LEAST COST DIETS FOR PIG PRODUCTION. III. REGRESSION ANALYSIS AND ECONOMIC ASPECTS OF THE WEANER DIETS

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SUMMARY

This paper represents the third in the series of studies designed to explore the scope and contributions of computerized diets to the overall improvements in the technical and economic efficiency in the pig industry. The present paper attempts to establish the functional relationships between the principal nutrient components (protein and energy) of weaners' diets on weight gain, feed utilization and carcass quality. The established functional relationship was used as a basis for incorporating animal performance into feed formulation activities while using linear programming techniques to derive expansion path diets. Cumulative feed intake was positively related to liveweight gain in weaner pigs. While protein and energy intakes are significant explanatory variable, they explained only 37 and 36 percent, respectively, of the total variations in liveweight gain. No significant relationship was found between carcass quality and protein and energy intake levels for pigs of the weight range studied. While it was clearly demonstrated that the formulation of expansion path diets using linear-programming techniques could be used for selecting least cost diets to achieve different weekly liveweight gains, its practical application must await results of animal feeding trials designed to test the performance of the derived expansion path diets.

INTRODUCTION

Animal performance studies (Aneke, Ogunfowora and Fetuga, 1977) involving computerized, conventionally formulated and some commercial diets for both weaner and fattening pigs gave clearly different responses for the weaners' diets, while responses on the fatteners' diets were fairly similar, indicating that the quality of the weaners' diet may be most critical in the economic production of pig meat. Economic appraisal of these diets showed the computerized diets to be

economically more efficient than the conventionally formulated diets while some of these were more efficient compared to the commercial diets (Aneke, et. al. 1977). It has been established that pig performance in terms of rate and efficiency of gain and carcass leanness is clearly related to the intake levels and therefore intake of particular nutrients, particularly protein and energy (O'grady and Bowland, 1971; Cooke, Lodge and Lewis, 1972; Fetuga, Babatunde and Oyenuga, 1975).

The present paper reports on the functional relationships between intake levels of different weaner's diets (Aneke, et. al., 1977) and liveweight gain in pigs and attempts to explore, in quantitative terms, the influence of the principal nutrient components (especially protein and energy) of the diets on live weight gain and carcass composition. The established functional relationship was used to make predictions about the feed and nutrient intake levels necessary to achieve a desired rate of gain, given the diet type, while the results were used as the basis for incorporating desired animal performance into the feed formulation process, thereby facilitating the extension of the linear programming technique to the formulation of expansion path diets.

METHODOLOGY

Regression analyses were carried out on the experimental data from the feeding trials with weaner pigs using seven different diets comprising 3 computerized

diets LPI—LP3, two popularly used commercial diets, C₁ and C₂ and two conventionally formulated diets, CF₁ and CF₂ (Aneke, *et. al.* 1977). Analysis was carried out first on the cumulative liveweight gain and the corresponding cumulative feed intake values for the various diets, (Heady and Dillon, 1981). Further analyses were carried out for both single and nutrient combination effects on liveweight gain and lean to fat ratio in pig carcasses. The production functions—quadratic and square—root functions were fitted to the data on:-

- (i) Cumulative liveweight gain and the corresponding cumulative feed intake values for the different weaners' diets.
- (ii) Weekly liveweight gain and the corresponding weekly protein and energy intake levels.
- (iii) Lean to fat ratio and the corresponding weekly protein and energy intake levels.

The protein and energy intake values used were calculated from the weekly feed intake values and the digestible energy and protein density of the diets.

ANALYSIS AND INTERPRETATION OF RESULTS

The quadratic function gave the equa-

tion of best fit as judged by the magnitudes of R², the coefficient of multiple determination, the F-test and the correct signing of most of the explanatory variables which reflects conformity with the logic of the theory of animal production. Accordingly, only the results of the quadratic function are presented and used as lead equation in the interpretation of results.

Cummulative Liveweight Gain Regressed on Cummulative Feed Intake Values for the Various Diets

The first set of regression analysis obtained from regressing cumulative liveweight gain on cumulative feed intake revealed the presence of autocorrelation. This is to be expected since the weight of the pig at each weekly weighting will be related to the weight of the animal at the end of the previous week. This problem was overcome by applying the method of first difference to the cumulative values used in the regression analysis (Koutsoyiannis, 1973). This is the same thing as regressing the observations on weekly liveweight gain on the weekly feed intake values.

