DETERMINING PROTEIN AND ENERGY LEVELS IN BROILER DIETS THAT MAXIMIZE PROFITS

G. M. PESTI*

ABSTRACT

Current theory holds that setting energy levels in feed formulation is not necessary because birds eat to maintain a constant energy intake. A large body of data suggests that although birds fed high energy diets eat less than those fed low energy diets, they also grow better. Current linear programming models do not consider differences in response from different energy or protein levels. Iterative linear programming techniques can be used to choose among alternative diets with various protein and energy levels. A quadratic programming model can choose the levels of protein and energy that maximize profits.

INTRODUCTION

The conventional wisdom among poultry nutritionists is that there is no energy "requirement" per se. Many also believe that the protein requirement should be expressed in terms of the energy level of the feed. These theories led to the development of the concept of the energy to protein ratio, and that there is some optimum energy to protein ratio (Donaldson et al. 1956). The assumption is made that birds adjust their feed intake to maintain a constant energy intake regardless of energy level. The constant intake leads to the same performance regardless of energy levels as long as nutrient to energy ratios are maintained.

When this theory has been tested, the results have been negative. Fisher and Wilson (1974) examined a number of experimental results from the literature and found that birds fed higher energy levels showed increased growth and used their feed more efficiently. These results were confirmed by Pesti and Smith (1984) for experiments after 1974.

Experiments were conducted in this laboratory to characterize the response of broiler chickens to diets with various protein and energy contents (Pesti, 1982; Pesti and Fletcher, 1983). 1 t was found that the broiler chicken's response was dependent. on the protein and energy levels of the diet per se, and not the energy to protein ratio. The growth curve of broilers fed a particular diet may be described by a quadratic function over time. Also, the' response of broilers fed several combinations of protein and energy were found to be described very well by a single function relating body weight to protein and energy intakes (Miller, Arraes and Pesti, 1986; Pesti, Arraes and Miller, 1987).

Two procedures are outlined here that may be used to estimate the optimum protein and energy levels for broiler diets. Using linear programming (LP) , the formulator chooses between protein and energy level alternatives. With the quadratic programming (QP) method, the protein and energy levels that maximize profits are chosen based on the growth responses to protein and energy levels and the prices of ingredients containing protein and energy.

*Department of Poultry Science, University of Georgia, Athens, GA 30602 USA

MATERIALS and METHODS

Three experiments were conducted with male commercial broiler chickens in floor pens. All chicks were fed a standard corn and soybean meal based starter diet for the first three weeks (23% protein and (14.18 MJ ME_n/kg). At three weeks of age four pens of 40 birds each were allocated to each of the protein and energy combinations, except for the central point which had eight replicates (Table 1). Diets for the three to eight week period were based on corn, soybean meal, wheat middlings and poultry oil. Amino acid minimums were kept constant as a percent of protein. Birds were weighed bi-weekly from five to eight weeks of age. Quadratic equations were fitted to weight and feed consumption data of chicks fed each diet (Table 2). These equations were used to determine the feed consumption and days to market of birds grown on each diet to a standard weight (1.82 kg; Table 3). Least-cost formulas were then calculated for each combination of protein and energy based on the following prices per hundred pounds (cwt., 45.4 kg): corn, $5.25; soybean meal, $8.35; wheat middlings, $4.50; and poultry oil, $14.75. From the formula cost (Table 4) and feed consumed (Table 3), the feed cost was determined. Since body weights were the same (1.82 kg) the protein and energy combination with the minimum cost is also the one that maximizes profit.

A single quadratic equation was also fitted to the data from all the combinations of protein and energy: weight gain = f (protein intake, energy intake). An additional equation was fitted relating protein and energy intakes to age of the birds (Table 5). This equation was combined with the ingredient composition, cost matrix and restrictions of one of the United States' leading broiler firms . The equation was then solved for the combination of protein and energy yielding maximum profits. The answer (output) was identical in form to that from linear programming (Table 6).

