Proceedings of the Arkansas Nutrition Conference

Volume 2022 Article 12

2022

Application of Simulation Modelling in Broiler Integration: Is it a Necessary Nutritional Tool?

Peter Chrystal
peter@completefeeds.co.nz

Recommended Citation
Chrystal, Peter (2022) "Application of Simulation Modelling in Broiler Integration: Is it a Necessary Nutritional Tool?," *Proceedings of the Arkansas Nutrition Conference*: Vol. 2022, Article 12.
Available at: https://scholarworks.uark.edu/panc/vol2022/iss1/12

Application of Simulation Modelling in Broiler Integration: Is it a Necessary Nutritional Tool?

Peter Chrystal[1]*

**Complete Feed Solutions, Sydney, NSW, Australia*

[1]Corresponding Author: P. Chrystal, peter@completefeeds.co.nz

Overview

Modelling techniques have been used in many industries globally to illustrate to others an understanding of the way processes work. Also, engineers and scientists employ models to predict the consequences of various courses of action. Simple pictorial models, such as the diagram of the chicken digestive system, are useful in education and may be more suitable than a photograph for the purposes of explaining how the animal converts ingested feed into components that can be assimilated, leaving residue that is excreted. Complex, predictive models seek to quantify a specified outcome based on defined inputs. Many attempts have been made over the past four decades to develop suitable growth performance response models for broilers. Broiler simulation models that have been developed, fall into two broad categories; firstly, empirical, stochastic models and, secondly, mechanistic, quantitative models that seek to represent the underlying mechanisms that produce end results. Whilst empirical models employ a series of equations derived from research observations to predict growth performance, they do not necessarily represent an understanding of the causal underlying mechanisms. The advantages of a robust mechanistic model allow the user to alter the response over time obviating the need for continuous experiments, required to constantly keep empirical models updated. Integrated broiler operations are surprisingly complex due to many variables requiring consideration and, must ultimately drive an objective function that maximises business profit per unit of broiler barn (or broiler shed) space over time. The EFG Broiler Model represents a mechanistic tool that predicts feed intake and growth response via a modified sigmoid Gompertz function, or growth curve. Although other mechanistic models are available, this paper will consider only the EFG model, as a proxy for good mechanistic broiler growth models. Thus, the purpose of this paper is to examine the application of the EFG model as an indispensable tool for broiler integrators and nutritionists.

