Least Cost Ration Formulation for Pig Production

By

O. OGUNFOWORA

Department of Agric. Economics,

and

B. L. FETUGA

*Department of Animal Science,
University of Ibadan, Ibadan.*

SUMMARY

STANDARD linear programming techniques have been used to formulate least cost rations for weaner and growing fattening pigs using analytical data available for a wide range of local feed materials, also considering cost per unit of ingredients, nutrient requirements for these two classes of pigs and weight of final mix. The effects of increasing protein levels exclusion of soyabean and cassava from the basic solution, inclusion of two levels of fish meal as well as the changing cost of ingredients on the composition and cost of weaners rations were also examined. Based on the technique described weaners' and growing fattening rations were obtained at the least cost of ₦127.5 and ₦94.8 per tonne respectively. Increasing protein level from 20.26 to 22.26% resulted in a price increase of ₦8.90 per tonne which represents a 6.98% price increase for a 9.87% change in dietary protein level. Exclusion of cassava and soyabean meal from a 20% protein diet resulted in a negligible price increase, while similar exclusion from a 22% protein diet incurred an additional cost of ₦7.2 per tonne. This increased cost was related to an increased inclusion of the more expensive maize and skim milk powder. Inclusion of 3 and 5% fish meal in the original solution resulted in a 6.75 and 15.5% increase in ration cost, increases which could only be justified under practical conditions by improved animal performance. It is concluded that the linear programming techniques may offer a wider scope for considering different alternatives in ration formulation than conventional and currently used methods and may prove more useful in improving profit margins in livestock production enterprises.

INTRODUCTION

THE protein shortage problem in the diet of the average Nigerian and other inhabitants of other developing countries have

been well documented (Oyenuga, 1968; FAO, 1969, 1974). In recent times, considerable interest has been shown in improving the situation, but success has been limited by the highly unorganised structure of animal production, especially cattle, which has made the dissemination of research findings on improved management and nutritional practices among the traditional cattle owner rather difficult. While cattle, sheep and goat are likely to continue to be important in the Northern States where extensive areas are available, pigs and poultry have great potential contribution to make in the short run, particularly in the south, where the population pressure on land and dense vegetation make the establishment of extensive pasture almost impracticable. Moreover, ruminant stock is so costly in terms of land utilization, taking up about 0.45-1.12 hectares to produce 20 kg. of protein annually in terms of beef and about 0.22 to 0.45 hectare for milk, whereas pigs and poultry would convert grain, seeds and waste products unfit for human consumption into meat. Thus unless feed-lot finishing of beef cattle can be incorporated into an efficient breeding and improved pasture management programmes, the southern states will have

to rely mostly on poultry and piggery industries for a fairly large proportion of their animal protein requirement.

Studies of the pigs and poultry industry seem to reveal that the initial enthusiasm in these enterprises is fading. The growth rate of the enterprises, especially piggery, is being impeded due largely to dwindling profit margins. (Kupoluyi, 1975; Makinde 1974; Ogunfowora, 1967). Dwindling profit is in turn a function of poor quality feeds, which manifests itself in poor performance of the animals, and high costs of production. Poor performance results from, among other factors, poor management practices and unbalanced rations, the latter arising from insufficient knowledge about the nutritional requirements of the animals, the nutrient composition of the feed ingredients, and most important, the haphazard substitution between feed ingredients necessitated by seasonal variations in the availability and costs of some of the basal ingredients like maize, guinea corn and groundnut cake and fishmeal.

The most important factor determining profit levels in intensive livestock enterprises is the cost of feeds (Ridgeon, 1960). In Nigeria, feed cost represents over 70%

of the total costs of producing livestock intensively, accounting for between 75 to 80% in swine production (Dettmers *et al.*, 1972) and over 70% in egg and broiler production (Kupoluyi, 1975; Makinde, 1974). Judging from the past prices of livestock feeds (Table 1) it is apparent that the costs of feeds have followed an upward trend.

This was largely due to steep rises in prices of maize, guinea corn, groundnut cake and fish meal whose prices have risen by 114; 115, 100 and 355%, respectively between July 1969 and March 1974 (Oyenuga 1974).

