# Determining the feed composition and feeding programme that will optimise the performance of a broiler flock

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**Abstract**

The optimum feeding programme for broilers is that which results in the highest profit for the enterprise, e.g. margin/m$^2$ per annum. Determining the optimum concentrations of amino acids relative to energy and the optimum nutrient density in each feed, and the optimum length of time that each feed should be fed, are therefore both nutritional and economic decisions. A combined feed formulation program, broiler growth simulation model and optimiser is described that can optimise the feeds and feeding programme of growing broilers. Two examples of the use of this optimiser are given, leading to a discussion on the merits of using a mechanistic approach to optimisation as opposed to an empirical method. Whereas mechanistic models are superior in most respects to an empirical approach, nevertheless there are aspects of the production process, which impact significantly on the optimum feeding programme, whose underlying mechanisms are as yet unexplained, and in such cases an empirical approach is seen as being a valuable extension to a mechanistic model.

## Introduction

The optimisation and control of amino acid contents in practical feeds are essential components of modern broiler production. Optimisation of amino acid contents involves adjusting the dietary contents used to take account of prevailing conditions, including economic conditions. Thus 'requirements' are seen as variables, subject to management decision, and not as fixed quantities to be looked up in a table.

This is not a new idea. In the 1960's econometricians were pointing out that once the production response of animals to variations in nutrient supply was known, then the optimum contents of supply could readily be determined e.g. to maximise profit or to meet some other economic objective (Dent and Casey, 1967). Various attempts have been made to apply these ideas in broiler production (Pesti *et al*., 1986; Miller *et al*., 1986), but in general the use of formal optimisation techniques has not reached the stage of routine use in broiler feeding. Instead, there remains a strong tendency among nutritionists to make use of tables of nutrient requirements.

Whilst there are probably many reasons for this, an underlying one is the difficulty of defining the animal response that is expected when nutrient contents are changed. The wide variety of factors that are known, or may be expected, to modify this response makes prediction a difficult task. In particular, in free-feeding birds, the response in feed intake is difficult to predict and has a critical effect on the choice of optimum feeds. Given these difficulties it is even more surprising that nutritionists favour the concept of fixed requirements when defining specifications for broiler feeds. With a fixed requirement, there is no way of determining the effect on growth, food intake or carcass composition of either increasing or reducing the concentration of an amino acid in the diet. It is also not possible to suggest how, or even whether, these requirements should change with the genotypes available to the broiler industry.

The traditional approach to solving this question has been to carry out short-term experiments in which broilers of a given age are offered feeds containing graded supplements of the amino acid under study. The concentration of amino acid in the feed producing the maximum growth response during the test period is often regarded as being the requirement for that amino acid. Although this method is fraught with potential errors (Gous and Morris, 1985) it is still the method preferred by some nutritionists and committees. The chosen 'requirement' also depends upon the method used to interpret the data (Morris, 1989). The resultant requirement is expressed as a fixed concentration in the feed, ideal for constructing tables of nutrient requirements and for least-cost formulation of feeds. But it is impossible to apply an accurate cost/benefit analysis to such numbers.

In spite of the wide range of methods employed, it is self-evidently true that this traditional approach has been successful in broiler production, although there is no good evidence to show that the feeds and feeding programmes used in commercial practice are necessarily the most profitable. However, it is also true that it has not been possible to collect sufficient empirical response data in this way for the results to be applied routinely in commercial practice. Attempts to do this by combining the results of many experiments, e.g. Boorman and Burgess (1986), were useful but still didn't provide a general resolution of the problem.

The Degussa Corporation (1995), using collected experimental data as described by Rodehutscord and Pack (1999) has produced an empirical model (Amino Chick) for calculating the economically optimum dietary lysine and methionine + cystine levels. The calculation can be done for any stage of the broilers' life (although it is not clear how this is done) and takes account of revenue both at the farm gate and for processing, and considers feed costs and the cost of synthetic amino acids. In reality the calculation optimises the level of supplementation with crystalline amino acids and not the overall dietary content. Mack *et al.* (2000) have presented new equations for use in this type of optimisation. More recently, empirical models have been developed by Eits (2004) and Fisher (2005), the two models (Nutri-Opt, and the Aviagen Balanced Protein Calculator) being designed to determine the optimum economic protein contents in feeds for broilers. These latter models are apparently being used with some degree of success.