Background

The term "mechanistic modelling" appears to have been introduced by Thornley and France (1984) nearly four decades ago. Mechanistic or causal models are preferred to empirical models because they are more likely to be robust and applicable to situations beyond the range of conditions tested in static, individual floor-pen trials (Morris,1983). Broilers respond to changes in dietary nutrients and the lowest feed conversion ratio (FCR) accompanied by maximum weight gain may not be the point at which maximum profit is realised. Thus, nutrient "requirements" cannot be defined for growing broilers for three important reasons. Firstly, the growth response to increasing input of any limiting variable is curvilinear. Secondly, this curve will change based on the potential output of the group of animals being considered and, thirdly, the position of the optimum on the curve will shift depending on input costs and revenue realised (Morris, 1983, Morris, 2006, Fisher, 2008, Gous, 2014). Formulating feed to fixed "requirements" is thus outdated and nutritionists need to integrate feed formulation into the management of the business to achieve a suitable commercial outcome (Azevedo et al., 2021a). Many nutritionists are reluctant to move to this dynamic, economics-based approach partly due to the difficulty associated with generating and updating required data. In the EFG Model and Optimiser, the factors to consider include the potential growth rate of the genotype, the nutrient content of the feeds offered and, the constraints placed on the bird by the environment and by the feed itself, which prevent them from consuming sufficient feed to grow at their potential (Gous, 2015). Whilst empirical models are useful and often as good as mechanistic models, the EFG mechanistic model is a valuable predictive broiler growth response tool, that includes economic assessments utilising fixed and variable input costs and finished product revenues. Modern broiler genotypes grow considerably more rapidly than those used decades ago (Vargus et al., 2020) and, Azevedo et al., (2021a) recently updated the response of two modern strains (Ross 308 and Cobb 500) of rapidly growing broilers to dietary balanced protein (BP). The equations generated were then used to determine the economic optimum (Azevedo et al., 2021b). Instructively, these authors demonstrated an increase in the margin difference between males and females when feed prices declined, or product revenue increased and *vice versa*. The optimum economic level of dietary BP was lowest for females and birds sold live compared with highest levels for males and birds sold as further processed. If the broiler integrator nutritionist can accurately predict the "basal" growth response of broilers using the EFG model, under the environmental conditions recorded and the feed offered, the optimiser can then be used to either minimise or maximise an objective function that includes margin over feed cost, margin/m^2/annum, cost per kg, N excretion, breast meat yield, body fat as a % of liveweight, liveweight gain or FCR (Gous, 2015). Arguably, for a broiler integrator, it is the economic objective functions that maximise either margin over feed cost or margin/m^2/annum that are most relevant. However, running the EFG optimiser is time-consuming and using the model function to address different "what if" scenarios require the nutritionist to formulate each feed prior to running the model. Australia and New Zealand's largest broiler integrator therefore requested a dynamic spreadsheet where dietary energy, standardised ileal digestible (SID) lysine (as a proxy for BP) or feed price could be changed providing instant outputs. Therefore, a range of diets, by feed phase (starter, grower, finisher and withdrawal) varying in apparent metabolizable energy, corrected for nitrogen excretion (AME$_n$) and/or BP were modelled and the output analysed using response surface methodology (RSM) to predict liveweight (g), liveweight gain (g) from zero to 50 days post-hatch, cumulative flock FCR (g food/g liveweight), European performance efficiency factor (PEF = livability$_{(\%)}$ × liveweight$_{(kg)}$ × 100 / FCR × flock age$_{(d)}$), cumulative feed intake (g), feed cost per kg liveweight, total cost/kg sold (flock), cumulative margin over feed cost and margin/m^2/annum. These data were transferred to an interactive spreadsheet whereby flock size, amounts of each phase of feed offered, with AME$_n$ and BP values for these phases and diet prices added. The spreadsheet model output predicts the deviations in growth response and associated economics for diets changed from the set that were in place at the time, or the "basal" diets.

Method

A total of 168 different wheat/soyabean-based, typical Australian diets (42 per phase) were modelled in EFG ranging from 11.92 to 13.18 MJ/kg AME$_n$ and 12.26 to 13.55 g/kg SID lysine for broiler starter; 12.03 to 13.29 MJ/kg AME$_n$ and 10.45 to 11.55 g/kg SID lysine for grower; 12.12 to 13.40 MJ/kg AME$_n$ and 9.12 to 10.08 g/kg SID lysine for finisher and 12.22 to 13.51 MJ/kg AME$_n$ and 8.55 to 9.45 g/kg SID lysine in withdrawal. Combinations included maintaining either a mid-point BP varying only AME$_n$, a mid-point AME$_n$ varying only BP, a range with fixed AME$_n$:BP ratios and a fourth set varying AME$_n$ from lowest to highest accompanied by BP from highest to lowest levels within the range described previously. The BP amino acid profiles applied were those recommended by Rostagno et al., (2017). Amounts of each phase offered were 500 g/bird of broiler starter crumble, 1200 g/bird broiler grower pellet, 2000 g/bird broiler finisher pellet and the balance as broiler withdrawal pellet. A single temperature profile was used starting at 34℃ declining gradually to 22℃ by day 35 then maintained at this temperature. Mean daily relative humidity was gradually increased from 60 to 85% from zero to 50 days post-hatch. Ross 308 fast feather (not feather sexable) male growth parameters used were 7.50 kg mature empty body mass at 0.043 rate of maturing per day and 14% mature body fat content. Three cropping schedules were selected ranging from 100% dressed at day 32 (25% of the flock); 80% dressed at day 38 and 20% further processed (30% of the remainder of the flock) followed by 30% dressed and 70% further processed at day 50 for the balance of the flock. Fixed, variable input costs and typical Australian revenues for chicken were used and data was modelled for a flock of 10000 as-hatched broilers weighing 44 g at day-old.