If reasonable margin of profit is to be maintained in the face of rising feed costs, either the prices of products will have to be significantly increased or the increase in the efficiency of production (in terms of yield and/or efficiency of feed utilization) must be more than proportionate to the increase in the costs of production. But a substantial rise in product prices will dampen demand, lead to a cut back in production and create excess capacity in the industry. It would appear that the most reasonable course of action is a combination of measures designed to reduce the cost of feeds and improve the quality of diets such that

Price Per Tonne of Livestock Feeds, 1972-1975

Kinds of Feed	Years			
	1972	1973	1974	1975
Chicks Mash	109	152	156	200
Growers Mash	100	130	13	160
Layers Mash	104	148	152	167
Breeders Mash	118	152	166	180
Broilers Starter	132	152	166	198
Broiler Finisher	130	148	162	196
Piggery Creep	148	137	198	198
Weaner Mash	109	119	178	178
Fatteners Mash	108	115	166	166

a high level of animal performance and feed efficiency could be obtained.

This study represents the first phase of a major study designed to examine the possibilities of increased efficiency and profitability in intensive livestock production through improved feed formulation and feeding programmes. More specifically, this phase uses Linear Programming (L.P.) tool to formulate different least cost rations which meet specific nutritional specifications for growing and fattening pigs from readily available feed ingredients in Nigeria.

II. THE CONSTRUCTION OF THE MODEL FOR LEAST-COST RATION

The various stages in the construction of least cost linear programming model are as follows:

- (i) Listing the available ingredients which represent the activities to be considered.
- (ii) Listing the prices per unit of the ingredients
- (iii) Specifying the levels, in percentage terms, of the nutrients which are crucial for growth.
- (iv) Specifying the nutrient composition of individual ingredients and
- (v) Specifying the limit of inclusion of certain feed-stuffs in the diets.

Ingredients or Activities in the Model

Table 2 represents the basic matrix used in this study. The table shows the various feed ingredients that could be used in a typical weaner's/fattener's ration, their nutrient composition and prices per ton. Any one of a set of combination of ingredients can adequately meet the nutritional specifications for pigs. However, the set of ingredients finally selected

should not only meet the nutritional specification but must do so at minimum cost.

Twenty three ingredients were considered in this study. They included grains, mostly maize and guinea corn which usually form a significant proportion of the energy-yielding nutrients in livestock feeds and contribute reasonable quantities of amino acids particularly the sulphur amino acids methionine plus cystine. These are readily available from local sources, although their supply is subject to seasonal variations. The quality also varies depending on the variety and efficiency of storage.

The next group of ingredients, blood meal, fish meal, dried milk powder, meat and bone scrap, supply the bulk of animal protein in the diet. They are also readily available from local sources and are subject to wide variation in quality depending on the processing techniques used. Groundnut cake, palm kernel meal, soyabean meal, cotton seed etc. provide the bulk of the plant protein and residual oil.

Calcium and phosphorus are to be supplied largely by oyster shell, bone meal, meat and bone scrap and di-calcium phosphate. Rice bran, wheat bran and palm kernel meal supply the bulk of the fibre. The vitamins and other minerals are to be supplied through the inclusion of vitamin-mineral premix which are usually imported.

Most of the Nigerian feedstuffs have been extensively evaluated for their nutrient composition (Oyenuga 1968, Fetuga 1972). Differences in composition and quality often arise due to local processing techniques, storage practices and agronomic treatment prior to processing.

Maximum Bone Meal	0.03				
Maximum Rice Bran	0.10				
Maximum Oyst. Shell	0.03				
Maximum Fish Meal I.	0.05				
Maximum D1. Ca. Ph.	0.05				
Equality Salt	0.0025				
Maximum Meat & Bone					
Scrap	0.010				
Maximum P.K.M.	0.10				
Maximum Cotton seed	0.40				
Maximum Dried Milk P.	0.30				
Maximum Dried Yeast	0.10				
Maximum Wheat Bran	0.10				
Equality A.D. Vit.	0.0046				
Maximum Fish M. Loc.	0.05				
Maximum Soybeans	0.30				
Maximum Cassava	0.05				
<i>Ingredient Restrictions</i>					
Maximum Maize	0.80				
Maximum G. Corn	0.80				
Minimum Groundnut Cake	0.05				
Maximum Blood Meal	0.10				
Maximum Brew. Grain	0.10				
		1.0	1.0	1.0	1.0

Restrictions in the Basic Model

Three distinct groups of restrictions (Columns B₁, B₂) are specified in this model. These are (i) the nutrient requirements specifications, (ii) the ingredient level specifications and (iii) the quantity of the total mix of ingredients generally referred to as the weight constraint.

(i) Nutritional Restrictions

The performance of intensive livestock enterprises is largely determined by nutrient content and balance, as well as the intake of the rations.