The major reason for the apparent reluctance to move from the empirical approach to a more dynamic theory is that there are so many factors that have to be integrated before the optimum economic feeding schedule can be determined. This is especially true of feeding programmes for growing animals. Factors to be considered include the potential protein growth rate of the genotype; differences between individuals at a time and within individuals over time; the effect of the state of the bird at the end of one period of feeding on the response to the feed in the next period; the effect of nutrient concentration and energy-to-protein ratio on food intake, carcass composition and protein gain; the fact that genotypes differ in the amount of excess energy that may be stored as body lipid, and the maximum rate at which this can take place; the effect of high or low environmental temperatures on all of the above; and the constraints placed on the animal by the environment and by the feed, which prevent some birds from consuming the necessary amount of a feed to grow at their potential. Without a well-constructed mechanistic model it would be impossible to deal with all these factors simultaneously in arriving at the optimum feeding programme for broilers. It is a daunting task to produce a mechanistic model that addresses all these factors, but some success has been achieved in producing a model that accurately simulates the voluntary food intake of growing broilers, and this has become the basis of an optimisation process that appears to hold much potential to address the issues faced by broiler nutritionists.

**Optimising the feeding programme for broilers**

The optimum feeding programme for broilers is that which results in the highest profit for the enterprise, e.g. margin/$m^2$ per annum. Determining the optimum concentrations of amino acids relative to energy and the optimum nutrient density in each feed, and the optimum length of time that each feed should be fed, are therefore both nutritional and economic decisions.

The information required for optimisation consists of feed costs at different nutrient levels, a description of all the relevant animal responses, both fixed and variable costs affecting the production system, and details of revenue. The complexity of the information required would depend on the level of organisation at which the optimisation is to be made. If it is required to optimise the profit of the broiler grower at the farm gate then responses in liveability, growth and feed conversion ratio will probably suffice. However, and more realistically, a wider view will be required and the effect of broiler nutrition on slaughterhouse variables (eviscerated yield, uniformity, rejects etc.) and further processing (carcass composition) will need to be defined. Mack *et al*. (2000) emphasised the importance of considering all aspects of the production cycle when making nutritional decisions.

Feed costs for any nutritional specification are readily calculated by linear programming. This will take account of feed ingredient availability, analysis and costs. Processing and transport costs may be added. Broiler production costs are complex but will usually be specified by each Company. So the only persistent problem in optimisation lies, as ever, in the definition of animal response.

In most commercial feed formulation, and in the approach to optimisation described here, the primary rule is that the ‘protein value’ of both ingredients and mixtures can be described by the level of the first-limiting amino acid, which is presumed to behave additively. Bird performance is assumed to be proportional to the level of the first-limiting ‘available’ amino acid. Whilst this scheme may be sufficient for day-by-day feed formulation, nutritional science recognizes some other factors that may influence the response to dietary protein. Briefly these include interactions amongst amino acids, amino acid balance, the effects of total protein supply and the control of non-essential amino acids. These topics are discussed briefly by Fisher (2000) and they need to be borne in mind when considering the optimisation of the first-limiting amino acid level.

**A new approach to optimisation**

We describe here the development of optimisation tools by EFG Software (Natal). This is a commercial product but the methods used are open and the work is presented here as part of the scientific development in this field.

In essence the method combines three types of computer program:

1. A feed formulation program using linear programming.
2. A broiler growth model.
3. An optimisation procedure.

The flow of information is very simple: the optimiser defines nutritional constraints for practical broiler feeds. These are passed to the feed formulation program, which determines the least-cost feed that meets these constraints. The characteristics of this formulated feed are then passed, as input, to the broiler growth model. This predicts the performance expected from this feed when given to a defined flock of broilers and the predicted performance is then passed to the optimiser to complete the cycle. The next cycle starts by the optimiser modifying the feed specifications, moving, according to some in-built rules, to an optimum point. The objective function to be optimised may be defined in terms of any output from the broiler growth model, but realistically would be an economic index of some sort. Examples are margin over feed cost, margin per $m^2$ per year, or maximum breast meat yield at an age or body weight.