Modelled output data was analysed in JMP® Pro 16.1.0 (SAS Institute Inc. JMP Software. Cary, NC, 2021), surface plots generated within each dietary phase offered and an overall weighted average for zero to 50 days post-hatch established. Equations generated in JMP® Pro were utilised withing Excel (Microsoft® Office, Office 16) to create a custom empirical model. Only data from the overall model will be reported for the purposes of this paper, however. All costs are shown in Australian dollars (AUD) and the average conversion rate from AUD to United States dollars (USD) was 0.70 in July 2022.

Results

Liveweight and liveweight gain prediction

Prediction equations for liveweight and liveweight gain (g) differed only within the constant term (intercept) by liveweight of the day-old broiler (44 g). All terms used in the prediction equations were significant ($P < 0.05$, $r^2 = 0.81$) and equation details are shown in Table 1. Predicted response surface for weight gain was maximised at the highest weighted average dietary SID lysine but only when accompanied by the highest AME_n modelled. At the lowest AME_n, there was a negative response to increasing SID lysine but the range in liveweight was only in the order of 2.6% (101 g/bird) to 3.9 kg's empty body weight at 50 days post-hatch (Figure 1).

Table 1 Parameter estimates for predicted formulae response surface graphs for broiler growth performance and economic assessments across variable standardised ileal digestible (SID) lysine (g/kg) and nitrogen corrected apparent metabolizable energy (AME_n, MJ/kg) from zero to 50 days post-hatch on a flock size of 10000 as-hatched broilers.

	Weight gain (g/bird)		Feed intake (g/bird)		FCR (g food/g lwt.)		PEF[2]		Feed cost (per kg lwt.)		Total cost (per kg (flock))		MOF[3] (AUD)		MOT[4] (AUD)	
Variables[1]		P-value		P-value		P-value		P-value		P-value		P-value		P-value		P-value
Intercept	3336	< 0.0001	12158	< 0.0001	3.278	< 0.0001	-12.09	0.450	0.189	0.031	3.208	< 0.0001	62491	< 0.0001	22676	< 0.0001
First order																
X_1	61.21	< 0.0001	-133.1	< 0.0001	-0.061	< 0.0001	21.31	< 0.0001	0.061	< 0.0001	0.018	0.050	-386.3	0.068	-386.1	0.068
X_2	-265.4	0.0002	-3638	< 0.0001	-0.792	< 0.0001	170.8	< 0.0001	0.214	0.001	0.029	0.791	5509	0.040	5513	0.040
Interaction																
X_1X_2	387.3	0.011	-110.1	0.622	-0.161	0.027	97.58	0.0005	-0.050	0.717	-0.408	0.111	10749	0.077	10749	0.077

[1] X_1: AME_n; X_2: SID lysine (balanced protein)

[2] European performance efficiency factor

[3] Margin over feed cost (Australian dollars)

