EVALUATING A BROILER GROWTH MODEL

C. FISHER\(^1\) and R.M. GOUS\(^2\)

**Summary**

Simulation models of broiler growth are useful both as scientific and commercial tools. The needs of these two areas can only be reconciled if the model is a ‘glass’ box, with the contents of the model being transparent and available to the user. Models are only representations of reality and some evaluation has to be done each time the model is used.

Evaluation can usefully be carried out in the following steps: 1. Consider the bounds of the model; 2. Evaluate the theoretical structure of the model; 3. Test the model against existing experimental data; 4. Evaluate the predictions of the model in practical applications.

Various aspects of evaluating the EFG Broiler Growth Model (EFG Software, Natal, S.A.) are presented in this paper.

**I. INTRODUCTION**

Proving the commercial value of predictive models used in broiler production is obviously essential; the more so if the model is itself a commercial product. Model evaluation is a multi-step process involving not only those who develop (and sell) the model but also its users. Critically, the process of evaluation will depend on the type of model under consideration.

The model discussed here (the EFG Broiler Growth Model) implements a theory of growth and feed intake in broilers outlined by Emmans and Fisher (1986) and developed further by its main author G.C. Emmans (1987, 1995). The principal features of the model are as follows: *Firstly,* potential growth, a genetically determined characteristic, is defined by three growth and one feathering parameter. A Gompertz curve relating the potential for feather-free body protein growth to post-hatching time is the central feature. Potential body fatness is also seen as being under genetic control. *Secondly,* by assuming that birds have a purpose - to achieve their potential growth of body protein - a general theory of *ad libitum* feed intake can be elaborated (Emmans, 1997). *Thirdly,* by analysing how the environment, both physical and nutritional, will prevent a bird achieving its potential, actual performance under defined conditions can be computed. *Fourthly,* nutritional transactions (energy and amino acids only) are considered in conventional ways except that food energy is computed as ‘effective’ energy (Emmans, 1994) and not in the more limited way as ME. *Fifthly,* by using these principles the model simulates the growth of body and feather protein, fat, water and ash over successive intervals of time with daily summary of outputs. At each stage the composition of the body is computed using equations based on allometry with body protein weight. Biological and economic indexes of performance allow the results to be assessed. Evaluating a theory-based model of this sort raises a dichotomy. On the one hand there is a scientific need to prove the model ‘wrong’ so that it can be improved. Conversely there is a need to prove the model ‘right’ so that it may be used. This contradiction may be resolved by seeing the model as a ‘glass’ box, rather than the usual ‘black’ box, so that users of the model can share fully the understanding of what it does and what it does not do. If models are to develop in both a scientific and commercial sense then such openness seems to be essential.

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\(^1\) EFG Software (Natal), Leyden Old House, Kirknewton, Midlothian, EH27 8DQ, U.K.
\(^2\) Dept of Animal and Poultry Science, University of Natal, Pietermaritzburg, South Africa.
II. MODEL EVALUATION

(a) Model bounds

Consideration of what the model includes and excludes is a useful first step in evaluation. Factors included are the genotype of the bird, including feathering; flock characteristics such as stocking density, mortality, distribution of mortality in time, and economic parameters; environmental variables temperature and humidity; diet composition in terms of energy and amino acids and the use of controlled feeding. Feed form, mash versus pellets, is partly implemented. Important factors that are not considered at this stage of development include: response to temperature stress, diurnal variations in temperature and lighting. With a theory based model desiderata for inclusion of a factor include not only its importance but also the availability of a proper theoretical treatment that is compatible with the rest of the model.

(b) Validating the theory

Evaluating and testing the theory that a model uses, independently of evaluating the overall model, is an essential process. Only in this way can the model be continuously improved. Models which become so complex that the component hypotheses cannot be independently tested may cease to be useful from a scientific point of view.

Potential feather-free body protein growth - a Gompertz curve: the assumed Gompertz curve, relating body protein, Bp, to time, is the central element of the growth theory of Emmans (1987, 1995). The curve defines two of the four genetic parameters in the model and through derived allometric relationships determines other body components. The assumption that a bird seeks to achieve its potential allows ad libitum feed intake to be simulated.

