MODELLING NUTRIENT RESPONSES AND PERFORMANCE OF BROILER BREEDERS AFTER SEXUAL MATURITY

By

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DECLARATION

I hereby declare that the research in this study is of my own work and it has not been submitted in any another university. Where use has been made of the work of others it is duly acknowledged in the text.

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……..

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GENERAL INTRODUCTION

With the worldwide increase in consumption of poultry meat in recent years, the production of hatchable eggs from broiler breeding stock has become a critically important component of the poultry industry. Surprisingly, a perusal of the literature pertaining to broiler breeder nutrition leads to the conclusion that research nutritionists have neglected these birds. It has been assumed in many cases that the research on laying hens is applicable to broiler breeders. However, fundamental differences are apparent between the two strains that should be investigated more comprehensively if the potential of broiler breeder hens is to be achieved.

Commercial laying hens have been selected predominantly for increased egg production whereas broilers have been selected for early rapid growth rate. By selecting for improved growth rate, both food consumption and mature weight of these birds has increased (Reddy, 1996), but because of the negative genetic correlation between body weight and egg production (Robinson *et al*, 1993) reproductive performance has not been improved. Broiler breeder hens differ from commercial laying hens, by their non-normal frequency distribution of egg outputs, their considerable lipid reserves, and by the fact that many do not lay in closed cycle. The practice of restricting feed intake during both the rearing and laying periods has become a standard management procedure in commercial broiler breeder operations and this differs from the manner in which commercial hens are fed. This raises important issues regarding the requirements of these birds for energy, amino acids and other essential nutrients, as the birds do not have the opportunity of meeting their nutrient requirements by adjusting food intake upwards when one or more of these nutrients is deficient in the feed. It is the duty of the nutritionist to provide the correct daily allowance of each nutrient in order to achieve maximum egg output by the flock, but given the variation between hens within a flock, such decisions need to be made on both biological and economic grounds.

Improved strains are continually being produced by breeder companies, which exhibit better growth, feed efficiency and productivity. The way in which broiler breeder hens were fed in the past might not be the most effective way to feed the latest strains. Getting the right amount of feed with the right nutrient levels at the right time is the most important part of feeding broiler breeders, and to succeed their daily nutrient requirements need to be

known. Information concerning the nutritional requirements of broiler breeder hens is limited in comparison to other types of domesticated poultry. However, enough information is available concerning energy and amino acid nutrition of this type of poultry to enable one to develop models useful for constructing accurate feeding programmes. The most appropriate way of estimating the nutrient requirement of broiler breeder hens during the laying period, or of optimising a feeding strategy, is by the use of simulation models.

Emmans and Fisher (1986) suggested that a better approach to the problem of describing requirements and of expressing them quantitatively can be achieved by considering: firstly, the bird's characteristics, secondly by defining resource scales carefully and thirdly by considering the quantities of each resource needed per unit of function. This approach has a greater chance of success than attempting to measure requirements by direct experimentation. Energy and amino acids are required for growth of tissues, egg production, maintaining normal body temperature, vital life functions and activity. For development of feeding programmes, we are most concerned with the three primary components, maintenance, growth and egg output. There are a number of factors that impact on the total nutrient requirement of the breeder. The maintenance component is affected by body size, environmental temperature, level of activity (housed in floor pens vs. cages) and possibly breed. Regarding the growth component, in the case of broiler breeders during lay the composition of growth needs to be addressed: whether this is only lipid gain or also includes protein gain. Lastly, the egg component is influenced by egg mass and hen age. In order to calculate energy and amino acid requirements, one must have knowledge of the requirements per unit of body protein weight, growth rate and egg mass. By continually monitoring the environmental conditions in the broiler breeder house, as well as body weight, egg weight and egg number, it is possible to estimate the state of the hens at any time and hence the optimum nutrient concentrations that should be fed the next day of the laying period by using the Breeder Model presented in this thesis.

