Optimising the feeding of commercial broilers

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Abstract

Optimising the feeding of commercial broilers during their growing period is made difficult because of the many interacting factors influencing the growth and food intake of these birds. Not all broilers are the same, nor are the environments in which they are housed, and the costs of feeding and the revenue derived from the sale of the product differs markedly from one locality to another. When making decisions about how to maximise some economic index, such as margin/m^2 annum or breast meat yield in a commercial broiler operation, all of these interacting factors should be considered simultaneously. This is now possible, using optimisation techniques, but only if food intake can be accurately predicted.

The basis of such an optimisation process is that the optimiser passes suggested feeds or feeding schedules to a feed formulation program, which produces a least-cost feed and passes this on to a broiler growth model that, in turn, evaluates the suggested feeding programme. By following certain rules the optimiser continues to alter the specifications for the feeds and/or feeding programme until no improvement can be made in the objective function. Without an accurate prediction of the amount of food that a given broiler will consume in the given environment, such an optimisation process is bound to fail. The broiler growth model described here predicts food intake accurately under most circumstances that would be experienced in a commercial broiler operation, making it possible now to optimise the feeding programme of commercial broilers under a wide range of biological, environmental and economic circumstances, using many different objective functions.

Introduction

Commercial broiler production is all about making decisions, and then implementing those decisions, the objective in most cases being to maximise profit for the enterprise. A decision is a choice between alternative courses of action, and is made by weighing up the consequences of those courses of action. The process of decision making is one that everyone practices every day: identify the problem; evaluate alternative courses of action; choose the most appropriate on some or other basis; implement the decision; evaluate the consequences; and repeat the cycle. In order to do this effectively, we need to be able to predict the consequences of these alternatives. There is a common belief that experience and/or experiments are an accurate means of predicting the consequences of different courses of action, but this is not the case. It is necessary to have an accurate theory in order to make the right decisions.

Experience is a poor predictor of performance in broiler production, simply because the broiler genotypes with which we work change each year. In Table 1, the time that it has taken a broiler to reach 1.8kg in liveweight, and the amount of food that has been needed per kg gain, are given for each decade over the past 50 years. There can be no doubt that experience with the broiler that was reared even ten years ago can be of little benefit when rearing the broilers of today.

Table 1. *Changes in the performance of broilers over the past 50 years.*

Period	Days to 1.8kg	Food per unit gain
1950	84	3.25
1960	70	2.50
1970	59	2.20
1980	51	2.10
1990	42	1.93
2000	36	1.55

The performance characteristics given in Table 1 are easily measured, and clearly show the remarkable rate of improvement in broiler performance in the past 50 years. Not as easily measured are the changes that have taken place as a result of selection by the primary breeding companies for improved food conversion efficiency, reduction in body lipid content, and increase in breast meat yield. These selection criteria have changed the broiler in subtle ways that are difficult to measure, and the effects are almost impossible to separate from the general improvement in performance, yet they have a profound effect on the way in which the broiler should be fed to maximise performance and efficiency. Most broiler producers would largely be unaware that such changes have taken place, especially if they have continued to make use of technology that suited the performance of broilers one to three decades ago.

The traditional approach to predicting performance has been to carry out experiments in which different nutrient contents are fed and the outcome is resolved. That this has been successful in broiler production is self-evidently true. 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 do not provide a general resolution of the problem. The Degussa Corporation (1995), using collected experimental data as described by Rodehutscord and Pack (1999) has produced a model (Amino Chick) for calculation of economically optimum lysine and methionine + cystine contents. 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 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.

The major problem with the use of experiments in attempting to predict performance is that there are so many variables that influence the performance of a broiler. Each time an experiment is conducted, different conditions prevail in the research facility, and different genotypes are used. Because we are interested in the interaction between the birds, the environment and the feed and feeding programme used, extremely complex experiments would be needed to test all combinations of these factors. And then, because of the changes that take place in the genotypes themselves, these experiments would have to be repeated at regular intervals in order to measure the changes in these interactions. The purpose of experiments should be to measure the numbers that will make a theory work, or to test the theory, or to allow us to choose between two theories, i.e. experiments should be conducted only once a theory or an hypothesis has been proposed.