The intake of nutrients such as the essential amino acids, lysine, methionine, cystine, tryptophan etc., affect the growth rate as well as carcass conformation (Blair *et al.* 1969; Jurgens *et al.* 1967; Fetuga *et al.* 1975a & b; Babatunde *et al.* 1971). Also, the energy supplied to pigs greatly influences the rate of liveweight gain. When pigs are fed imbalanced rations, growth rate and efficiency of liveweight gain are reduced, resulting in low levels of profit. It is important therefore, when formulating rations to do so in such a way that all the important nutritional factors are provided.

Protein: The protein needs of pigs should be judged in terms of supplying adequate amounts and a proper balance of the essential amino acids from the main protein constituents, fish meal, blood meal and groundnut cake, etc. The exact quantitative requirements for the major nutrients under tropical conditions have not been worked out, but reasonably reliable quantitative data have been obtained from experiments under tropical conditions. Due to a lack of definiteness surrounding available published dietary requirements and feed composition data, minimum and maximum range of values have been used in the model.

For growing pigs, 22 to 24% crude protein in the diet has been found to be adequate (Babatunde *et al.* 1971). The specifications for lysine, methionine, cystine and tryptophan were 0.95 to 1.20; 0.36 to 0.40; 0.26 to 0.27 and 0.16 to 0.18% respectively based on reports by Fetuga *et al.* (1975a & b). A general evaluation of some commonly used protein concentrates (Fetuga, 1972) showed lysine and methionine to be the amino acids most likely to limit diets based on them. The model therefore made allowance for the provision of these amino acids from synthetic sources if necessary.

Energy: Dietary energy levels control voluntary feed intake in pigs as well as the proportion of lean to fat in finished carcasses (Bowland, 1968 and Robinson and Lewis, 1964). A minimum energy level of 3.25 kcals/g and 3.00 kcals/g were specified for weaners and growing fattening pigs respectively.

Minerals: Calcium and phosphorus are important minerals in diet formulations for pigs. The other minerals are usually provided in the Vitamin-mineral premixes commercially available for different classes of pigs, additional calcium and phosphorus need to be provided in adequate amounts and in a fixed proportion i.e. a ratio of 1.5 to 1, since inadequate supplies result in poor utilisation of diets as well as certain well described conditions. For the weaners, minimum and maximum specifications for calcium and phosphorus were 0.65 to 0.80 and 0.50 to 0.60 per cent respectively.

Small quantities of fibre are necessary to stimulate intestinal motility. A maximum level of 2.5 and 7.5% were specified for the weaner's and fatter's diets respectively.

Fats: The need for fats and essential fatty acids in pigs diets is still controversial. It is however conventional to include a source of fat in diets for young pigs. Levels between 2 to 3.5% were specified for both weaners' and growing fattening diets. Fats, apart from supplying the essential fatty acids also serve as sources of additional energy in diets.

Ingredients Constraints

Certain restrictions on the levels of inclusion of available ingredients were imposed to conform with proper nutritional requirements and take account of their availability and costs. The model was structured in such a way as to ensure a balance between protein supply from both animal and vegetable sources to keep in balance the amino acid contributions from these sources. Accordingly, groundnut cake was restricted to a minimum of 5% of the ration, while blood and fish meals were restricted to a minimum of 5% and a maximum of 10% respectively. The maximum level of 10% specified for blood meal was because of its unbalanced amino acid pattern, while that for fish meal was based on cost considerations. Similarly, palm kernel meal was restricted to a maximum level of 10% in the weaners ration and a maximum level of 20% in the fatteners ration, because of its high fibre content.

The forms in which some nutrients exist in the ration influence the efficiency of utilization. For example, in grains, a third to two thirds of the phosphorus is in the phytate form; the proportion is even higher in cotton seed and soyabean meals. Accordingly, allowance was made in the models for the non-availability of phosphorus from grains and vegetable source by ensuring that the ration contains reasonable percentages of oyster shell or

meat and bone scrap or bone meal to provide readily available calcium and phosphorus. In order to provide sufficient minerals and vitamins as well as improve the palatability of the diet, the model also specified that salt and Vitamin-mineral premix should be 0.25% and 0.46% of the mix respectively. Columns B₁ and B₂ of table 2 shows the restrictions specified in the basic model for the inclusion of various ingredients in the weaner's and grower's/fattener's rations, respectively.

(iii) The Weight Constraint

The weight constraint fixes the quantity of the mix within which the nutrient requirements and the ingredient specifications must be met. The model was constrained to produce exactly 1,000 kilogrammes of the mix.