The essential assumption is that potential growth in Bp follows a smooth, continuous path which can be described empirically by a growth curve. The Gompertz curve is chosen because it represents the available data better than alternative curves, because of its mathematical properties leading to derived allometric relationships for all body components and because its parameters, although largely empirical, can be visualised and estimated experimentally. A frequent error in growth modelling is to apply such curves to observed growth data without applying the caveat that environmental conditions must be non-limiting. Under limiting conditions there is no inherent reason why growth should be continuous or smooth with respect to time, nor follow any single empirical curve. Hruby et al. (1996) describe protein growth of modern broiler strains under putative non-limiting conditions created by choice-feeding. They found that the Gompertz curve described their data very effectively and was statistically superior to the other forms examined (logistic and polynomial). The parameters of the Gompertz curve can be estimated from suitable data sets on immature birds (see Hancock et al., 1995 for an example).

The definition of energy transactions in terms of ‘effective energy’ (Emmans, 1994) gives the model an important source of strength. In comparison with ME, effective energy (EE) takes account of diet composition (crude fibre, fat, digestibility) on energy utilisation. Few data sets are available to test the calculation of feed intake using the ideas of the effective energy system. Håkansson et al. (1978) present one set for broilers (see Emmans, 1994) which gives strong support to the theory. However use of these data to test the model is only partly justified since they were used by Emmans to quantify one of the parameters used in the prediction system. The turkey data in Figure 1 (Fisher and Emmans, 1992) provide a valid test of the system.
The idea that birds strive to achieve their potential is best examined by looking at changes in fatness following a change in diet composition. Gous (1995) described an experiment to test this aspect of the model at this meeting. A single result is shown in Figure 2. Birds were made fat or lean at 1kg by feeding low and high protein levels. A range of protein levels was then given to each group during a recovery period. It can be seen that the lipid content of the fat birds did not change greatly after 1kg, implying a much lower lipid content in the growth. The lean birds however showed increasing fat content. The fatness of both groups reflected the protein content given during re-alimentation but by 2kg both groups had the same lipid content when given a sufficient level of protein. These data are consistent with the theory used in the model that birds will strive to achieve an inherent body composition determined by their genotype.

(c) Validating the model: comparison with experiments

Comparison of model predictions with the results of experiments provides the most readily available method of evaluating a model. Logically all possible experiments of a given type should be tested but this is time consuming work and such an ideal has not been achieved. The examples presented here were selected because they were good experiments and described in the literature in sufficient detail. In preparing this paper no experiments have been rejected because they failed to show the model in a good light.

This type of comparison raises many complex issues and is subject to many difficulties both theoretical and practical. The main difficulties are: Firstly; the available description of the experiment will not contain all the information required by the model. Estimates must be used. Secondly; the observed performance may, unknowingly, be influenced by factors which lie outside the bounds of the model. In these circumstances calibration of model output simply to make them look like the experimental results is not justifiable. Thirdly; the performance of the birds may not, in fact, wholly reflect the variables that the experimenter thought were under control. This is probably a common feature of nutrition experiments. A special case is that factors that are held constant, especially the environment, may interact with the treatments being used; such interactions are not revealed by the experiment but may influence model calculations.
Such points are discussed below in the context of individual experiments. Comparison of the results of a lysine response study with model predictions is shown in two ways in Figure 3. In Figure 3A predicted performance across treatments is correlated with the experimental results. This type of comparison is widely used in modelling, especially when the variation in the real-world results is not subject to experimental control. The interpretation of such a comparison rests on the magnitude of the correlation and the goodness-of-fit to the line \( x = y \). Both these may be examined formally but the statistical testing of such hypotheses is the subject of considerable controversy (Thornton and Hansen, 1996; Colson et al., 1995). This will not be discussed here.

A less formal test is to compare the response to the experimental variables as observed and as predicted by the model. (see Figures 3B, C, D). This is more useful for the present purpose and this type of graph is mostly used in this paper. At this stage formal statistical comparisons have not been made although these could be devised, for example by comparing residual standard deviations.

(d) Amino acid response studies

Han and Baker (1993) describe responses to lysine level in broilers from days 22 to 43. The experimental results and their reproduction using the model are shown in Figure 3. For gain-over-food (FCE) there is a very close correlation between the observed and model results in both males and females (Figure 3A). The responses in FCE are also quite well reproduced, especially in males (Figure 3B). These results test those components of the model concerned with nutrient utilisation; these are generally strong. A more severe test is to look at the components of FCE separately as this requires that responses over time and ad libitum food intake are simulated.