RESULTS AND DISCUSSION

The theory of optimum energy to protein ratios holds that birds fed the same ratio of energy to protein should exhibit the same performance. This is what was observed for carcass fat but not for body weight or feed conversion (Table 1). Note that among broilers fed approximately the same energy to protein ratios, those fed the higher protein and energy levels had the best growth and feed conversions. Body weight increased with increasing levels of protein and energy. Carcass fat, however, increased with increasing energy level, but decreased with increasing protein level.

The profitability of each protein and energy combination could be calculated by subtracting the feed cost from the live bird weights times the value per pound. However, the producer desires a bird of a certain size. to make the comparison more valuable, the data need adjusted to the same size bird. This can be done by fitting quadratic growth curves to the data for broilers fed each diet combination (Table 2). The desired weight is first substituted into the weight equation and it is solved for t (time in days of age). Then this value for t is substituted into the feed consumption equation. Once feed consumption is known, feed conversion can be calculated. As protein or energy levels increase, feed consumption and days to market to a given weight decrease (Table 3).

Since returns from birds of the same weight can be assumed to be equal, profits can be maximized by multiplying feed consumption by the cost of each diet and choosing the lowest one (Table 4).

TABLE 1 How protein and energy levels of the growing diet affect broiler performance at 49 days of age*

Protein level (%)		Metabolizable energy (MJ/kg)				
		12.14	12.68	13.18	13.93	14.23
22.0	Body weight (kg)			1.88		
	Feed consumed (kg)			3.78		
	Feed conversion			2.01		
	Energy:Protein ratio			143		
	Carcass fat (g/100 g)			11.2		
20.9	Body weight (kg)		1.84		1.91	
	Feed consumed (kg)		3.79		3.75	
	Feed conversion		2.05		1.96	
	Energy:Protein ratio		145		157	
	Carcass fat (g/100 g)		11.9		11.9	
19.8	Body weight (kg)	1.83		1.88		1.92
	Feed consumed (kg)	3.80		3.78		3.73
	Feed conversion	2.08		2.02		1.95
	Energy:Protein ratio	146		159		172
	Carcass fat (g/100 g)	11.1		12.4		13.3
18.6	Body weight (kg)		1.79		1.88	
	Feed consumed (kg)		3.72		3.75	
	Feed conversion		2.08		1.99	
	Energy:Protein ratio		163		176	
	Carcass fat (g/100 g)		12.4		13.0	
17.5	Body weight (kg)			1.80		
	Feed consumed (kg)			3.77		
	Feed conversion			2.09		
	Energy:Protein ratio			180		
	Carcass fat (g/100 g)			13.5		

* From Pesti and Miller, 1987.

TABLE 2 Quadratic trends of weight and feed consumption as a function of time for each level of protein and energy fed[1]†

Protein level (%)	Energy level (MJ/kg)	b_0	b_1	b_2	R^2
		Weight = $b_o + b_1t + b_2t^2$			
17.5	13.18	.59179**	.00694	.00130***	.98
18.6	12.68	.55505*	.00979	.00124**	.98
18.6	13.72	.36369	.01997	.00121***	.98
19.8	12.13	.31604	.02490*	.00104***	.98
19.8	13.18	.25201	.02735**	.00109***	.98
19.8	14.23	.00172	.04269**	.00091***	.98
20.9	12.68	.39047	.01933	.00117***	.98
20.9	13.72	.00239	.04295***	.00090***	.98
22.0	13.18	.08094	.03834**	.00095***	.98
		Feed consumption = $b_0 + b_1t + b_2t^2$			
17.5	13.18	1.02002***	-.05222**	.00421***	.99
18.6	12.68	1.45416***	-.07999***	.00453***	.99
18.6	13.72	1.18298***	-.06249***	.00433***	.99
19.8	12.13	.74182*	-.03441	.00394***	.99
19.8	13.18	1.36557***	-.076032***	.00456***	.99
19.8	14.23	.62627*	-.02400	.00372***	.99
20.9	12.68	1.23256***	-.06720***	.00443***	.99
20.9	13.72	.94825*	-.04681**	.00409***	.99
22.0	13.18	1.59502***	-.09168***	.00479***	.99

[1]Using ordinary least squares. R^2 = coefficient of determination; t = time in days of age

* P<.1; ** P<.05; *** PP<.01.