[4] Margin over total cost

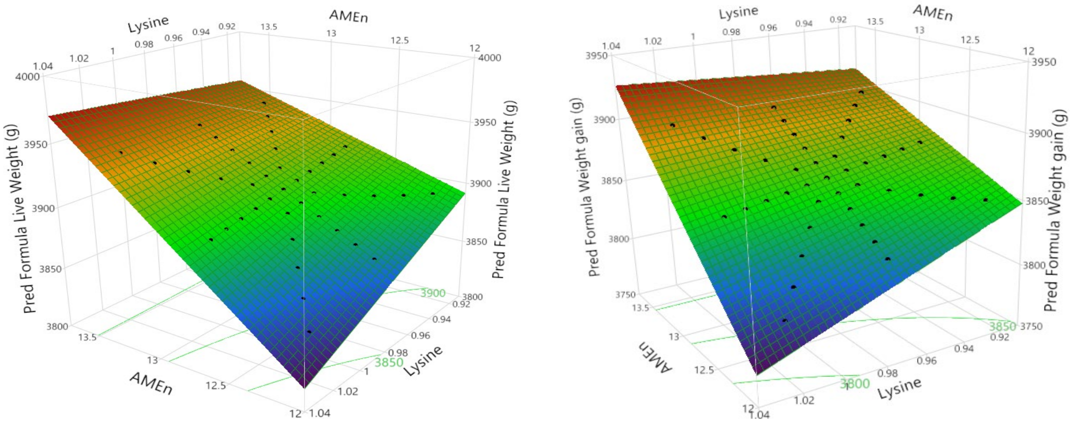

Figure 1 Influence of standardised ileal digestible lysine (g/kg) and nitrogen corrected apparent metabolizable energy (AME$_n$, MJ/kg) on liveweight and liveweight gain (g) with EFG modelled diet combinations depicted as dots on the respective surfaces.

Feed intake and feed conversion ratio (FCR)

Cumulative feed intake was influenced to a greater extent by changes in SID lysine compared with changes in AME$_n$ over the range modelled ($P < 0.0001$, $r^2 = 0.98$). However, the influence of changing SID lysine or AME$_n$ was similar for FCR ($P < 0.0001$, $r^2 = 0.81$). The parameter estimates are shown in Table 1 and the generated response surfaces in Figure 2.

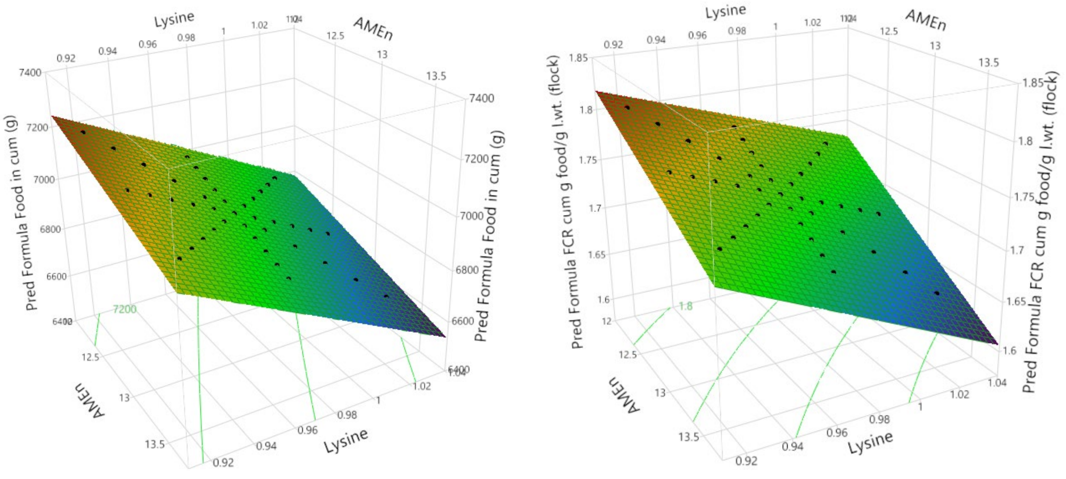

Figure 2 Influence of standardised ileal digestible lysine (g/kg) and nitrogen corrected apparent metabolizable energy (AME$_n$, MJ/kg) on feed intake (g) and flock feed conversion ratio (FCR, g food/g liveweight, flock) with EFG modelled diet combinations depicted as dots on the respective surfaces.

European performance efficiency factor (PEF)

PEF was influenced by both AME$_n$ and SID lysine and AME$_n$ by SID lysine interaction ($P < 0.001$, $r^2 = 0.95$). However, the constant term, or intercept, was not significant ($P = 0.450$) although its influence on the predicted final PEF would be low since it is a small number. The equation parameter estimates are shown in Table 1 and the surface response is shown in Figure 3. The highest PEF response was at a combined maximum AME$_n$ and SID lysine modelled.