In males the simulation of the growth response is quite successful (Figure 3C). Simulated birds are slightly larger at low lysine levels and, more significantly, show declining body weight at lysine levels above 0.8%. The pattern of food intake response described by the model is considerably different from the experiment, with higher intakes at low lysine levels and a much steeper decline at higher levels. In females there is a similar pattern of results but overall the comparison is less good than in the males (Figure 3D).

This experiment thus shows a reasonable agreement between the model and the experiment, but more importantly, it reveals the serious limitations of this type of test and also, what can be learned about nutrition experiments by using a model. In simple terms, the theory of the model envisages that the bird attempts to eat enough food to meet its lysine requirement. Thus at low lysine levels food intake will increase and the birds will be fatter. The model tries to analyse what factors prevent the bird eating enough food to reach its potential and, in general and in this case, the ability to lose heat will normally be the limiting factor. Han and Baker (1993) do not describe the environmental temperature used in this experiment. But the birds were kept in cages in a temperature controlled building and for the model exercise described here it was assumed that the effective temperature experienced by the birds was constant at 21°C. This assumption is quite critical but fine-tuning is not really worthwhile since the effective temperature experienced by a bird on deficient feed may be different from that on an adequate feed. The deficient bird will certainly be 'colder' and may well modify its behaviour, and thus the effective temperature, as a result. Such issues will profoundly affect the results obtained in an experiment, but they are usually ignored. It is difficult to see how they can be taken into account in an exercise of the kind being discussed here.
Figure 3 Responses to lysine in broilers aged 22-43d. Data from Han and Baker (1994). For simulation the model was calibrated to give similar growth rates in males at the lysine level which was just adequate. Birds were kept in cages and the room temperature was set at 21°C. Diets as described by the authors with some additional calculation. A. Correlation of observed and predicted FCE. B. Responses in FCE. C. Gain and food intake, males. D. Gain and food intake, females.

At the higher levels of lysine, where commercial decisions are likely to be made, this temperature effect will probably be quite small. However at these higher levels the model predicts reductions in food intake, and fatness, as lysine increases. As fatness reduces, the birds tend to become a bit smaller since maximum gain of other body components has already been reached (Figures 3C and 3D). These effects were not seen in the experimental data. Some approximate calculation of the response in terms of the fat-free body show that differences in fatness account entirely for the lack of agreement between the model and the experiment in this area of the response (these data are not shown here). The most likely explanation is that the experimental feeds became limiting in some other nutrient and the birds continued to eat for this in spite of having sufficient lysine. Such a nutrient may be another amino acid or a mineral or vitamin. The use of the model encourages the consideration of such possibilities and the improved design of experimental feeds.
(e) Responses to environmental temperature

The response of broilers to variations in environmental temperature presents the most severe challenge to modellers. Apart from cold-thermogenesis, which can probably be ignored in practice, heat is produced as a result of maintenance and activity, protein and lipid growth, digestion and nitrogen excretion (Emmans, 1994). Heat loss to the environment at a given effective temperature will reflect feathering, posture, blood flow, panting and so on. Effective temperature will be determined by factors such as radiant input, conductive losses, humidity, air movement and diurnal variations.

The integration of this complexity into a single model has made quite a lot of progress (e.g. Bruce and Clark, 1979) and is more widely applied in pig models (Moughan, et al., 1995) than in current broiler models. However whilst the modelling is feasible it has not been demonstrated that the considerable increase in complexity will lead to improved commercial predictions. Specifically the management of broilers at high temperatures, in excess of about 31°C, may be too complex to benefit directly from modelling.

The EFG Broiler Growth Model has a simple set of rules about the effect of temperature. A single effective temperature (and humidity) is provided as input for each day. Heat loss calculations take account of humidity, feathering, stocking density and are scaled for a given genotype and degree of maturity. Heat production calculations are based on the effective energy scheme (Emmans, 1994) and take account of a wide variety of factors. Specifically the model does not contain concepts of either physiological or behavioural adaptation by the bird to temperature and thus it is not a high temperature model. Limitation of heat loss is the most common factor determining food intake so the model reflects very sensitively the various inputs. Even with a simple set of rules model behaviour is often very complex in this area. Simulation of a temperature experiment is illustrated in Figure 4. Charles et al. (1981) studied post-brooding temperatures in the range 15-27°C and also used four dietary nutrient density levels and broilers of both sexes. The scatter diagram in Figure 4a shows that the overall correlation between observed and simulated responses was reasonably close. The overall pattern of response in FCE (Figure 4b) is also well reproduced by the model, given the complexity of this experiment. Separate consideration of growth and feed intake (data not shown) reveals that the response of both components to temperature is well predicted. However the response to diet composition is less successfully simulated.