†From Pesti and Miller, 1987.

TABLE 3 How protein and energy levels of the growing diet affect the performance of four pound broiler@

Protein level (%)		Metabolizable energy (MJ/kg) 12.14	12.68	13.18	13.73	14.23
22.0	Body weight (kg			1.82		
	Feed consumed (kg)			3.60		
	Feed conversion (feed/gain)			1.98		
	Days to market			47.2		
20.9	Body weight (kg)		1.82		1.82	
	Feed consumed (kg)		3.72		3.50	
	Feed conversion		2.05		1.93	
	Days to market		48.0		46.8	
19.8	Body weight (kg)	1.82		1.82		1.82
	Feed consumed (kg)	3.80		3.62		3.48
	Feed conversion	2.10		2.00		1.92
	Days to market	48.6		47.3		46.8
18.6	Body weight (kg)		1.82		1.82	
	Feed consumed (kg)		3.82		3.58	
	Feed conversion		2.10		1.97	
	Days to market		49.0		47.2	
17.5	Body weight (kg)			1.82		
	Feed consumed (kg)			3.83		
	Feed conversion		2.11			
	Days to Market			48.6		

*From Pesti and Miller, 1987.

TABLE 4 How the protein and energy levels and ingredient costs influence the diet that minimizes feed cost per bird*

Protein level (%)		Metabolizable energy (MJ/kg) 12.14	12.68	13.18	13.73	14.23
22.0	Formula cost ($/cwt)			7.285		
	Feed cost ($/bird)			.582		
20.9	Formula cost		6.875		7.421	
	Feed cost		.575		.575	
19.8	Formula cost	6.658		6.972		7.540
	Feed cost	.573		.566		.578
18.6	Formula cost		6.669		7.122	
	Feed cost		.576		.569	
17.5	Formula cost			6.702		
	Feed cost			.580		

Atlanta prices for January, 1986.

Formula cost includes 1.7 pounds of starter diet (23% protein and 13.39 MJ M.E./g; $7.561/cwt).

*From Pesti and Miller, 1987.

For the example prices used here, the diet with 13.18 MJ/kg and 19.8% protein would be the one to feed. Savings would be as much as $.016 per bird over the diet with the same energy level and 22.0% protein. This is a considerable savings for a complex processing 1.2 million birds per week. It suggests how critical it can be for a company to know the technical relationships and exploit them by appropriate economic analysis.

If the prices of the high energy ingredients (corn and poultry oil) were to double relative to the others, the maximum profit diet to feed would be the one with 12.15 MJ/kg and 19.8% protein. If the cost of the high protein ingredients were to double (soybean meal, poultry by-product meal, L-Lysine and DL-Methionine), the best diet to feed would be the one with 13.73 MJ/kg and 18.6% protein.

An alternative approach is to fit a single equation relating body weight to protein and energy intakes (Table 5) instead of the eighteen equations of Table 2. This equation is also an excellent fit from a statistical point of view. To this equation the matrix from any standard LP feed formulation problem can be added. The constraints on protein and energy levels are relaxed and the equation is solved to give the combination of protein and energy that maximizes bird weight to a given feed cost. A second equation relating protein and energy intakes to age of the bird is also necessary to calculate days to market. The output looks indentical to the LP output with additions such as the feed consumption and weights of the birds (Table 6).