Structure of the Model

Based on the foregoing discussion, the cost-minimization model for pigs can be formalized as follows:

$$(\text{Min}) \quad Z = \sum_{j=1}^n C_j X_j$$

The minimization of Z is subject to the conditions that:

$$\begin{aligned} \text{(i) Protein} & \leq \sum_{j=1}^n a_j x_j \\ \text{(ii) Energy} & \leq \sum_{j=1}^n b_j x_j \\ \text{(iii) Fibre} & \leq \sum_{j=1}^n r_j x_j \\ \text{(iv) Weight} & \leq \sum_{j=1}^n d_j x_j \\ \text{(v) Fat} & \leq \sum_{j=1}^n e_j x_j \\ \text{(vi) Methionine} & \leq \sum_{j=1}^n f_j x_j \\ \text{(vii) Cystine} & \leq \sum_{j=1}^n g_j x_j \end{aligned}$$

	$\sum_{j=1}^n$	$h_j x_j$
(viii) Lysine	$\leq$	
	$\sum_{j=1}^n$	$i_j x_j$
(ix) Tryptophan	$\leq$	
	$\sum_{j=1}^n$	$k_j x_j$
(x) Calcium	$\leq$	
	$\sum_{j=1}^n$	$l_j x_j$
(xi) Phosphorus	$\leq$	
(xii) X	≥ 0	

where Z is the cost of the ration to be minimized, X_j is the quantity of the j^{th} feed ingredient in the ration, C_j is the price per unit weight of the j^{th} ingredient, $a_j, b_j, \dots, r_j$, represent the percentage provision of crude protein, energy and fibre etc. of the j^{th} feed ingredient, while d_j is the proportional contribution by weight of the j^{th} ingredient to the ration. Condition xii implies that ingredients should be included at non-negative levels.

III. SOLUTIONS AND DISCUSSION OF THE MODELS

Using the nutritional ingredients and weight constraints specified in table 2, table 3 shows the cost and composition of weaners and growers rations. Within the framework of the nutritional requirements, the nutrient composition of the ingredient specified, the rations were compounded at the least cost of ₦127.5 and ₦94.8, per tonne respectively. Maize and cassava provided the bulk of the energy requirement in the weaners ration while groundnut cake, soyabean meal and blood meal are the major protein sources. The inclusion of methionine at .08% was to make up the requirement of 0.36% specified for the weaners. The specified nutrient requirements were met in both solutions and the actual level of the important nutrients are given in table

3. These nutrient levels were achieved with a mixture which totally excluded fish meal, a source known to be currently very expensive and is not locally produced.

As expected, the grower's ration was significantly cheaper, costing ₦94.8, and showed marked difference in composition from the weaners ration. The bulk of the energy was provided by a combination of cassava, guinea corn and maize while blood meal was the major source of protein. The ration contains high proportion of fibrous ingredients like wheat bran, rice bran and brewers' grains. Synthetic methionine and A—D Vitamins and oyster shell were also included to meet the specified requirements of amino acids, minerals and Vitamins for growers. The ration also provided 16.20% protein and 2653 kcal of energy/kg of diet.

The Effect of Increasing Protein Level on the Composition and Cost of Weaners' Ration

In order to determine the cost of increasing the protein content of weaner's ration, the basic model was solved for 20.26 and 22.26% protein while maintaining the initial specifications for the nutrients and ingredients in the model. The results are presented in table 4.

The additional cost of increasing protein level was ₦8.90 per tonne of ration, representing a 6.98% rise in cost for a 9.87% rise in the level of protein. The fat content of the higher protein ration increased by 6.06%, but remained within the maximum limit of 3.5%, while the energy level was reduced by 9.7% though still above the minimum level specified for weaner pigs in the model. All the other nutrient requirements are adequately provided by both rations.

TABLE 3

The Percentage Composition of the Least-cost Diets for Weaners and Growers, May 1975 Prices, C1

	Ingredients and Nutrients	Weaners Ration	Growers Ration
INGREDIENTS	Guinea corn	—	17.36
	Maize	51.10	22.72
	Cassava	15.00	20.00
	Groundnut cake	8.28	—
	Blood meal	5.67	4.52
	Dried milk powder	—	—
	Soyabean meal	3.00	—
	Cotton seed	0.70	3.47
	Rice bran	—	6.48
	Wheat bran	6.32	6.76
	Dried yeast	7.64	—
	Brewers grains	—	17.08
	Bone meal	0.55	—
	Oyster shell	0.97	0.73
	Meat and Bone Scrap	—	—
	Salt	0.25	0.30
	D.L. Methionine	0.08	0.10
	A — D. Vitamins premix	0.46	0.50
NUTRIENTS	Cost Per Tonne of Mix	₦127.5	₦94.8
	Protein, %	20.26	16.20
	Fibre, %	2.35	7.50
	Fat, %	3.30	3.49
	Energy, kcal/kg. diet	3790.00	2653.00
	Methionine, %	0.36	0.27
	Lysine, %	1.20	0.79
	Cystine, %	0.26	0.19
	Tryptophan, %	0.20	0.13
	Calcium, %	0.80	0.55
	Phosphorus, %	0.60	0.45
	Ca: P ratio	1.33 to 1	1.22: 1