The production functions obtained are presented below:-

Diets	Equations	R ²	F	DW	DL	DU
C ₁	$Y = -0.34 + 0.33x - 0.0005x^2$ (0.03) (0.0002)	0.96	813.56	0.51	1.49	1.74
C ₂	$Y = 1.02 + 0.20x + 0.00045x^2$ (0.03) (0.0003)	0.92	442.59	0.40	1.51	1.74
LP ₁	$Y = 0.67 + 0.50x - 0.0015x^2$ (0.04) (0.0005)	0.97	587.53	0.93	1.34	1.72
LP ₂	$Y = 0.95 + 0.51x - 0.0016x^2$ (0.04) (0.0006)	0.96	537.85	0.49	1.34	1.72
LP ₃	$Y = 0.44 + 0.47x - 0.0017x^2$ (0.04) (0.0004)	0.96	341.43	0.45	1.45	1.72
CF ₁	$Y = 1.26 + 0.40x + 0.005x^2$ (0.07) (0.001)	0.94	293.49	1.03	1.29	1.72
CF ₂	$Y = 1.14 + 0.35x - 0.000016x^2$ (0.01) (10.000001)	0.93	344.44	0.44	1.34	1.72

Where Y = Cummulative liveweight gain
and x = Cummulative feed intake.

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The figures in parenthesis represent the standard error of estimates. An examination of the above equations reveals that the R^2 values are high indicating that cumulative feed intake levels account for between 92 and 97 percent of the variations in liveweight gain. The regression coefficients are also significant ($P < 0.01$) showing that feed intake is an important explanatory variable. The responses of the linear programmed diets (LP) are similar but differ from the conventionally formulated (CF) and Commercial (C) diets. The CF diets are, however, similar in the way they influenced liveweight gains in pigs. On average, an intake of 1kg. of any of the LP diets produced 0.4kg. liveweight gain. The commercial diets influenced weight gains differently. While the intake of 1kg. of diet C_1 produced 0.33kg. liveweight gain, similar intake of diet C_2 Produced 0.20kg. liveweight gain.

A comparison of the marginal physical productivities (MPPs) calculated from the regression equations for the various weaner diets and the observed feed con-

version efficiency (FCE) values for these diets are presented in table 1. The comparison shows that the estimating equations are reliable. For example the mean feed conversion efficiency of 3.670 for the C diets indicates that 3.670kg. of feed is required to put on 1kg. of liveweight gain. The average MPP of 0.264 is a very good approximation of the observed mean FCE value. This further confirms the reliability of the functional equations for predicting feed requirements of the weaner pigs at various predetermined liveweight gains within the liveweight interval of 8—34kg. given the type of diet.

Effect of Protein Intake on Liveweight Gain

The regression equation describing the relationship between protein intake and liveweight gain is presented below:-

$$Y = 0.78 + 1.44X - 0.07X^2 \dots \dots (1)$$

$$R^2 = 0.37; \quad F = 83.75; \quad DW = 2.13$$

where Y = Weekly liveweight gain in kg.

X = Weekly protein intake in kg.

TABLE 1
Comparison of Marginal Physical Productivities (MPP) of the Various Diets
with the Observed Feed Efficiency Values

DIETS	MPP	FEED CONVERSION EFFICIENCY
Linear Programmed Diets (LP)		
LP1	0.497	2.380
LP2	0.507	2.340
LP3	0.466	2.830
Mean	0.490	2.520
Conventional formulation (CF)		
CF1	0.390	2.260
CF2	0.350	2.730
Mean	0.370	2.500
Commercial diets (C)		
C1	0.329	3.620
C2	0.199	3.710
Mean	0.264	3.670

The critical level for Durbin Watson Statistics for the data used are $DL = 1.65$ and $DU = 1.69$. The Durbin Watson statistics of 2.13 shows that there are no autoregressive disturbances.