Amino acid requirements of broilers are invariably estimated from the results of experiments in which broilers of a given age have been offered diets containing graded supplements of the amino acid under study. The concentration of amino acid in the diet producing the maximum growth response 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 preferred method by some nutritionists and committees. The resultant requirement is expressed as a fixed concentration in the diet, ideal for constructing tables of requirements and for least-cost formulation of feeds. But it is impossible to apply an accurate cost/benefit analysis to such numbers.

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. In fact, little, if any, notice has been taken of the changes that have been made to broiler genotypes, even though these have been extremely impressive. It is assumed by most nutritionists that faster-growing broilers would exhibit a higher food intake, which would compensate for the lower-than-required amino acid content of the diet. But Morris and Njuru (1990) have demonstrated convincingly that this does not always happen.

Fisher *et al.* (1973) showed that there was an advantage in seeing the requirements of animals as variable, dependent on the marginal cost of the amino acid and the marginal returns of the product. Prediction equations could then be used to determine the optimum amino acid intake for a given set of economic conditions. In spite of a general acceptance of the theory that requirements for amino acids should not be seen as being fixed, the tendency remains to do so.

The major reason for this apparent reluctance to move from the outdated and inaccurate system to the 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 different nutrient concentrations and energy-to-protein ratios on food intake, carcass composition and protein gains; the effects of differences between genotypes in the amount of excess energy that may be stored as body lipid, and the maximum rate at which this can take place; the effects 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 the birds from consuming the necessary amount of a feed to grow at their potential.

It is only through the development of a plausible theory, and the advent of computers, that it has been possible to integrate all of these factors into a workable form. It is now possible to predict voluntary food intake, and this has opened up a number of opportunities that were not available previously to nutritionists, geneticists and producers wishing to make the broiler production enterprise more efficient and profitable. In fact, there is no defensible way of estimating the nutrient requirements of growing animals, or of optimising the feeding of broilers, other than by the use of simulation models.

An overview of a theory of growth and voluntary food intake

Describing the genotype - Potential growth rate

In order to predict food intake it is necessary to have some view on what a bird or an animal is attempting to achieve when faced with a given food. Emmans (1981) suggested that broilers attempt to grow as fast as possible, and in such a way as to reproduce as early and as efficiently as possible. Based on this premise, it is necessary to know the potential growth rate of a broiler before a theory of food intake can be applied. But predicting the performance of animals is a general problem in animal production, the solution depending, in part, in being able to describe the animals adequately (Emmans and Fisher, 1986). In the past there has been neither consensus nor any general discussion in the literature on methods of defining genotypes that would allow similarities and differences between animals to be compared. However, with the advent of simulation models for describing the growth and food intake of animals, an adequate description of the genotype has become essential.

Poultry scientists and producers often misunderstand the concept of potential growth rate. It is not the maximum growth rate that can be achieved by a flock of broilers of a given genotype under commercial husbandry conditions, but the maximum growth rate that the genotype can possibly achieve when given perfect nutritional and husbandry conditions. The carcass composition of a bird grown under such conditions would reflect the genotypic composition of the bird, unaltered by external factors - this being particularly important in respect of the lipid content of the bird, which is significantly influenced by deviations from a perfect feed, feeding strategy and environment.

The approach suggested by Emmans (1989) to describe and evaluate different genotypes begins with a definition of potential protein growth, and the live weight of the animal is built up from this, using the allometric relationships that exist between protein, water, ash and lipid, i.e. a bottom-up approach. He has shown that a few, simple, assumptions can lead to a description of an animal that is sufficient for predicting its performance in non-limiting conditions and for calculating what these conditions are. It seems sensible to be able to predict performance in non-limiting conditions before the more difficult question is tackled, namely, that of defining growth in limiting conditions.