TABLE 4

The Effect of Increasing Protein Level on the Composition and Cost of Weaner's Ration May 1975 Prices, C1*

Ingredients	Level of Protein		
	20.26 %	22.26 %	% Change
Maize	51.10	49.68	-2.78
Cassava	15.00	14.83	-1.13
Groundnut cake	8.28	8.56	+3.38
Blood meal	5.67	6.00	5.82+
Dried Milk Powder	—	2.40	—
Soyabean meal	3.00	3.00	—
Cotton seed	0.70	3.90	+82.1
Wheat bran	6.32	2.91	-54.0
Dried yeast	7.64	5.23	-31.3
Bone meal	0.55	—	-0.55
Oyster shell	0.97	0.68	-30.0
Meat and Bone Scrap	—	2.01	—
D.L. — Methionine	0.08	0.09	+11.1
Salt	0.25	0.25	—
A — D Vitamins premix	0.46	0.46	—
Cost Per Tonne of Mix	₦127.5	₦136.4	6.98
Protein	20.26	22.26	9.87
Fat	3.30	3.50	6.06
Energy	3790.00	3753	-0.97

* All the other nutrients, except those reported in this table, remain at the same levels as for weaners in table 3.

All things being equal, the increase in protein level should be accompanied by improved animal performance in terms of higher rate of gain and improved feed efficiency. This will not only affect throughput but also the improved efficiency in feed utilization will reduce the cost of pig production.

The Effect of Excluding Cassava and Soyabean meal on the Composition and Cost of Weaner Rations

The solution shown in table 3 for weaners included cassava and soyabean. Small scale feed production may be able to take advantage of the available quantities of these ingredients. Large scale feed mixing based on the above solution may be limited by the quantities of soyabean and cassava currently available. To determine the effect of excluding cassava and soyabean meals on the composition of the weaner ration, the model was redesigned to exclude these ingredients and provide a minimum of 20 and 22% levels of protein. The new ingredient composition, nutrient levels as well as costs obtained are presented in table 5. The differences in cost for the 20 and 22% protein diets were ₦0.2 and ₦7.2 respectively. Maize provided the bulk of the energy, while the quantity of cotton seed was increased in both diets. In the 22% protein diet, the quantity of dried milk powder was significantly increased. The nutrient levels were however maintained within the specified limits. The solution obtained and the price changes illustrate some of the effect of ingredient substitution under conditions of scarcity of some commonly used ingredients.

Effects of Different Levels of Fish meal' on the Cost and Composition of Weaners nation.

Fish meal has remained the standard

against which most other feed-stuffs intended for inclusion in practical type diets have been compared because of its high content of lysine, methionine and cystine as well as its contribution of some unidentified growth factors. It has the added advantages of good flavour and taste which enhance palatability and acceptability of diets. In recent years, the drop in fish production in Peru and Chile (Talabi, 1974) has resulted in a reduction in supply to many of the importing countries and its cost has significantly increased relative to other protein concentrates. Because of this high cost, small inclusions of fish meal are likely to alter significantly the cost per unit of finished diets. In order to determine the additional cost of including fish meal in weaners' rations, limits of 3 and 5% were forced into the linear programming solution. The effects on costs and composition were examined for rations designed to provide a level of 20.26% protein. The inclusion of 3 and 5% fish meal resulted in 6.75 and 15.5% increase in cost of ration (Table 6). Table 5 also indicates that the same level of essential nutrients were provided by all the rations. Any differences in animal performances that may be obtained from these rations can mostly be attributable to better digestion and availability of amino acids in the rations containing fish meal rather than to any differences in the overall nutrient levels. The increased performance that may be obtained from the inclusion of fish meal would have to be such as to justify the increase in cost of rations. One draw back of the present model is the fact that it cannot be immediately obvious from this result whether the improvement in animal performance would justify the additional cost of the ration due to fish meal inclusion. This would need to be investigated under controlled experimental and commercial

TABLE 5

The Effect of Excluding Cassava and Soyabean on the Composition and Costs of Weaner's Ration, May 1975 Prices