Figure 4. Effect of temperature and diet nutrient density on broiler performance. Data from Charles et al. (1981); mixed sex broilers reared in environmental chambers to 49 days. The model was not calibrated to the data set.
The model predicted that the four feeds used would support rather similar growth rates with wide variations in feed intake. The birds themselves responded by keeping intake fairly constant across feeds but showing wide differences in growth. The possible reasons for this difference between the experiment and the model are legion and speculation is not really rewarding. However it should be noted that the predicted model response is consistent with most nutritional experiments of this sort (Fisher and Wilson, 1974) whilst this experiment showed an unusual pattern of response.

(f) **Responses to dietary energy and nutrient density**

Leeson et al. (1996a) describe two experiments in which dietary energy (Exp. 1) and both energy and protein (Exp. 2) were diluted with a mixture of sand and oat hulls. Extensive dilution, up to 50%, was used, so this experiment provides a good test for a simulation model. Comparison of experimental and model results is shown in Figure 5. In general there is good agreement between the two. Food intake tended to be overestimated by the model; this may have reflected factors such as temperature, feeding space or an overestimate of the feeding value of oat hulls or an underestimate of the moisture content of the sand. None of these factors was defined in the paper describing the experiment. The model predicted much larger responses in body fatness than were indicated by the data reported for abdominal fat pad weight (data not shown).

![Figure 5](image)

Figure 5. Effect of diet dilution on broiler performance (Leeson et al., 1996a). Diet compositions were recalculated to provide the information required by the model. The model was not calibrated to the data set. Left-hand figure; Exp.1 in which energy was diluted. Right-hand figure; Exp 2 in which both energy and protein were diluted.

A more classical energy-protein experiment was described by Pesti and Fletcher (1983). This provides a useful test because it involves an old genotype and thus illustrates the capacity of the model to deal with genetic change. Also a very narrow range of response was reported so the test is a precise one. The experimental and model predictions for FCE and body fatness are shown in Figure 6. For FCE the agreement is very close both in pattern and amplitude of response. For fatness there is less close agreement although part of the pattern is reproduced. In general the model sees adjustment of body fatness as a larger component of
response than the birds revealed. There are many possible reasons for this: temperature is not well defined and some features of diet design may also have influenced the actual experimental results.

The correlation of experimental and model results for the FCE data shown in Figure 6 was 0.904, being highly significant. For growth and feed intake considered separately the correlations were negligible. This again emphasises that the prediction of the rates of growth processes over time is much more difficult than predicting nutrient utilisation.

Figure 6. Response to energy and protein in broilers. Data from Pesti and Fletcher (1983). The model was adjusted to a 1970’s genotype (see Oldham et al. 1997) and diet compositions were re-calculated.

(g) Controlled feeding

Controlled or restricted feeding is becoming a common feature in the broiler industry in Europe and user control of intake is a necessary feature of the model. Since the prediction of the rate of intake over time is the most challenging problem tackled in the model it is to be expected that removal of this element will increase considerably the accuracy with which the model reflects the real world.

Leeson et al. (1996b) report experiments in which four dietary energy levels were fed either ad libitum or according to a controlled intake pattern. The effect of feed restriction on growth and feed intake is well represented by the model and Figure 7b suggests that the low feed intake (and hence high conversion) observed at the highest energy level when fed ad libitum might be an artefact. In all cases the response to energy is also well simulated. The overall effects of the treatments on feed conversion (Figure 7c) are very small and the small differences between the model and the experiment probably reflect only such issues as temperatures and feathering. The reduction in fatness with declining energy content was overestimated somewhat in the ad libitum fed birds with almost exact agreement under controlled feeding (Figure 7d). This emphasises that the difficult prediction is of feed intake over time and all the factors which affect it, whilst the close agreement under controlled feeding suggests that the rules for nutrient intake and the resultant partitioning are about correct.
(h) Using the model

This section on model use is included under the heading ‘Model Evaluation’ to stress the importance of continuing evaluation by the model user and of the scientific transparency of the model.