Optimising the feeding of broiler breeders during the laying period is made difficult because of the many interacting factors influencing their performance All the hens are not the same, they are not housed in the same environments, and the costs of feeding and the revenue derived from the sale of the product differs from one locality to another. The solution to this problem lies in the use of simulation models to describe the causal relationship between inputs and the predicted responses.

This thesis explored new concepts and components for a simulation model to predict the nutrient requirement and performance of broiler breeders after sexual maturity.

CHAPTER 1

SOME IMPORTANT THEORETICAL ASPECTS OF NUTRIENT MODELLING

1.1 INTRODUCTION

Broiler breeder nutritionists face real problems when formulating feeds for their clients. Because the nutrient requirements of broiler breeders change during the laying period depending on the potential performance of the bird, on its state, on the feed being offered and on the environment in which the bird is kept, it is extremely difficult to make a decision about the composition of the feeds and feeding schedule that will maximise returns on the varied broiler breeder farms on which the feeds are to be used. Indeed, all the hens are not the same, they are not housed in the same environments and the costs of feeding and the revenue derived from the sale of the product differs from one locality to another. As a result, the published nutrient requirements expressed as fixed concentration in the diet, and feeding programmes, that many nutritionists use as the basis for their nutritional decisions are likely to be appropriate under only a very few circumstances.

Emmans (1987) pointed out that the conventional approach, of direct experimentation to determine the requirements for each nutrient and energy, has two substantial disadvantages. The first is that a huge number of experiments would be needed because there are many nutrients, several sources of energy and many different kinds of birds. Secondly, each bird is continually changing its state during the course of an experiment and changes take place over time in the genotypes themselves. With a fixed requirement, it is not possible to determine the effect of increasing or reducing the concentration of nutrients in the feed on performance or feed intake, and whether these requirements should change with the genotypes available to the industry. There are so many interacting factors that it is virtually impossible for the human mind to assess accurately the consequences of alternative management strategies on either the efficiency of production or the long-term profitability of an enterprise (Black, 1993). With the progress in data processing, and a better knowledge of biological science, assessment of animal production and nutrient requirements, aided by mathematical modelling, has become a dynamically developing field of nutrition research.

Mathematical modelling of biological processes can be defined as one of the most efficient means for determining the nutrients requirements of animals, and predicting the impact of feed intake on performance at a given time, or in a given time interval. In a model, the biological processes of the animal are described with a system of mathematical equations, which are based on the knowledge of the genetic, biochemical and physiological processes as well as the environmental impact. By transforming the concepts and knowledge into mathematical equations and integrating them in computer programs using simulation modelling techniques, this vast store of information can be applied directly to improving the management of commercial animal enterprises (Black *et al*., 1993).

1.2 MODELLING

1.2.1 Types of models

In science, the purpose of a theory is to allow a prediction to be made of the response of a system, in a given state, to a stimulus. In agriculture, the systems of interest are complex and several theories may need to be used in combination; such a set of theories is called a model (Emmans, 1981).

Models are broadly described as either static or dynamic, either deterministic or stochastic, either empirical or mechanistic (Zhang and Coon, 1994). Time is described explicitly in a dynamic model, whereas only one instant of time is described in a static model. Deterministic models have only one outcome representing the average of the population. These kinds of models predict the response of only one animal. Stochastic models, however, deal not only with the mean but also the variation in the population. A distinction is made between genetic and environmental variation. An empirical model describes the response of an animal to a given set of circumstances and is usually in the form of a predictive equation derived from one of more experimental data sets using biometric procedures. Mechanistic models focus more on metabolic processes within the animal. They may operate at the tissue, cellular or molecular level. Such models are more flexible and may be expected to predict responses and requirements over a wide range of conditions. Generally, the most desirable models are those that are dynamic, stochastic and mechanistic. Animal simulation models are generally dynamic systems, whose purpose is to imitate the behavior of animals to different internal and external stimuli.