The system allows for use of all the data considered above. The broiler growth model allows for multiple harvesting from one flock and calculates revenues from any mixture of whole-bird sales or processing. Typical economic variables are included although these are readily customized to fit with individual enterprises. In the broiler growth model the protein nutrition of the broiler has to be simplified to some extent; for example the effects of amino acid imbalance on feed intake have to be ignored.

The key to this approach clearly lies in the ability of the broiler growth model to reflect accurately the performance expected under commercial conditions. This is a complex topic and one that cannot be discussed in detail here. Growth models are improving over time and models developed in different laboratories can be included in optimisation schemes of the sort described here. However, at this time there is unfortunately little evidence of the development of modelling in the poultry research community.

The computer program, which carries out these calculations, is embedded in the feed formulation program, WinFeed. Practical feed specifications are set up in the usual way and these provide the starting point for the optimisation. A feeding programme is set up from these feeds (list of feeds with time or quantities given) and then the optimisation is started. This takes account of all the other settings in both the feed formulation program (feed prices, feed and nutrient constraints etc.) and the broiler model (genotype, environment, fixed and variable costs, sources and rates of revenue). Mortality is input to the model.

At present the program optimises three aspects of a commercial broiler feeding programme: it optimises amino acid and energy contents in each feed in a given feeding schedule; it optimises the nutrient density of each feed in the feeding schedule, and the optimum feeding schedule is determined, given feeds of a fixed composition.

*Optimising amino acid contents in each feed*

The optimum relationships between the essential amino acids and energy change during the growing period, and the optimiser determines the relationship within each specified feeding period that maximises (usually) or minimises the objective function. The objective is to determine the optimum amino acid to energy ratio in each of the feeds in a given feeding programme such that the overall performance is maximised. The objective is not to determine independently the optimum ratio in each of the feeds on offer. Because the performance on one feed impacts on the performance on subsequent feeds, this is an essential prerequisite in optimising the feeding of broilers.

To optimise amino acid contents the process works only with lysine. The contents of the other essential amino acids are controlled by reference to an (user-controlled) 'ideal' protein ratio. Both amino acid and energy contents may be optimised simultaneously, or the user may fix either of these, thereby increasing flexibility.

Where this optimiser has been used in practice, sensible answers are produced: optimum lysine contents for broilers are lower for females than males; when protein prices increase, the optimum lysine contents and the optimum level of broiler performance both decrease; and when protein prices decrease, there is very little change in the suggested feeding strategy. In these circumstances the program suggests that you just take the extra margin.

*Optimising nutrient density*

Where the user wishes to retain a given ratio between the essential amino acids and energy, the program will optimise the nutrient density in each of the feeds in the feeding programme, by maximising the objective function over the entire growth period. As Fisher and Wilson (1974) have shown, the optimum nutrient density depends on such factors as sex, the ratio between input and output costs, and mixing and transport costs. These factors, and others, need to be considered by the user in determining the optimum nutrient density of each of the feeds in the programme. Again, each feed needs to be optimised whilst considering the effect of the other feeds in the programme on the objective function: they should not be determined in isolation.

*Optimising the feeding schedule*

Many broiler producers do not have the opportunity of having feeds mixed according to their specifications, but are constrained by the proprietary feeds available to them. An almost infinite variety of options is open to such producers in designing their feeding schedule, which can be based on amounts fed in each period or on fixed feeding periods for each feed. The optimum feeding schedule is dependent on the composition of the feeds, their respective prices, the revenue to be derived from the sale of the broilers, and many other biological and economic considerations.

An example of the way in which a nutritionist might use this optimiser is given below. The scenario used was a mixed flock of broilers reared to 35 days, with revenue generated on a processed basis, and with baseline feed ingredient availability and price set at some arbitrary conditions. The objective function chosen in all cases was margin over food cost. Revenue was generated at three levels, the ratios of revenue to feeding cost per bird being approximately 1.4, 2.8 and 4.2; and prices of protein-containing ingredients were at two levels, the base level being 15% below the higher cost of ingredients. A three-phase feeding programme was used, with ME and lysine contents in each phase, as well as the amount of feed allocated in each phase, as shown in Tables 1 and 2.