Values for the genetic parameters that define an animal can be measured by rearing animals in environmental conditions that are as near to ideal as possible. Under these conditions, growth curves are obtained which represent the genetic potential for a particular genotype. The growth curves obtained in this way allow comparisons to be made between breeds and strains. Examples of such investigations are in Hancock *et al*. (1995), and Gous *et al*. (1999).

Predicting nutrient requirements

For a model of growth to be successful it must be able to calculate the nutritional and environmental requirements of the bird that are needed for potential growth, and it must be able to predict the consequences of deviations from these optimum conditions. A growing animal needs to be supplied with nutrients in order to meet the requirements for maintenance of the body and for the growth of all other components of the body, including feathers. The resources needed to meet these requirements can be determined from knowledge of the growth rate and composition of the various components of the body. The resources available for supplying these requirements, which are present in various feedingstuffs, need to be described in the same terms as are used to describe the nutrient requirements.

The requirement for protein depends on the amino acid composition of that protein and the rate at which it is being produced. The sum of each amino acid required for the maintenance and the growth of feather and of body protein constitutes the daily requirement for each of the amino acids. The retention of lipid, water and ash has no protein requirement. The scale on which the amino acids required by the animal are measured, and on which the amino acids in the feed are described must be the same. The conventional wisdom is to express this in terms of digestibility. The marginal efficiency with which the first limiting amino acid is used for protein retention above maintenance is not necessarily constant, but can be modified by the supply of other amino acids and by the supply of energy. An accurate theory would take these factors into account.

Emmans (1984) has shown that the metabolizable energy (ME) scale is not a sufficiently accurate means of describing the energy content of a feedstuff. The ME scale is unable to differentiate between the efficiency of utilization of the energy emanating from the three digestible components of protein, lipid and carbohydrate, nor does it take account of the effect of indigestible organic matter on the energy available to the animal from the diet. The energy scale proposed by Emmans (1984) to take account of these deficiencies in the ME system is known as the effective energy (EE) scale and is the preferred energy system to be used in simulation modelling.

Predicting voluntary food intake

The implication from the above discussion is that an animal has requirements for certain resources that it needs in order to maintain its current state and to grow according to its growth plan. Because the animal is motivated to grow at this potential rate, the acquisition of food as a means of obtaining the required resources becomes a priority. Appetite can be seen to be dependent on the nutrient requirement of the animal and the content of those nutrients in the food (Emmans and Fisher, 1986).

In order to predict how much food the animal will consume when given *ad libitum* access to a food, it is necessary first to be able to predict the rate of intake on a balanced food in a thermally neutral environment. This rate of intake is termed the desired food intake (Emmans and Fisher, 1986) and is that which will allow the potential growth rate to be attained. Because the animal is assumed to eat to satisfy its requirement for the first limiting feed resource, food intake would be expected to deviate from the desired intake when the food is imbalanced in some way or if the animal were placed in an unfavourable environment. In the case of a marginal deficiency of an essential nutrient the animal may be capable of consuming sufficient of that imbalanced food to grow to its potential, but as the deficiency was made more severe, protein growth would fall below the potential. The inability of the animal to eat sufficient of such an imbalanced food is due to the constraints of feed bulk, and the inability to lose to the environment the additional heat that would be produced if more food were consumed. This theory of food intake is explained comprehensively by Emmans and Fisher (1986).

The most important consequence to the commercial broiler producer of providing broilers with a feed marginally deficient in an amino acid is that the bird will overconsume energy in an attempt to obtain sufficient of the limiting resource, and this energy will be deposited as lipid. It has been shown that broilers exhibit statistically significantly higher feed conversion efficiencies and lower lipid contents when higher concentrations of amino acids than are conventionally used in the broiler industry are included in the feed (Gous *et al*., 1990).