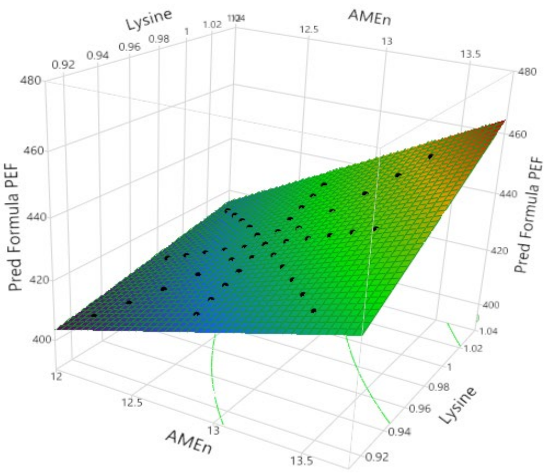

Figure 3 Influence of standardised ileal digestible lysine (g/kg) and nitrogen corrected apparent metabolizable energy (AME$_n$, MJ/kg) on the European performance efficiency factor (PEF) with EFG modelled diet combinations depicted as dots on the predicted response surface.

Feed and total cost per kg

Feed cost (AUD) per kg liveweight was influenced independently by the parameter constant, AME$_n$ and SID lysine ($P < 0.05$, $r^2 = 0.81$). However, there was no interaction between AME$_n$ and SID lysine on feed cost per kg liveweight. In contrast, only the intercept constant parameter and AME$_n$ had any influence on total cost (AUD) per kg sold over a 10000-broiler flock accompanied by a poor correlation coefficient ($r^2 = 0.15$) for the whole model (Table 1). Interestingly, the highest predicted feed cost/kg liveweight was at the highest dietary AME$_n$ and SID lysine whilst the highest total predicted cost/kg sold for the flock was at the highest AME$_n$ and the lowest SID lysine modelled (Figure 4).

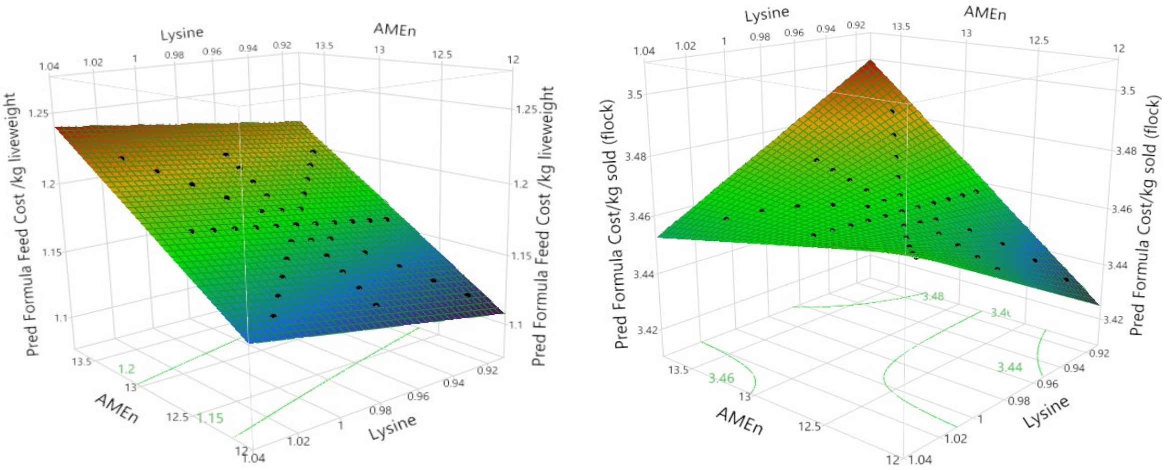

Figure 4 Influence of standardised ileal digestible lysine (g/kg) and nitrogen corrected apparent metabolizable energy (AME$_n$, MJ/kg) on feed cost per kg liveweight in Australian dollars (AUD) and total cost per kg sold for the flock (AUD) with EFG modelled diet combinations depicted as dots on the respective surfaces.