Ingredients	Percentage		Composition	
	Minimum Protein 20%		Minimum Protein 22%	
	With Cassava & Soyabean	Without Cassava & Soyabean	With Cassava & Soyabean	Without Cassava & Soyabean
Maize	51.10	67.03	49.68	65.22
Cassava	15.00	—	14.83	—
Groundnut cake	8.28	4.73	8.56	—
Blood meal	5.67	6.08	6.00	6.00
Dried Milk Powder	—	0.14	2.40	4.25
Soyabean meal	3.00	—	3.00	—
Cotton seed	0.70	2.60	3.90	8.86
Wheat bran	6.32	7.83	2.91	2.13
Dried yeast	7.64	9.05	5.23	8.76
Bone meal	0.55	0.26	—	0.85
Oyster shell	0.97	1.48	0.68	1.14
Meat and Bone Scrap	—	—	2.01	0.64
D.L. — Methionine	0.08	0.08	0.09	0.10
Salt	0.25	0.25	0.25	0.25
A—D Vitamins premix	0.46	0.46	0.46	0.46
Fish meal	—	—	—	1.33
Cost of 1 Tonne of Mix	₦127.5	127.7	136.4	143.6
Protein, %	20.26	20.27	22.26	22.27
Fibre, %	2.35	2.49	2.35	2.5
Fat, %	3.30	3.5	3.5	3.5
Energy, (kcal/kg)	3790.0	1748.0	3826.0	3797.4
Methionine, %	0.36	0.36	0.36	0.36
Lysine, %	1.20	1.20	1.20	1.20
Cystine, %	0.26	0.26	0.26	0.26
Tryptophan, %	0.20	0.18	0.20	0.17
Calcium, %	0.80	0.80	0.80	0.80
Phosphorus, %	0.60	0.60	0.60	0.60

conditions. A reduction in the current prohibitive prices of fish meal would reduce the percentage cost increase and this reduction can only be achieved through an increase in the volume of fish meal from local sources and an improvement in its quality through better processing techniques.

The Effect of Changing Cost of Ingredients on the Cost and Composition of Rations

Some of the major constituents of rations such as maize, guinea corn and fish meal are subjected to considerable price variations related to seasonality in production and irregular supply due to poor

distribution mechanisms. Such price variations would affect the cost of finished feeds and therefore the overall economic efficiency of pig and poultry enterprises. Under circumstances of varying prices, the need for substitution with cheaper materials arises. It is important for the feed miller to know the extent to which such substitution can be made, and the consequent change in cost, while still meeting the recommended nutritional requirements of the animal. With the conventional linear programming solution it is possible to determine the range within which the price of ingredients can change without affecting the composition of the ingredients

TABLE 6

The Effect of Different Levels of Fish Meal on Cost and Composition of Weaner's Ration Providing 20.26% Protein, May 1975 Prices

Ingredients	Without Fish meal	With 3% Fish meal	% Change	With 5% Fish meal	% Change
Fish meal	—	3.00	—	5.00	—
Guinea corn	—	—	—	5.92	—
Maize	51.10	49.23	-3.65	46.48	-9.0
Cassava	15.00	15.00	—	15.00	—
Groundnut cake	8.28	9.27	11.95	6.78	-18.1
Blood meal	5.67	4.01	-29.3	5.45	-3.9
Dried Milk Powder	—	—	—	1.89	—
Soyabean meal	3.0	1.37	-54.3	—	—
Cotton seed	0.70	2.07	195.7	4.27	501.0
Wheat bran	6.23	6.22	.16	—	—
Dried yeast	7.64	8.15	6.8	4.43	-42.0
Bone meal	0.55	—	—	—	—
Oyster shell	0.97	0.90	—	0.50	-48.5
D.L. — Methionine	.08	0.073	-8.75	0.13	62.5
Salt	0.25	0.25	0.25	0.25	—
A — D Vitamins premix	0.46	0.46	—	0.46	—
Cost Per Tonne of Mix	₦127.5	₦136.1	6.75	₦147.3	15.5
Fibre, %	2.35	2.5	—	2.5	—
Fat, %	3.30	3.5	—	3.5	—
Energy, kcal/kg.	3790	3787	—	3611	—
Methionine, %	.36	.36	—	.36	—
Lysine, %	1.20	1.20	—	1.20	—
Cystine, %	.26	.26	—	.26	—
Tryptophan, %	.20	0.19	—	.16	—
Calcium, %	.80	0.80	—	.80	—
Phosphorus, %	.60	0.60	—	.60	—

in the mix. For example, in table 7, the price of maize can fall to ₦103 per tonne or rise to ₦165 per tonne without affecting the proportion at which maize is included in the ration, provided of course, that the prices of other ingredients remain constant. However, the cost of the ration will change in accordance with the change in the price of maize. If the price of maize per tonne were to rise above ₦165 or fall below ₦103 it may have to be removed from the mix or its level of inclusion changed in favour of or at the expense of other ingredients.