The regression coefficient for protein intake is statistically significant ($P < 0.05$) indicating that protein intake is a significant explanatory variable in the observed liveweight gains of the pigs. However, protein intake explained only 37 percent ($R^2 = 0.37$) of the total variation in liveweight gain. This value seems low since protein and energy are generally regarded as the major nutrients affecting animal performance. This raises some doubts as to whether the total protein intake as calculated from the protein density of the diet were actually available for

the pigs metabolic processes. The ingredients' nutrient level specifications in the original study was based on total, rather than on available levels of the major nutrients. Values for available nutrient levels are not readily available and would vary for different batches of the same ingredients depending on processing conditions, storage, extent of spoilage and the nature of other inherent components. These tend to cause variable availability of the nutrients, particularly the amino acids, and affect animal performance accordingly. The low R^2 obtained here is perhaps a further indication that in observed animal responses, available rather than the total levels of nutrients in mixed feed is more important in determining performance.

Effect of Energy Intake on Liveweight gain:

The regression equation describing the relationship between energy intake and liveweight gain is given below:—

$$Y = -29.87 \pm 0.95x - 0.0003x^2 \dots\dots\dots(2)$$

(0.02) (0.003)

$$R^2 = 0.36; F = 80.05; DW = 2.06$$

where Y = Liveweight gain in kg. and x = weekly energy intake in kilocalories.

The critical values for the Durbin-Watson Statistics were the same as in equation (1). The observed DW of 2.06 therefore indicates that there were no autoregressive disturbances. The regression coefficient for energy intake is significant ($P < 0.05$), but the coefficient for square term is not. This means that while energy intake is an important explanatory variable, the square term which reflects the extent to which diminishing returns occurs cannot be relied upon. Energy intake explained only 36 percent of the total variation in liveweight gain observed in pigs. This also raises some doubts as to the availability of the energy for growth purposes from the various dietary energy sources, or that

other factors were more critical in influencing performance than energy intake. Protein and energy are known to be related in the way they influence animal performance, inadequacy of one influencing the efficient utilisation of the other. The reactions involved in the rendering of amino acids unavailable also involve energy yielding components of feeds such as the simpler carbohydrates and fats. Thus, any situation which tends to affect amino acid availability may be expected to affect the availability of total dietary energy. The complex inter-relationships in nutrient utilization may account for the low explanatory power of the energy component obtained.

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Effect of Protein and Energy Intake on Lean to Fat Ratio.

The regression equation relating energy and protein intake to the proportion of lean to fat in the carcass of growing pigs is presented below:—

$$Q = 11.98 - 0.07 \times_1 - 0.06 \times_2 \pm 0.09 \times_1^2 \pm 0.004 \times_2^2 - 0.13 \times_1 \times_2 \dots (3)$$

(3.84) (6.21) (6.92) (0.003) (0.1)

$$R^2 = 0.26; \quad F = 1.70; \quad DW = 1.98.$$

where Q = Lean to fat ratio, $\times_1$ = Energy intake in kcals, $\times_2$ = Protein intake.

All the regression coefficients are not significant. This, coupled with the low R^2 value, suggests that protein and energy intake *per se* did not influence carcass leanness at the slaughter weight studied. This result seems to agree with the findings of Aunan, et. al. (1961), Clawson et. al. (1962), Greeley, et. al. (1964). This result might be expected as the lean to fat ratio measurements were taken at approximately 34kg, a point at which rapid lean tissue accretion is still in progress and fat deposition is not yet at its maximum for the breed of pigs used. Wide variation in digestible energy intake would be required to cause significant differences in the deposition of fatty tissue. However, the level of nutrients in the different diets were similar, particularly for the LP and

CF diets which were formulated to nutrient requirement specifications that varied within narrow limits.

INCORPORATION OF ANIMAL PERFORMANCE ON THE DIET FORMULATION PROCESS

The functional relationships between liveweight gain and intake of some major nutrients could be used as a basis for incorporating animal performance into the feed formulation process. For this exercise, the relationship examined was the effect of energy intake and percentage protein of the diet on liveweight gain. The regression equation obtained is presented below:—

$$Y = 6.47 \pm 0.12 \times_1 - 0.68 \times_2 - 0.00035 \times_1^2 \pm 0.019 \times_2^2 - 0.0011 \times_1 \times_2 \dots (4)$$

(6.08) (1.25) (0.0003) (0.03) (0.004)

$$R^2 = 0.37; \quad F = 33.00; \quad DW = 2.10$$

where
Y, $\times_1$ and $\times_2$ are as defined above.

