition of Feedstuffs

Feedstuff / Nutrient		Manganous sulphate	Meat & Bone Meal	Millet	Oyster shell	Palm kernel cake	Pineapple pulp
Crude Protein	%		50.1	9.0	1.2	20.2	5.65
Digestible Protein	%		41.1	8.7		15.9	0.8
Fat	%		9.3	4.9	0.8	6.6	3.0
Fiber	%		2.2	8.0		11.4	13.5
Calcium	%		10.74	0.05	37.7		0.4
Phosphorus	%		5.346	0.3	0.07	0.64	0.08
Ca / P Ratio			2.01	0.17	538.57	0.00	5.00
Gross Energy	kcal		n.a.	4118.9		4800.0	4700.0
Digestible Energy	kcal		3476.0	3256.0		n.a.	n.a.
Manganese	mg	45500.0	12.32			101.6	
Arginine	%		4.0			n.a.	
Lysine	%		7.0			n.a.	
Methionine	%		1.4			n.a.	
Cystine	%		0.6			n.a.	
Tryptophan	%		0.2			n.a.	
Vitamin A	U.S.P. units						
Vitamin B_{12}	mg						
Thiamine	mg		1.1	7.26			
Riboflavin	mg		4.4	3.74			
Pantothenic Acid	mg		3.74				
Niacin	mg		47.74	23.32		44.0	
Pyridoxine	mg						
Biotin	mg						
Choline	mg		1999.8				
Folic Acid	mg						

Table 1 continued Nutrient Composition of Feedstuffs

Feedstuff / Nutrient		Rice Polished	Rice Bran	Skim-milk, dried	Soybean meal	Vetrivit	Wheat Bran
Crude Protein	%	7.4	7.4	33.1	44.9	22.0	16.0
Digestible Protein	%	5.7	5.18	29.8	42.0	n.a.	13.1
Fat	%	0.4	2.0	1.1	1.1		4.3
Fiber	%	0.4	27.0	0.6	5.8		11.2
Calcium	%	0.01	0.2	1.28	0.29		0.16
Phosphorus	%	0.09	0.3	1.04	0.65		1.22
Ca / P Ratio		0.11	0.67	1.23	0.45		0.13
Gross Energy	kcal	3941.0	3600.0	n.a.	4197.6		4600.0
Digestible Energy	kcal	n.a.	3256.0	n.a.	3300.0		2508.0
Manganese	mg		417.78	1.0	32.34		115.72
Arginine	%	0.6	0.5	1.2	2.6		1.0
Lysine	%	0.3	0.5	2.8	2.8		0.6
Methionine	%	0.3		0.8	0.6		0.1
Cystine	%	0.1	0.1	0.5	0.6		
Tryptophan	%	0.1	0.1	0.4	0.6		0.3
Vitamin A	U.S.P. units					1320,000.0	2000.0
Vitamin B_{12}	mg			0.055		1,980.0	
Thiamine	mg	0.66	22.44	3.52	7.04	429.0	7.92
Riboflavin	mg	0.66	2.64	20.02	3.3	539.0	3.08
Pantothenic Acid	mg	3.96	23.54	33.66	14.52	770.0	29.04
Niacin	mg	17.82	303.16	11.44	26.84	2,310.0	209.22
Pyridoxine	mg		29.04	3.96			24.2
Biotin	mg		0.418	0.33	0.33		
Choline	mg			1423.44	2607.0	2,310.0	1080.2
Folic Acid	mg			0.616	6.226	99.0	1.65