The effect of a change in the general price structure on the composition and costs of ration cannot be examined through the final solution. Changing

price structure may be caused by shortage in supply or general inflation, causing the relative prices of the ingredients to change. Under such circumstances, a new linear programming model has to be constructed using the new set of prices. In table 8, we examine the effect of different price levels (C_1 and C_2 in table 2) on the composition and cost of grower's ration. The first set of costs, C_1 , represents the average feed producers' costs of ingredients obtained from small scale feed producer in the Western State. The second set of cost (C_2) is that of Pfizer, which pays much lower prices for the ingredients because of cost economies due to bulk purchases and more efficient purchasing network. Both sets of prices were for May 1975.

TABLE 7

Stability of the Mix of the Ingredients to Changes in their Prices (Weaner's Ration)

Included Ingredients	Amount	Price Per Tonne (₦)	Range over which solution remains stable	
			Lower Range (₦)	Upper Range (₦)
Maize	51.10	130	103	165
Cassava	15.00	100	92	—
Groundnut cake	8.20	175	150	183
Blood meal	5.67	80	11	90
Soyabean meal	3.00	150	144	—
Cotton seed	0.70	60	9	104
Wheat bran	6.32	70	25	96
Dried yeast	7.64	130	95	164
Bone meal	0.55	50	48	71
Oyster shell	0.97	40	*	*
Salt	0.25	174	*	*
D,L — Methionine	0.08	2000	*	*
A — D Vitamins premix	0.46	1121	*	*
<i>Excluded Ingredients</i>		<i>Shadow prices (₦)</i>		
Guinea corn		22.40		
Di-calcium phosphate		62.24		
Palm kernel meal		29.00		

TABLE 8

Effect of Changing Costs of Ingredients on the Composition and Costs of Grower's Ration. (Average Producer Costs Vs. Pfizer Costs, May 1975 Prices)

Ingredients	Using Average Producer Cost (C ₁)	Using Pfizer Cost (C ₂)	% Change
Guinea Corn	—	16.19	—
Maize	38.58	23.79	—38.34
Cassava	20.00	20.00	—
Groundnut cake	0.37	—	—
Blood meal	3.99	4.62	15.79
Cotton seed	3.89	3.34	—14.14
Wheat bran	5.88	6.78	15.31
Dried yeast	1.80	—	—
Brewers grains	16.09	17.11	6.34
Rice bran	7.81	6.56	—16.01
D, L — Methionine	0.06	0.08	33.3
Salt	0.30	0.30	—
A — D Vitamins premix	0.50	0.50	—
Oyster shell	0.73	0.73	—
Cost per ton of Mix	₦97.7	₦94.30	—3.48
Protein, %	16.18	16.20	0.12
Fat, %	3.49	3.49	—
Fibre, %	7.5	7.5	—
Energy, Kcal/Kg	3289.0	2692.56	—18.13
Lysine, %	0.80	0.90	12.5
Methionine, %	0.27	0.27	—
Cystine, %	0.18	0.18	—
Tryptophan, %	0.13	0.13	—
Calcium, %	0.55	0.55	—
Phosphorus, %	0.45	0.45	—

Table 8 shows that the cost advantage of using Pfizer prices was of the magnitude of 3.48%. In addition, the protein and lysine contents of the ration using Pfizer prices increased by 0.12 and 12.5%, respectively. The composition of the ration under the two price regimes also shows marked variation. Guinea corn replaced some part of maize in ration C₂ while rice bran, blood meal, wheat bran and cotton seed were changed by over 14% each. Synthetic methionine was increased by about 33% in order to maintain the same level of methionine as in the C₁ ration.

The effects of the variation in ingredient prices on the cost and composition of ration was also examined under two levels of protein specifications. The

first specification was the provision of 20% minimum protein. Table 9 shows the costs and composition of the rations under the two price regimes and protein specifications.

The cost of one tonne of ration under 20% minimum protein specification was ₦127.5 using the average feed producer prices, and ₦120.1 using Pfizer prices, a difference of 5.80%. The protein level provided using average feed producer price was 20.26% while 20.27% protein was provided using Pfizer prices. All other essential amino acids and minerals were adequately provided by both rations. Significant changes took place in the level of soyabean meal, cotton seed, groundnut cake, wheat bran and dried yeast as shown in table 9.