Margin over feed cost and per unit of shed space over time

Margin over feed (MOF) cost (AUD) and margin over variable or total cost in the EFG model output are effectively parallel curvilinear responses (Figure 5) since both economic assessments include revenue and the same variable feed and/or other costs associated with selecting an objective function of MOF or margin/m^2/annum. The EFG Model presents the data on a cumulative flock basis even when the objective function used is per unit of floor space (m^2) over time.

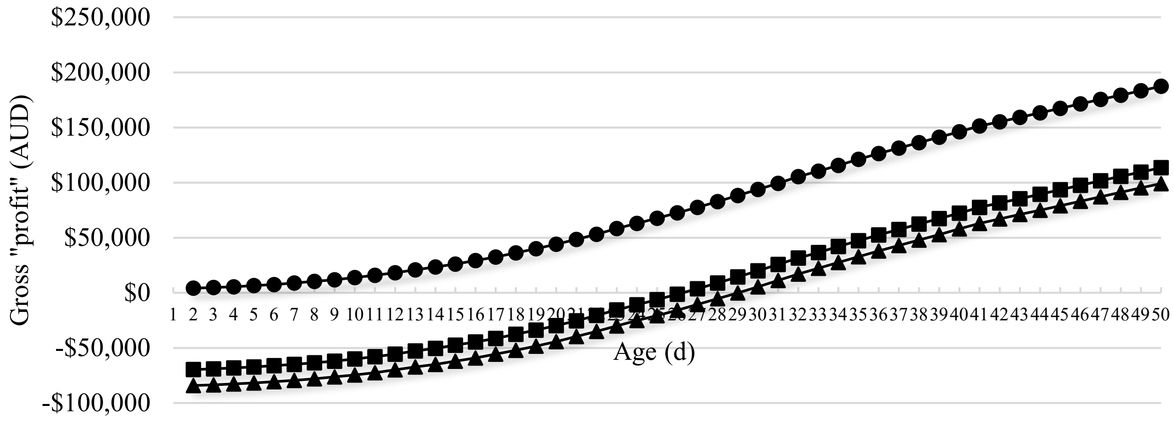

Figure 5 EFG Modelled economic assessment in cumulative Australian dollars (AUD) over a 10000-broiler flock placed (as-hatched) from 1 to 50 days post-hatch, with income minus feed cost (●), income minus feed plus variable costs (■) and income minus total costs (▲).

Since the margin over cost lines are parallel, the parameter estimates for margin over individual costs have the same probabilities. Only the parameter estimates for the intercept (or constant) and SID lysine influenced MOF and margin over total costs ($P < 0.05$). However, the model prediction for maximum profit would be influenced by both the cost of dietary energy and BP and a contour plot of MOF suggests this is highest in the top right quadrant whilst the true maximum MOF is at the weighted average SID lysine and AME_n indicated by the blue arrow in Figure 6. The predicted whole modelled MOF (JMP® Pro) compared with EFG simulated MOF was significant ($P = 0.018$) but the correlation was poor ($r^2 = 0.22$).