As the potential growth rate of broilers is increased by genetic selection, so the daily amino acid and energy requirements of the bird are increased, but these do not increase in the same proportion. The amino acid requirements increase proportionately faster than does the energy requirement, thus a higher amino acid to energy ratio is required as the rate of growth of broiler strains is increased. This was well illustrated by the results of an experiment by Morris and Njuru (1990) in which diets of increasing protein content were fed to broilers and laying-type cockerels. The maximum gain in weight and in protein content in the cockerels was achieved on diets with considerably lower protein contents than was needed to maximise the gain in the broilers.

Dealing with the environment

The rate of intake of a given food by a given type of bird in a given state will depend on the temperature of the environment in which it is kept. Emmans and Fisher (1986) have suggested that the heat loss of the bird varies in some way with the temperature of the environment, and as the ability of the bird to store heat is effectively zero, its rate of heat loss must equal its rate of heat production. The environment clearly places an upper limit on the amount of heat that a bird can lose to the environment and this has important consequences in the design of feeds for fast growing broilers. As the rate of growth of broilers has been improved, so the environmental temperature at which they would be comfortable has been reduced, although this constraint on the potential growth rate of modern fast-growing broilers has largely been ignored.

Heat production will increase as food intake increases providing that, at all intakes, the environment is thermally neutral. It follows that the temperature of the environment that is thermally neutral will decrease as the rate of food intake increases. Food intake is predicted to increase as the feed content of a limiting nutrient is decreased, so the growth rate, which defines the requirement, and the composition of the feed, which determines the desired food intake, interact to define the temperature that will be thermally neutral for the bird at that time. Feeds with a low nutrient to energy ratio will cause the thermoneutral temperature to decrease. The calculations involved in determining the consequences of these interactions are complex and therefore benefit from well-constructed simulation models.

Optimising the feeding programme for broilers

The optimum feeding programme for broilers is that which results in the highest profit for the enterprise. Determining the optimum nutrient density, the optimum concentrations of amino acids relative to energy in each feed, and the optimum length of time that each feed should be fed, is therefore an economic decision.

The information required for optimisation consists of feed costs at different levels of amino acid provision, 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 profit of the broiler grower is to be maximised 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, rejects etc.) and further processing (carcass composition) will need to be defined. Mack *et al.* (2000) emphasised the importance of broiler Companies 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. Consider some of the procedures that would be necessary in optimising a feeding programme. It would be necessary to determine the potential growth rate and potential degree of fatness of the birds to be fed; the distribution of potential growth rates (greater when mixed sexes are used); the environmental conditions that could be provided, and the cost of altering the prevailing conditions; the costs of a range of feeds differing in nutrient density at each given energy-to-protein ratio; the cost of mixing and then transporting these feeds to the production site (which would place an upper limit on the number of feeds that could be considered in any production cycle). Consider then that the birds can adjust their intake of a given food to an extent, this being limited by the environmental conditions; that the effect of feeding a relatively low quality food initially can be compensated for at a later stage if the conditions are such that the bird can either consume more food later, or draw on lipid reserves, thereby exhibiting an improved feed conversion efficiency. Consider, too, that the amount of lipid in the gain is of importance to some producers, but not to others; and that the length of the production cycle can be altered considerably by the use of different feeding programmes. It becomes clear that it is naive to imagine that any one, or even any series, of experiments could begin to address the question of defining the optimum feeding. Only with the use of an accurate simulation model could such an optimisation be contemplated.

A new approach to optimisation

An optimisation tool has recently been developed 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, shown in Figure 1, is very simple. The optimiser defines nutritional constraints for practical broiler feeds. These are passed to the feed formulation program where the least-cost feed that meets these constraints is determined. The characteristics of this formulated feed are then passed, as input, to the broiler growth model. The performance expected from this feed when given to a defined flock of broilers in a given environment is predicted by the model, and this 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 can 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.