Protein and energy intake together explained only 37 percent of the variation in liveweight gain and only the coefficients of $\times_1$ and $\times_2^2$ are significant at 5 percent level of probability. The negative sign for protein is, however, disturbing since one would normally expect a positive relationship between liveweight gain and the level of protein intake. Since the varying levels

of protein were derived from different ingredient sources as distinct from the same set of ingredient sources, it is possible that the response function as fitted here represents the average value of several response functions. Accordingly, representing them with an overall function could account for the wrong sign for the protein coefficient.

Isoquant equation was derived from equation 5 as follows:—

$$X_1 = \frac{-(0.12 - 0.0011X_2) \pm \sqrt{(0.12 - 0.0011X_2)^2 - 4(-0.00035)(6.47 - 0.68X_2 + 19X_2^2 - Y)}}{-2(0.00035)}$$

Various values of X_2 were then substituted into the above equation to obtain corresponding values of X_1 at specified levels of liveweight gain. Table 2 shows the values for X_1 and X_2 for 5 levels of weekly liveweight gain.

A critical analysis of table 2 reveals two distinct types of substitution between protein and energy. Below 18 percent level of protein, the level of energy increases with the level of protein but the rate at which energy increases is diminishing. Above 18

percent level, however, the level of energy decreases with an increase in the level of protein but the rate at which energy decreases is at an increasing rate. This implies that, at a given level of liveweight gain, decreasing amount of energy is sacrificed for protein below 18 percent level while an increasing amount of energy is sacrificed for protein above the 18 percent level. This is clearly shown in Table 3 and figure 1.

TABLE 2
Energy and Protein Co-ordinate Points for 5 Levels of
Weekly Liveweight Gain

Protein X_2 Percentage	Rate of Gain (Kg) Per Week				
	3	3.25	3.50	3.75	4
	K cals DE Per Week X_1				
12	21.10	24.07	27.11	30.24	33.46
13	23.53	26.56	29.67	32.87	36.17
14	25.54	28.63	31.80	35.06	38.43
15	27.13	30.25	33.47	36.79	40.21
16	28.25	31.41	34.67	38.02	41.48
17	28.92	32.10	35.37	38.74	42.23
18	29.10	32.29	35.57	38.95	42.45
19	28.82	31.99	35.26	38.63	42.12
20	28.05	31.21	34.46	37.80	41.26
21	26.83	29.95	33.16	36.46	39.88
22	25.15	28.23	31.39	34.64	37.99
23	23.05	26.07	29.17	32.35	35.63
24	20.54	23.49	26.52	29.63	32.83

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TABLE 3
Relationship Between Protein and Energy at Different Levels of Liveweight Gain

3Kg Liveweight Gain/Week			3.25Kg Liveweight Gain/Week	
Protein Level X_2	Energy Level X_1	Change in Energy Level	Energy Level X_1	Change in Energy Level
12	21.10	—	24.07	—
13	23.53	2.43	26.56	2.49
14	25.54	2.01	28.63	2.07
15	27.13	1.59	30.25	1.62
16	28.25	1.12	31.41	1.16
17	28.92	0.67	32.10	0.69
18	29.10	—	32.29	—
19	28.82	0.28	31.99	0.30
20	28.05	0.77	31.21	0.78
21	26.83	1.22	29.95	1.26
22	25.15	1.68	28.23	1.72
23	23.05	2.10	26.07	2.16
24	20.54	2.51	23.49	2.58

Considering the 4Kg weekly liveweight gain isogrowth curve in figure 1 for example, a small decline in the energy content of the diet (say from A to B) will necessitate a considerable increase in the protein level of the diet from B to C in order to keep the animal on the 4Kg. isogrowth curve.

The problem of incorporating animal performance boils down to selecting the least cost nutrient combination on specified isogrowth curve. This could be accomplished by iterative programming using different protein and energy co-ordinates on the isogrowth curve as bounds or nutrient constraints. Ideally a large number of co-ordinates on an isogrowth curve should be programmed so as to increase the probability of including the cheapest ration which meet the required nutrient combination for producing the specified liveweight gain. However, computer time and cost considerations limited the programming exercises to five co-ordinates which were selected to include the critical range of protein and energy requirements for the weaner pigs (Babamunde, *et. al.*, 1971; Fetuga *et. al.*, 1975, a & b).