Experience has shown many applications of the EFG Broiler Growth Model. These range from it being used as a starting point in the development of ‘in-house’ models by large companies to a wide range of direct applications in broiler nutrition and production decision making. The most common use is alongside R & D programmes where a question is simultaneously addressed by the model and by an experiment. Such application is analogous to the retrospective analyses presented above and offers the following advantages over reliance on experiments alone. Firstly; there is much greater understanding about the interactions between the three components involved – genotype, feed and environment. These are all inevitably involved in the outcome of an experiment. Secondly; treatment options can be evaluated before the experiment starts, giving a better choice of treatments. Thirdly; probable underlying biological changes e.g. in body composition, can be followed in detail. Fourthly; assessment of a wider range of biological outcomes can easily be made, and fifthly; economic assessment of the results under different scenarios can be easily done.

For some types of decision the use of experiments may be either impossible or too constrained. The use of a model then has additional value. Some examples from recent experience illustrate this. 1. A broiler production company normally slaughtered large male birds at 55 days. With some frequency market conditions dictated a delay in slaughter of 7-10 days. How should the birds be fed during such a ‘holding’ period? Use of the model allowed a wide range of options to be tested. 2. A broiler company with no R & D facilities was able to re-direct policy on amino acid levels with great benefits. 3. Experiments on feeding programmes, i.e. the sequence and timing of feeds, are difficult simply because so many options are available and because interactions with other factors are likely to be important. An example of using the model is shown below. 4. Restricted or controlled feeding experiments are also very complex owing to the almost unbounded range of options concerning timing and degree of restriction. Unravelling this complexity with a model has had great commercial benefit.

Saleh et al. (1997) report a typical ‘feeding programme’ experiment. Starter feed was given for 7, 14 or 21 days and a finisher feed from 21, 28 35 or 42 days to broilers killed at 56 days. All 4x3=12 options were tested. The biological effects of the treatments were very small and reproduction of this experiment in the model is complex and not very easy. However the correlation result in Figure 8a suggests reasonable agreement between the experimental and model results. Figure 8b shows body lipid growth on the two treatments which gave the fattest (starter 0-14, finisher 21-56 days) and the leanest birds (starter 0-21; finisher 42-56 days). This additional information about the changes taking place during the experiment clearly enhances its value considerably. Economic calculation within the model allows the results to be assessed under different scenarios and for the assessment of the results to be made at different ages.

III. DISCUSSION

It seems to be important to develop modelling in the scientific community if progress is to be made. For this purpose models will have to be open. It is suggested here that developers of commercial models can both benefit, and make a more useful contribution to the poultry industry, if they take a similar approach.
It is not possible here to discuss the many areas where further development of both theory and modelling technique is required, nor to list the approaches which have been or might be useful. Undoubtedly a central problem in simulation modelling is the need to consider populations of birds rather than a single ‘average’ bird. The structure of the EFG Broiler Growth Model facilitates this in the way that genotypes are described (see Emmans and Fisher, 1986) and some examples are given by Gous (1997, in press). Similar issues in pig modelling have been discussed by Ferguson et al. (1997).

Figure 7. Restricted feeding and dietary energy level in broilers. Data from Leeson et al. (1996b). Model predictions made without calibration.

It is clear that different parts of any model will have different strengths. In the type of model discussed here the description of nutrient utilisation and growth, once intake is known, is relatively strong or ‘hard’. The prediction of food intake over time is much more difficult and presents more challenging problems.

Systems of broiler production are being developed in which real-time data on bird growth and feed intake are continuously available in addition to control of inputs. The creation of models to use such data and to provide sophisticated methods of optimising production in such systems should be a much simpler task than the one discussed here.

REFERENCES


Figure 8. A feeding programme experiment (Saleh et al., 1997). The left-hand figure shows the correlation between experimental observations and model predictions for body-weight (●), FCR (■), abdominal fat (▲), closed symbols refer to time of feeding the starter feed, open symbols time of feeding finisher feed. All data were scaled to a single treatment to facilitate presentation of the different responses. The right-hand figure shows the development of body lipid in model runs which emulate two of the treatments used.