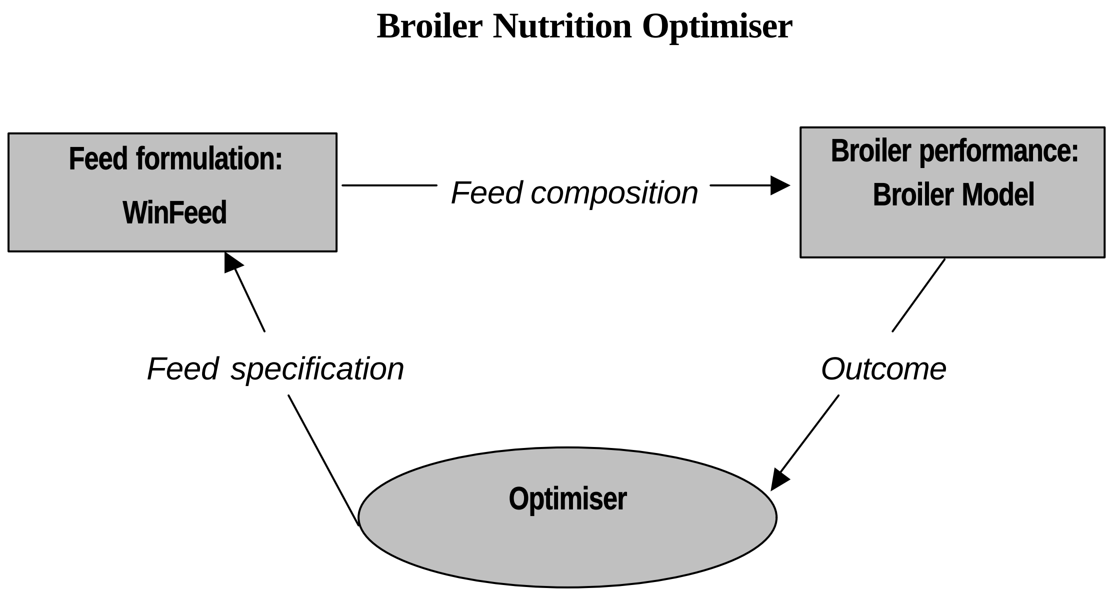

Figure 1. *Flow of information in optimising the feeding programme of a broiler chicken*

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 customised 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. 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 the calculations shown in Figure 1, is embedded in the windows-based 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 contents in each feed, given a 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 the 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. In the present versions of the program both amino acid and energy contents are optimised simultaneously, although the user may fix either of these, thereby increasing flexibility.

Optimising nutrient density

Given that 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, may be considered by the user in determining the optimum nutrient density of each of the feeds in the programme.

Optimising the feeding schedule

Many broiler producers do not have the opportunity of having feeds mixed according to their specifications, but are constrained to make use of proprietary feeds. 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.

Results

Development of this computer program is still in its final stages and it is not possible to present an analysis of optimum amino acid levels for broiler production under any specific circumstances. However some illustrations of the use of the program may be given. For this purpose the three different optimisers were used to illustrate the effects of changes to different variables on the optimum feed composition or feeding schedule. Birds were reared to 42 days in all cases, and revenue was generated on a liveweight basis only. Feed ingredient availability and price were set approximately at current South African conditions. Broiler house turn round (seven days), fixed production costs (R2.1/m2/year) and variable costs (R4.4/bird/cycle) are illustrative. Mortality was set at 5%. Revenue was generated at R6.5/kg liveweight.

Optimising amino acid contents in each feed

In this exercise a three-stage feeding programme was used, with starter (0-16 days); grower (16-32 days) and finisher (32-42 days). Table 2 shows a brief summary of results for male and female broilers fed (a) at current prices, (b) at prices for protein sources only increased by 25%, and (c) at prices for protein sources only decreased by 25%. In all other respects the three cases were identical. Protein prices adjusted were for fishmeal, soyabean meal, sunflower meal, maize gluten 60%, DL-methionine and L-lysine HCl.