1.2.2 Model building

The building of models ranges from the use of empirical regressions derived from experimental observations to a deductive approach using a sequence of mathematical equations (Whittemore, 1981). Gous (1986) firmly believes that the "empirical approach currently used to determine responses to treatments in poultry feeding should and must give way to a systems approach for the sake of utilising research resources more efficiently and providing a more solid foundation on which further developments in both research and management can be based". The empirical relationships between responses and their causes produce regression equations that contain biologically sound constants and parameters but are limited to the bounds of the original trial. Furthermore, they are static and inflexible, contributing little to the understanding of the actual nature of the predicted responses. The use of empirical elements will always be included in simulation models due to the lack of hard facts about the causal forces behind the resultant response. They should, however, be updated or replaced when further knowledge about cause-effect relationship are elucidated (Black *et al.*, 1993). The deductive approach or factorial model is more interpretive and flexible and allows prediction beyond the circumstances in which the information was collected. Due to the current gaps in nutrition theory, the deductive model may contain a large number of hypotheses.

The ideal model should be a system based on first principles and quantifying causal forces, which turns inputs into responses (Brockington, 1979). This requires an understanding of the mechanism in which a system operates and a knowledge of the causes of responses so that new responses can be predicted. Due to the hypothetical nature and the current limitations in knowledge, the best models will include both empirical elements and deductive processes. A model consists of a large series of sequential calculations or text statements. This predisposes the use of computers to rapidly and accurately calculating, storing and presenting response data to varying inputs (Black *et al.*, 1989).

1.2.3 The modelling process

1.2.3.1 *An overview of the procedure*

The major steps of modelling are presented in Figure 1.1 and follow the methodology suggested by Black (1993).

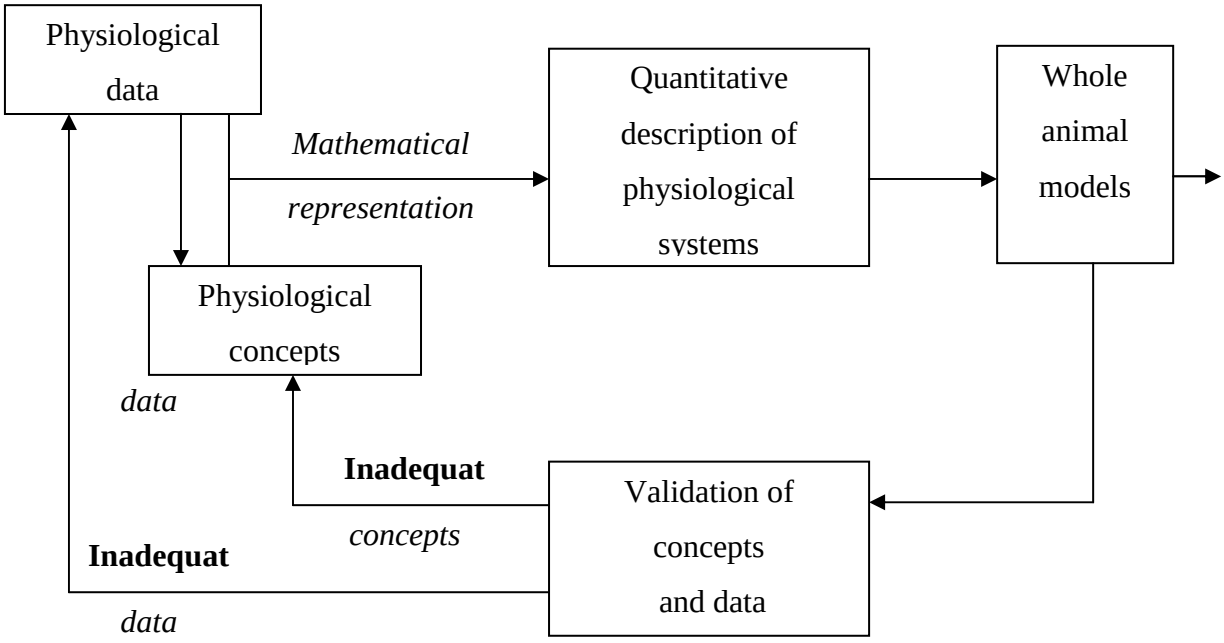


Figure 1.1 A modelling process (after Black, 1993)