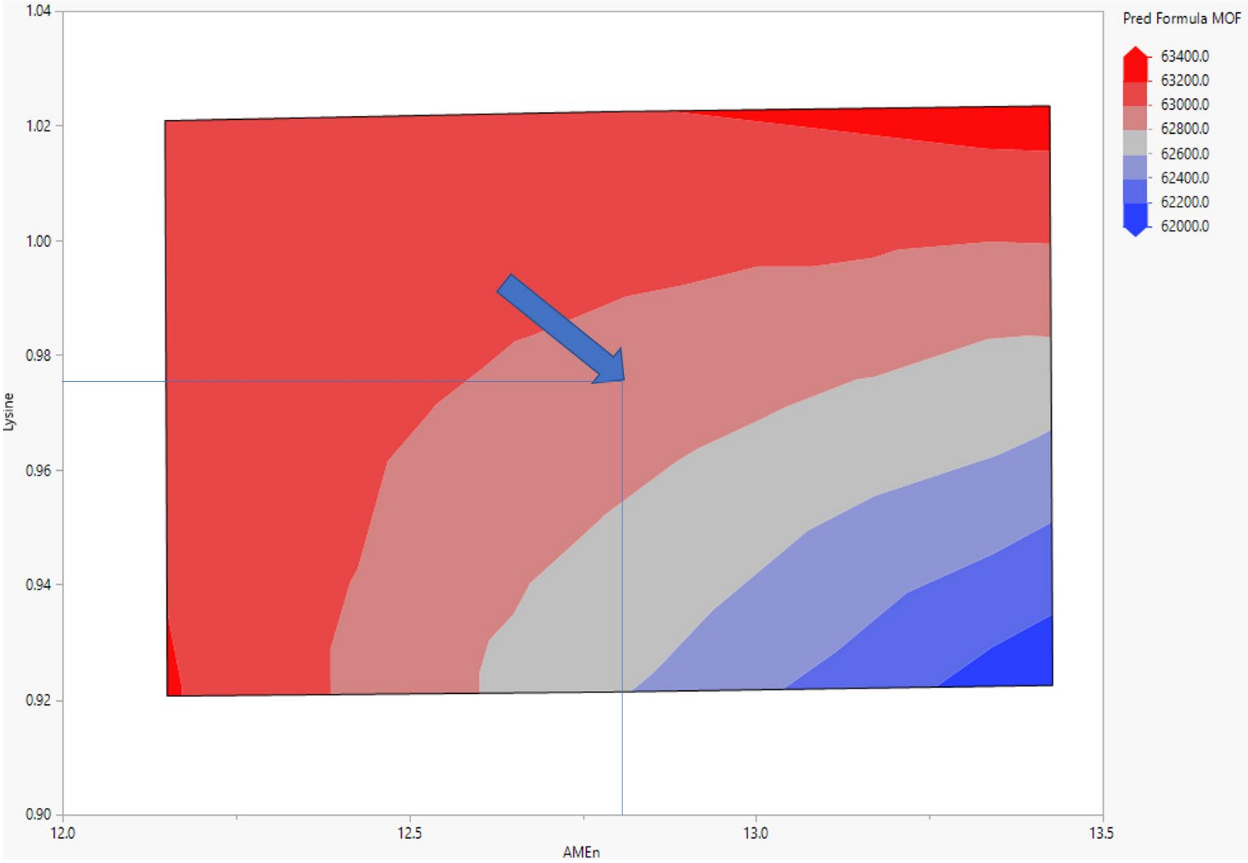

Figure 6 Maximum margin over feed cost (MOF) is at a weighted average standardised ileal digestible (SID) lysine and nitrogen corrected apparent metabolizable energy (AME_n, MJ/kg) indicated by the blue arrow, overlaid by the contour plot of the predictive equation revealing highest MOF at highest nutrient density.

Implications and conclusions

The initial limitation to construction of a rapidly predictable spreadsheet model is responses are confined to the limits in dietary energy and BP simulated. Extrapolation of responses beyond simulated values are fraught with danger and this limits the use of a spreadsheet model. Furthermore, predicting growth performance and economics is more complex than one can capture within a spreadsheet due to the numerous possible combinations of dietary energy, BP and economics.

For EFG modelled liveweight and liveweight gain, despite statistically significant parameter estimates, the data points in the leverage plots reveal that responses to both AME_n and BP are not linear. Weight gain increases with increasing dietary energy reaching a maximum around 13.1 MJ/kg thereafter declining and, AME_n levels were not simulated above 13.5 MJ/kg. This effect can be partly addressed by creating many different equations and applying these at the points where responses change. However, the response to BP is dependant on dietary energy level and, whilst the residual values within the predictions are small, the shape of the EFG modelled data cannot be fully captured within a spreadsheet.

Unsurprisingly, predicting feed intake from changes to AME_n and BP was accurate to within 0.58% (40g on 6910g total feed intake) but this was within a set temperature and humidity profile and relatively narrow ranges of feed bulkiness as measured by water holding capacity that ranged from 2.641 to 2.915 g water/g diet. The generated JMP® Pro data for FCR was accurate to within 0.9 % representing a maximum deviation of 1.5 points of FCR from the 1.730 modelled average. Generated PEF prediction equations were also representative of the EFG modelled output and accurate to within 1.17% (maximum 5 index points from the mean = 426).