Table 2. *Effect of changing the price of protein on optimum lysine levels, and broiler production at these optimum levels (calculated data). The objective function used was margin over feed costs.*

			Lysine, %		Broiler production @ 42 days		
Sex	Prices	Start.	Grow.	Finish.	Body wt kg	FCR	Margin c/bird
M	Normal	1.5	1.1	0.9	2.71	1.840	1093
M	+20%	1.2	1.0	0.9	2.52	1.926	948
M	-20%	1.6	1.1	0.9	2.72	1.839	1176
F	Normal	1.5	0.9	0.8	2.28	1.984	912
F	+20%	1.2	0.9	0.7	2.19	2.103	838
F	-20%	1.5	0.9	0.9	2.29	1.966	980

These illustrative results at least show the expected pattern. 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. 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.

In no circumstances should the data in Table 2 be used as a recommendation for feeding broilers. The work is at too early a stage for this. Also the program currently works only in steps of lysine of 0.1%, so some fine-tuning may be missed.

Optimising nutrient density

In this example, three broiler feeds were again offered, but the ratio between the amino acids and AME in these feeds was fixed. The starter was fed to day 16, the grower to day 28 and the finisher was fed thereafter. Optimisations were conducted using males and females reared separately, and combined, at two revenues. The results are in Table 3.

Table 3. *Liveweight, feed conversion ratio (FCR), breast meat as percentage of liveweight, and margin/m^2 annum at 42d on feeds of optimum nutrient density (ND). The objective function used was margin over feed cost.*

Sex	Revenue R/kg	AME at optimum ND starter	grower	finisher	liveweight at 42d	Food intake	FCR at 42d	Breast %
M	base	13.23	12.09	11.46	2510	4520	1.800	17.66
M	+25%	13.00	12.40	12.40	2495	4256	1.706	17.58
F	base	13.15	12.56	11.76	2038	3786	1.858	18.91
F	+25%	13.00	12.60	13.40	2113	3793	1.796	18.23
M/F	base	13.23	11.93	11.47	2262	4218	1.877	18.28
M/F	+25%	13.00	12.60	13.00	2293	3942	1.727	17.99

At the optimum, the initial feed for males had a higher nutrient density than for females, but in the subsequent feeds this was reversed. By increasing revenue the optimiser changed the nutrient densities of the feeds in such a way as to improve considerably the FCR in each case.

Again, the results from this optimisation should not be used for commercial purposes, as the conditions described in setting up this optimisation are unlikely to be similar to conditions in practice.

Optimising the feeding schedule

Three feeds were again offered, with fixed (13.00 MJ/kg) AME contents and lysine contents reducing from 13.7g/kg in the starter, to 12.4g/kg in the grower and 11.0g/kg in the finisher. The objective function was to maximise feed conversion ratio (FCR) for males and females separately, and to compare this with the base feeding schedule, in which the starter was fed to 14d, the grower to 28d, and the finisher thereafter. The results are in Table 4.

Table 4. *Optimum feeding periods for three feeds of fixed composition, for male and female broilers reared separately. The performance is compared with the base feeding schedule, of starter to 14d, grower to 28d and finisher thereafter. The objective function maximised was feed conversion ratio (FCR).*

Sex	Optimum feeding period			Liveweight at 42d of age		FCR		Breast, g	
				Base	Opt	Base	Opt	Base	Opt
M	0 - 8	9 – 14	15 - 42	2495	2494	1.655	1.622	461	462
F	0 - 7	8 - 10	11 - 42	2094	2094	1.831	1.786	403	403

The optimum feeding periods for the two sexes differ, sensibly, reflecting the lower amino acid requirements of the females compared with the males. The FCR was considerably improved over the base levels by optimising the periods over which each feed should be fed, even though the body weight at the end of the growing period was the same. The decision as to the optimum time to switch from one feed to the next is dependent on many variables, and the result in Table 4 should therefore be used for illustrative purposes only, and should not form the basis of feeding decisions under different circumstances.

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