The result of optimising the amino acid content whilst retaining the initial energy levels used in the three feeds, under the different cost scenarios, is given in Table 1. In all cases the objective function (margin over food cost) for the optimum result was greater than the base value. The relative improvement over the base value (shown as 'Change, %' in Tables 1 and 2) was greatest when the ratio of income: feed cost was lowest (1.4 *vs*. 2.8 *vs*. 4.2).

Table 1. Optimum lysine contents of starter, grower and finisher feeds for a mixed-sex broiler flock as influenced by changes in the cost of dietary protein sources (100 and 115) and the revenue for processed broilers (100, 200 and 300) using a fixed feeding schedule of 800g starter (12.6MJ AME chick/kg), 1200g grower (13.3MJ AME adult/kg), and the remainder, to 35d of age, finisher (13.5MJ AME adult/kg).

| | Base Lysine g/kg | Base cost of protein sources Revenue, relative | | | Cost of protein sources +15% Revenue, relative | | |
|---|---|---|---|---|---|---|---|
| | | 100 | 200 | 300 | 100 | 200 | 300 |
| Starter | 12.7 | 11.7 | 12.6 | 12.8 | 11.2 | 12.2 | 12.4 |
| Grower | 11.8 | 9.7 | 9.7 | 9.7 | 9.5 | 9.5 | 9.8 |
| Finisher | 10.0 | 9.3 | 9.6 | 9.6 | 9.3 | 9.3 | 9.6 |
| Final weight | 1978 | 1962 | 1991 | 1993 | 1937 | 1980 | 1991 |
| Cum. Food | 3130 | 3231 | 3258 | 3260 | 3204 | 3259 | 3255 |
| FCR | 1.583 | 1.642 | 1.633 | 1.632 | 1.649 | 1.641 | 1.632 |
| Breast, g | 337 | 333 | 339 | 340 | 328 | 337 | 339 |
| Ab. Fat, g | 27 | 29 | 30 | 30 | 29 | 29 | 30 |
| Change, % | 0 | +12.2 | +3.0 | +2.0 | +24 | +4.0 | +2.4 |
| Income:cost ratio | | 1.41 | 2.83 | 4.24 | 1.26 | 2.51 | 3.77 |

Similarly, the results of the optimisation of the feeding programme used, with the baseline feeds kept constant, are presented in Table 2. Again, the optimiser was able to improve the margin over food cost under all pricing scenarios, this improvement also being greatest when the ratio of income to feeding cost was lowest.

Table 2. Optimum feeding programme for a mixed-sex broiler flock as influenced by changes in the cost of dietary protein sources (100 and 115) and the revenue for processed broilers (100, 200 and 300) using three feeds of fixed composition (starter, 12.7g lysine/kg; 12.6MJ AME chick/kg, grower, 11.8g lysine/kg; 13.3MJ AME adult/kg, and finisher, 10g lysine/kg; 13.5MJ AME adult/kg) to 35d of age.

| | Base Feeding program g | Base cost of protein sources Revenue, relative | | | Cost of protein sources +15% Revenue, relative | | |
|---|---|---|---|---|---|---|---|
| | | 100 | 200 | 300 | 100 | 200 | 300 |
| Starter | 800 | 126 | 163 | 163 | 95 | 158 | 174 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Grower | 1200 | 547 | 589 | 611 | 589 | 580 | 589 |
| Finisher | 1172 | 2558 | 2475 | 2454 | 2544 | 2493 | 2465 |
| | | | | | | | |
| Final weight | 1978 | 1996 | 1999 | 1999 | 1994 | 1999 | 1999 |
| Cum. Food | 3130 | 3246 | 3242 | 3242 | 3241 | 3243 | 3242 |
| FCR | 1.583 | 1.621 | 1.617 | 1.617 | 1.621 | 1.618 | 1.616 |
| Breast, g | 337 | 340 | 341 | 341 | 339 | 341 | 341 |
| Ab. Fat, g | 27 | 31 | 31 | 31 | 31 | 31 | 31 |
| Change (%) | 0 | +10.8 | +1.03 | +1.9 | +20.0 | +3.8 | +2.4 |
| Ratio of Income:cost | | 1.41 | 2.83 | 4.24 | 1.26 | 2.51 | 3.77 |

There are a number of points of interest in these results. The lysine contents specified in the Base feeds minimised FCR and carcass (abdominal) fatness but except at the lowest revenue exhibited the lowest final body weight, breast meat yield and margin over food cost. In Table 1 the FCR using the Base feeds was between 5 and 6 points better than on the 'optimised' feeds, yet the margin over feed cost was between 2 and 24% less than on the optimised feeds. When choosing to minimise FCR no account is taken of the cost of feed or the revenue produced, thereby favouring high protein (and hence high cost) feeds. A smaller, leaner carcass is produced, but at a price. It is essential therefore that a broiler producer specifies the objective function before designing the optimum feeds for the operation.