TABLE 5 Estimates of the coefficients of regression for the weight of male broilers fed on diets of various protein and energy concentrations[1]†

Source of variation	Estimate	Standard error
Intercept	.041988**	.0189
Cumulative protein intake [kg]	1.457695**	.0118
(Protein intake)^2	-1.758822**	.0027
Cumulative energy intake [MJ]	.026180**	.0016
(Energy intake)^2	- .000423**	.0002
Protein-energy interaction	.039050*	.0200

* Significant at the 0.05 level
** Significant at the 0.01 level

[1]Coefficient of Determination (R^2) = 0.99 Protein and energy intakes include those during the first 3 weeks of the broilers lives (.206 kg and 11.70 MJ, respectively). For example, predicted weight for chicks fed 220 g protein/kg and 12.13 MJ ME/kg at 42 d = 0.042 + 1.457695(0.531 + 0.206) - 1.758822(0.531 + 0.206)^2 + 0.02618(29.29 + 11.70) - 0.000423(29.29 + 11.70)^2 + 0.039050(0.531 + 0.206) (29.29 + 11.70) = 1.703 kg; (Observed = 1.751 ± 0.008).

†From Pesti et al. 1986.

Unlike current LP models, when the prices of ingredients change, the QP solution will change. LP chooses the combination of ingredients meeting minimum specifications at least cost. QP chooses the combination of ingredients that maximizes the weight of the bird for a certain feed cost.

TABLE 6 Outputs (diet formulations) and predicted performance of 1.84 kilogram broilers from linear (LP) and quadratic (QP) programming models*

Ingredient (g/kg)	LP[1]	QP
Corn	584	540
Soybean meal	144	185
Animal fat	18	10
Protein supplement	31	38
Blood meal	7	8
Ground limestone	7	8
Deflourinated phosphate	8	5
CholineCl (350 g/kg)	2	2
Methionine (MHA)	1	2
Feather meal	58	78
Dried whey	43	23
Wafer meal	92	97
Vitamin premix	1	1
Fixed ingredients[2]	4	4
Trace mineral premix	1	1
Nutrient		
Protein (g/kg)	200	235
ME (MJ/kg)	13.37	13.13
Performance		
Live weight (kg)	1.84	1.84
feed consumption (kg)	3.68	3.52
Technical feed converison	2.00	1.91
Days to market	44.0	44.2
Feed costs (cents)[3]		
per bird	72.54	71.00
per kilogram bird	39.399	38.546

[1]Based on National Research Council (1977) constraints for 3 to 6 week old broilers.

'Antibiotics and anticoccidial drug.

[3]Based on 12 94 cents/kg for corn and 23.76 cents/kg for soybean meal.'

*From Pesti et al. 1986.

REFERENCES

DONALDSON, W. E., COMBS, G. F. and ROMOSER, E. L. (1956). Poultry Sci. 35: 1100.
FISHER, C. and WILSON, B.J. (1974. In "Energy Requirements of Poultry", p. 151-184, editors T. R. Morris and B. M. Freeman. (Br. Poult. Sci. Ltd., Edinburgh).
MILLER, B. R., ARRAES, R. A. and PESTI, G. M. (1986). So. J. Agric. Econ. 18: 141.
NATIONAL RESEARCH COUNCIL. (1984). "Nutrient Requirements of Poultry". (National Research Council, National Academy of Sciences, Washington, DC).
PESTI, G. M. (1982). Br. Poult. Sci. 23: 527.
PESTI, G. M. and FLETCHER, D. L. (1983). Br. Poult. Sci. 24: 91.
PESTI, G. M. and SMITH, C. F. (1984). Br. Poult. Sci. 25: 127.
PESTI, G. M., ARRAES, R. A. and MILLER, B. R. (1986). Poultry Sci. 65: 1040.
PESTI, G. M., MILLER, B. R. (1987). Least-cost poultry feed formulation: Principles, Practices and a New Microcomputer Program. University of Georgia Agricultural Experiment Station Bulletin.