The cost of diets formulated in WinFeed (within the EFG model) for differing levels of dietary energy and BP were accurately predicted from equations generated by JMP® Pro. However, these are static prices based on a point in time rather than allowing continuous updates of pricing. An approximation of pricing differences by converting static prices into relative percentage ranges allowed a more dynamic approach to actual diet cost changes. The assumption, by necessity, is that the relative changes in raw material cost remains constant for dietary energy and BP and this does not happen in practice. The total cost per kg sold on a flock basis and MOF could not be reliably predicted through generated equations. Two main reasons are firstly, there is a range of total cost and resultant MOF at each level of BP, based on the dietary energy and *vice versa* and, secondly, the point of maximum MOF is not static and will move based on total cost and product revenue. Additionally, whilst the lowest total cost/kg for the flock is accompanied by the highest MOF, the parabolic shape of these curves is defined by the individual data points selected during optimisation and thus cannot be readily defined by equations. Therefore, a “rapid” spreadsheet empirical model to calculate broiler growth performance for a broiler integrator with a given set of dietary and environmental parameters is possible but, calculating the MOF with any degree of certainty can only be done within the model itself due to the numerous variables that drive a mechanistic model. In conclusion, combining nutrition with the dynamic goal of the business to maximise profit margin is essential for any broiler integrator and, a reliable mechanistic model such as the EFG Model and optimiser is an indispensable nutritional tool in this endeavour.

Literature Cited

Azevedo J. M., M. P. Reis MP, R. M. Gous RM, B. B. Leme BB, J. C. P. Dorigam and N. K. Sakomura. 2021a. Response of broilers to dietary balanced protein. 1. Feed intake and growth. Anim. Prod. Sci. 61:1425-1434. doi:10.1071/AN20655

Azevedo J. M., M. P. Reis MP, R. M. Gous RM, B. B. Leme BB, J. C. P. Dorigam and N. K. Sakomura. 2021b. Response of broilers to dietary balanced protein. 1. Determining the optimum economic level of protein. Anim. Prod. Sci. 61:1435-1441. doi:10.1071/AN20655

Fisher C. 2008. Improving nutrition through modelling. Pages 20-32 in 27th Annual WPSA Scientific Day (World Poultry Science Association: Pretoria, South Africa)

Gous, R. M. 2014. Modelling as a research tool in poultry science. Poult. Sci. 93: 1-7.

Gous, R. M. 2015. A model to optimise broiler productivity. Pages 175-187 in Nutritional Modelling for Pigs and Poultry. Eds N. K. Sakomura, R. M. Gous, I. Kyriazakis, L. Hauschild. CABI: Wallingford, UK.

Morris, T. R. 1983. The interpretation of response data from animal feeding trials. Pages 2-23 in Recent Advances in Animal Nutrition – 1983. Butterworths, London.

Morris, T. R. 2006. An introduction to modelling in the animal sciences. Pages 1-5 in Mechanisitic Modelling in Pig and Poultry Production, Eds, R. Gous, T. Morris and C. Fisher. CABI: Wallingford, UK.

Rostagno, H. S., L. F. T. Albino, M. I. Hannas, J. L. Donzele, N. K. Sakomura and F. G. P. Costa. 2017. Brazilian tables for poultry and swine. UFV: Vi¸cosa, Brazil.

Thornley, J. H. M. and J. France. 1984. Role of modelling in animal research and extension work. Pages 4-9 in Modelling Ruminant Nutrition, Digestion and Metabolism. Proc.2nd International workshop. Eds R. L. Baldwin and A. C. Bywater. University of California Press. Davis, California.

Vargas L., N. K. Sakomura, B. B. Leme, F. Antayhua, M. Reis, R. M. Gous and C. Fisher. 2020. A description of the potential growth and body composition of two commercial broiler strains. Br. Poult. Sci. 61:266–273. doi:10.1080/00071668.2020.1716300