As pointed out above, when the income: cost ratio is high the margin over feed cost is relatively insensitive to changes in the amino acid supply or the feeding programme used: improvements of only 1 to 4% over the base levels were evident under these conditions. However, where profitability is low (low income: cost ratio) this sensitivity increases markedly, and gains of between 10 and 24% were obtained: it is under such conditions that a broiler producer needs to be particularly careful in choosing the optimum feeds and feeding schedule, as the range in profitabilities, and hence the cost of getting it wrong, is highest under these conditions.

In the above examples, where profitability was low, the amino acid supply in the starter period was reduced, but not that in the two subsequent periods. Similarly, the amount of starter was reduced when the feeding programme was optimised, but not the amounts of grower and finisher. This had the effect of reducing final weight and breast meat yield, but the margin over food cost (the objective function) was considerably increased. Such a deviation from the Base feeds could not be entertained when using tables of nutrient requirements, nor are empirical models capable of determining the effects of changes in just one period of growth on overall performance and profitability. Yet it is critical to consider the entire growing period when attempting to optimise the feeding programme of broilers.

When Fisher and Wilson (1974) developed their empirical mechanism for optimising the nutrient density of broiler feeds they divided the rearing period into two, on the grounds that the responses to nutrient density differed considerably in the two periods, as did the responses of males and females within each period. Such differences in response are important when determining the optimum feed or feeding programme, as are the effects of the state of the birds at the end of one period on the response to feed in the subsequent period. We have demonstrated in our research facilities that the response obtained to feeds varying in protein content or in nutrient density varies depending on the state of the birds at the start of the test period. Fatter birds are capable of drawing on lipid reserves as a source of energy, and thus need less energy than would birds that were lean at the start of such a feeding period. This has important consequences on the optimum feeds and feeding programmes for broilers, and such consequences are outside of the capabilities of empirical models.

Many exercises could have been reported here: differences would have resulted had males and females been reared separately, or had the revenue been generated from live-bird sales only, from a combination of live- and dressed-birds, or if further processing had been considered. Partial cropping of the broilers would have resulted in yet another set of optimum feeds, as would the effect of higher or lower stocking densities than those used in this exercise. Similarly, the optimum feeds would be very different for strains that are capable of overconsuming energy when faced with a marginal deficiency of protein, or an unbalanced feed, compared with strains that cannot do this. And, of course, because the objective function plays a pivotal role in defining the optimum feeds and feeding programme, different optima could have resulted depending on the objective function chosen. Such refinements are possible when using a mechanistic model, and are more likely to produce realistic results under the various scenarios listed than would empirical models.

However, there are some variables that do not lend themselves to mechanistic modelling. The underlying mechanisms that deal with the effects of feed composition on mortality and flock uniformity, for example, are unknown, yet there appears to be such a relationship within some strains that should be accounted for when optimising the feeding programme of broilers. Similarly, there is a tendency in the broiler industry to make use of lighting programmes to slow down the growth rate of some strains, as a means of reducing metabolic disorders such as Ascites. Although the underlying mechanisms are not known, it is possible to simulate the reduced growth rate that results from this practice by reducing the rate of maturing parameter in the growth equation used, but this does not relate mechanistically to a reduction in mortality. Similarly, the effects of vaccination and other stressors on growth rate and food intake may be simulated by reducing the rate of maturing parameter, thereby empirically adjusting performance within a mechanistic model. Such additional empirical features should be under the control of the model user, rather than the model developer, until the underlying mechanisms are understood. There is merit in combining empiricism within a mechanistic model, given that some of these variables play an important role in defining the optimum feeding programme for broilers.

Acknowledgement

Computer programming by Alan Gous, Linda Longley and Helmut Schuster.

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