TABLE 9

The Effect of Changing Costs of Ingredients and Protein Requirements on the Composition and Cost of Weaner's Ration, (Average Producer Costs Vs. Pfizer Costs, May 1975 Prices)

Ingredients	20% Minimum Protein			22% Minimum Protein		
	Average Producer Costs (C ₁)	Pfizer Costs (C ₂)	% Change	Average Producer Costs (C ₂)	Pfizer Costs (C ₂)	% Change
Maize	51.10	50.20	-1.76	49.68	48.67	-2.03
Cassava	15.00	15.00	—	14.83	15.00	1.15
Groundnut cake	8.28	10.00	20.77	8.56	10.00	16.82
Blood meal	5.67	6.00	5.8	6.00	6.00	—
Dried Milk Powder	—	—	—	2.40	1.69	-29.58
Soyabean meal	3.00	0.70	-76.67	3.00	3.00	—
Cotton seed	0.70	0.26	-62.86	3.90	4.34	11.28
Wheat bran	6.32	8.67	37.18	2.91	3.56	22.34
Dried yeast	7.64	6.12	-19.90	5.23	4.78	-8.60
Bone meal	0.55	—	—	—	0.34	—
Oyster shell	0.97	1.00	3.09	0.68	0.71	4.41
Meat and Bone Scrap	—	1.24	—	2.01	1.07	-46.77
D, L — Methionine	0.08	0.09	12.50	0.09	0.11	22.22
Salt	0.25	0.25	—	0.25	0.25	—
A—D Vitamins premix	0.46	0.46	—	0.46	0.46	—
Cost Per Tonne of mix	₦127.5	₦120.1	-5.80	₦136.4	₦122.6	-10.12
Protein, %	20.26	20.27	0.05	22.26	22.26	—
Fat, %	3.3	3.38	2.42	3.5	3.5	—
Energy, kcal/kg.	3790.0	3757.0	-0.87	3824	3824.0	-0.06
Fibre, %	2.35	2.5	6.38	2.35	2.49	5.96
Lysine, %	1.20	1.19	-0.83	1.20	1.18	-1.67
Methionine, %	0.36	0.36	—	0.36	0.36	—
Cystine, %	0.26	0.26	—	0.26	0.26	—
Tryptophan, %	0.20	0.14	-30.00	0.20	0.20	—
Calcium, %	0.80	0.80	—	0.80	0.80	—
Phosphorus, %	0.60	0.60	—	0.60	0.60	—

Under the 22% minimum protein specification, the cost of ration using Pfizer prices was 10.12% cheaper, even though both rations provide 22.26% protein. Essentially the same ingredients were included, except for bone meal which was not present in the ration using average feed producer prices.

The foregoing analysis have shown very clearly how the use of linear programming can help in the rational formulation of efficient but inexpensive rations in a situation where the prices of ingredients undergo constant changes. The solutions to such programming exercises not only show the price stability range of the ingredients, but could also reveal the extent of substitution between ingredients when prices change, in order to compound a least-cost ration which conforms with a set of nutritional standards. The extent of the advantage will depend, on how easily the particular ingredients are substitutable in the mix.

CONCLUSION

The linear programming techniques for least cost ration formulation offer a much wider scope for considering different alternatives than currently used conventional methods. The use of this method which meets nutrient requirements from analytical data provided, taking into account the relative cost of alternative sources may result in savings in feed costs which could be substantial and therefore in turn result in improved profit margins thus encouraging the expansion of the enterprise. Its use is however subject to certain guidelines and pre-requisites. The L.P. matrix is usually constructed using single valued estimates of technical coefficients or nutrient composition of the various ingredients. It is however well known that the variation in quality and composition of

different batches of the same ingredient may be considerable, the variation in quality resulting from considerable variation in the availability of nutrients in the ingredients. Consequently, there is a need to establish a range of compositional values obtained through extensive analysis of different batches of several commonly used feed ingredients. Rapid test that would screen ingredients and discard those that are severely defective would also go a long way to make the use of this technique more effective.

It is noteworthy that the model used in the present study ignores other costs of feed production. However, such costs as labour, machine and building depreciation, insurance, marketing costs, bags etc. are essentially common costs and will vary between mills, depending on their scale of operation, capacity utilization and management organisation. Consequently, it was not considered necessary to include these costs in order to formulate least-cost rations, although models could be constructed to maximise returns while taking account of capacity utilisation, market demands and operating costs in least-cost ration formulation. Finally, while cost reduction may be achieved through linear programming, this must in all cases be related to animal performance as it is clearly known that the cheapest rations are not necessarily the most efficient. In this study an attempt has been made to elucidate the principles and scope of this technique while it is hoped in subsequent studies to test the several solutions in relation to actual animal productivity.

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