Table 4 shows the ingredient composition and costs of five different diets which

provide the animals' requirements for attaining a liveweight gain of 3Kg per week. It can be seen from table 4 that diet 4 is the cheapest among these diets. This procedure could be used to select least cost diets for other isogrowth curves in figure 1 and an expansion path established by joining the least cost nutrient combinations on successive isogrowth curves. The diet composition for the least cost points on the family of isogrowth curves in figure 1 could then be formulated using LP techniques. The expansion path diets could be used to guide changes in diet formulation designed to attain different weekly liveweight gain at the least cost. To be of practical use to pig farmers, however, the expansion path diets have to be subjected to practical feeding trials designed to confirm whether or not they could produce the estimated weekly liveweight gain.

A critical examination of table 3 and 4 shows some divergencies between the estimated energy levels (Table 3) and the programmed energy levels (Table 4) for corresponding levels of protein. This goes to confirm our earlier assertion that the level of nutrient availability as estimated from production function could be markedly different from the computerized

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levels since the latter is computed from the nutrient composition of the ingre-

dients making up the diets.

CONCLUSION

Though the regression analyses showed protein and energy intake levels to be significant explanatory variables, they explained only 37 and 36 percent respectively, of the total variations in liveweight gain. This raises some doubts as to whether the protein and energy intakes calculated from the total levels of these nutrients in the diets and feed consumed were actually available for the pigs' growth processes and emphasised the need for further research to determine the extent of nutrient availability from the local feed ingredients as well as other factors in diets that may limit the utilization of dietary protein and energy for growth. It will be noted that there are usually some divergencies between the nutrient composition used as activity coefficients in the LP models and their availability, the extent of divergencies being a function of the ingredient, method of processing, storage and the presence of inherent fac-

tors that have been shown to render some nutrients unavailable. In general, however, the above findings on the effects of protein is in agreement with findings of some earlier workers (Heady and Dillon, 1961; Dent, 1964 and Flinn, et. al. 1972). While it was clearly demonstrated that the incorporation of animal performance into the feed formulation process was possible using regression and linear programming tools of analysis, its practical application to commercial livestock enterprises will have to await further work designed to test animal performance when fed on the derived expansion path diets. There is also an urgent need for further research to narrow or eliminate the divergence between nutrient availability from various ingredients and the activity coefficients (nutrient composition of ingredients) generally used in the linear programming matrix.

TABLE 4
Ingredient Composition and Costs of Weaners Diets Which Meet 3kg. Weekly Liveweight Gain

<i>Ingredients</i>	<i>% Diet 1</i>	<i>% Diet 2</i>	<i>% Diet 3</i>	<i>% Diet 4</i>	<i>% Diet 5</i>
Wheat Bran	6.91	6.55	4.79	10.00	1.22
Yeast	4.31	3.33	3.69	4.91	4.41
Brewers Grains	2.67	2.98	2.09	1.67	0.27
Oyster Shell	0.95	0.84	0.80	1.30	0.71
Bone Meal	0.79	0.89	0.94	0.35	1.04
Blood Meal	7.10	8.35	8.56	7.97	8.99
Ground Yellow Maize	66.42	66.19	65.48	58.54	64.02
Groundnut Cake	5.00	5.00	5.00	5.00	5.00
Salt	0.25	0.25	0.25	0.25	0.25
Cassava	5.00	5.00	5.00	5.00	5.00
Cotton Seed Cake	—	—	2.78	4.06	8.42
Rice Bran	—	—	—	0.36	—
Vitamin Premix	0.46	0.46	0.46	0.46	0.46
TOTAL MIX =	99.87	99.84	99.84	99.86	99.80
Cost	118.96	118.27	118.91	115.34	119.90
Protein %	18.96	18.75	20.00	20.50	22
Energy Kcals	3700.70	3701.44	3735.44	3667.97	3804.46
Lysine	1.14	0.70	1.20	1.20	1.19
Methionine	0.36	0.36	0.36	0.36	0.36
Tryptophan	0.16	0.16	0.16	0.16	0.16

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