The animal is a physiological system with measurable features (physiological data) and biological processes (physiological concepts). The first step in modelling is to complete an investigation to collect basic data that, in the case of laying birds, could be weekly body weights, rate of lay or daily feed intake. The physiological processes and the control of the system are then developed from this information. Traditionally in science, these two steps are repeated many times until the system can be described at some uniform level of detail. The system is then represented by mathematical equations that can be solved rapidly by computer programs in a quantitative and dynamic approach. There are two parts to the mathematical representation. The first is defining the form of the mathematical equations used to describe each component of the system while the second is to establish the quantitative values for the constants within each equation (Black, 1993). The next step is to test the validity of the proposed model with regard to concepts and data, by comparing

predictions with experimental results. Whenever there is a considerable difference between the model predictions and experimental observations, new approaches of concepts and equation parameters can be devised and tested within the model. When the outcomes from the model and the experiment agree over a wide range of different circumstances, some confidence in the understanding of the system is obtained and this could be the final model.

1.2.3.2 *Testing and evaluating models*

The term “testing” is generally taken to mean that the model is mathematically, numerically and logically correct, and that it is free from “bugs” (Black, 1993). Before making recommendations in feeding programmes, the Model should be submitted to strict evaluation. Model evaluation is concerned with establishing the appropriateness and accuracy of predictions over a wide range of simulated conditions. According to Black (1995), models can be evaluated in three ways: 1) simulation of experiments reported in the literature, and comparison of simulated to measured requirements (in the case of models to predict nutritional requirements); 2) subjective evaluation of the response of model predictions to changes in input values (behavioral analysis); 3) testing whether the predictions made by the model to changes in selected parameters are sensible. Evaluation is an ongoing process and often leads to the development of new concepts about the mechanisms controlling the system (Black, 1993).

1.3 A SYSTEMS APPROACH FOR PREDICTING NUTRIENT REQUIREMENTS OF LAYING BIRDS

1.3.1 Methodology

The methodology used in the development of the Breeder Model described here follows a concept suggested by Emmans (1987) and Emmans and Oldham (1988) for growing animals. The problem of predicting nutrient requirements of laying birds could be approached by considering the bird to be a system with a purpose, namely, attempting to meet specific reproduction and/or growth characteristics. The system will comprise a bird in some body condition or state having a particular genotype. Depending on the genotype and its state, it can be seen as trying to stay alive in its current state (maintenance), to gain

weight (growth) and to produce eggs (Figure 1.2). To accomplish these functions, the bird will need a supply of energy and protein, as amino acid, as well as major and minor minerals and vitamins from its feed. To transform maintenance, growth and egg production into quantitative requirements for amino acids and energy, the values of a set of nutritional constants will be needed. Given a set of environmental and nutritional resources, the desired food intake will be that amount of food that satisfies the animal's requirements for the limiting nutrient(s) in the feed. However, the animal may not be able to consume its desired intake because of a number of constraints such as a food that is too bulky or an unfavorable environment (e.g. an environment too hot for the animal to lose the amount of heat produced from consuming the food offered it). The actual food intake and subsequent performance will depend on whether or not the animal is able to eat its desired food intake. Where a fixed daily allowance of feed is offered to the birds, as is the practice with broiler breeders, any variations in feed intake will have a direct effect on the optimum content of each of the amino acids in the feed. The objective of such a simulation model would be to determine the optimum contents of energy and amino acids for birds differing in potential laying performance whilst being kept under differing environmental conditions.

A central problem to all simulation models is the need to keep the description of the system as simple as possible without limiting its usefulness (Ferguson, 1996). Models designed to predict nutrient requirements can be simplified by adequately describing the genotype, its current state and the nutritional constants. For a model to predict performance, such as egg production by a laying hen, it must be able to calculate the nutritional and environmental requirements of the bird that are needed for maximum potential performance, hence a description of the feed and the environment will also be necessary.

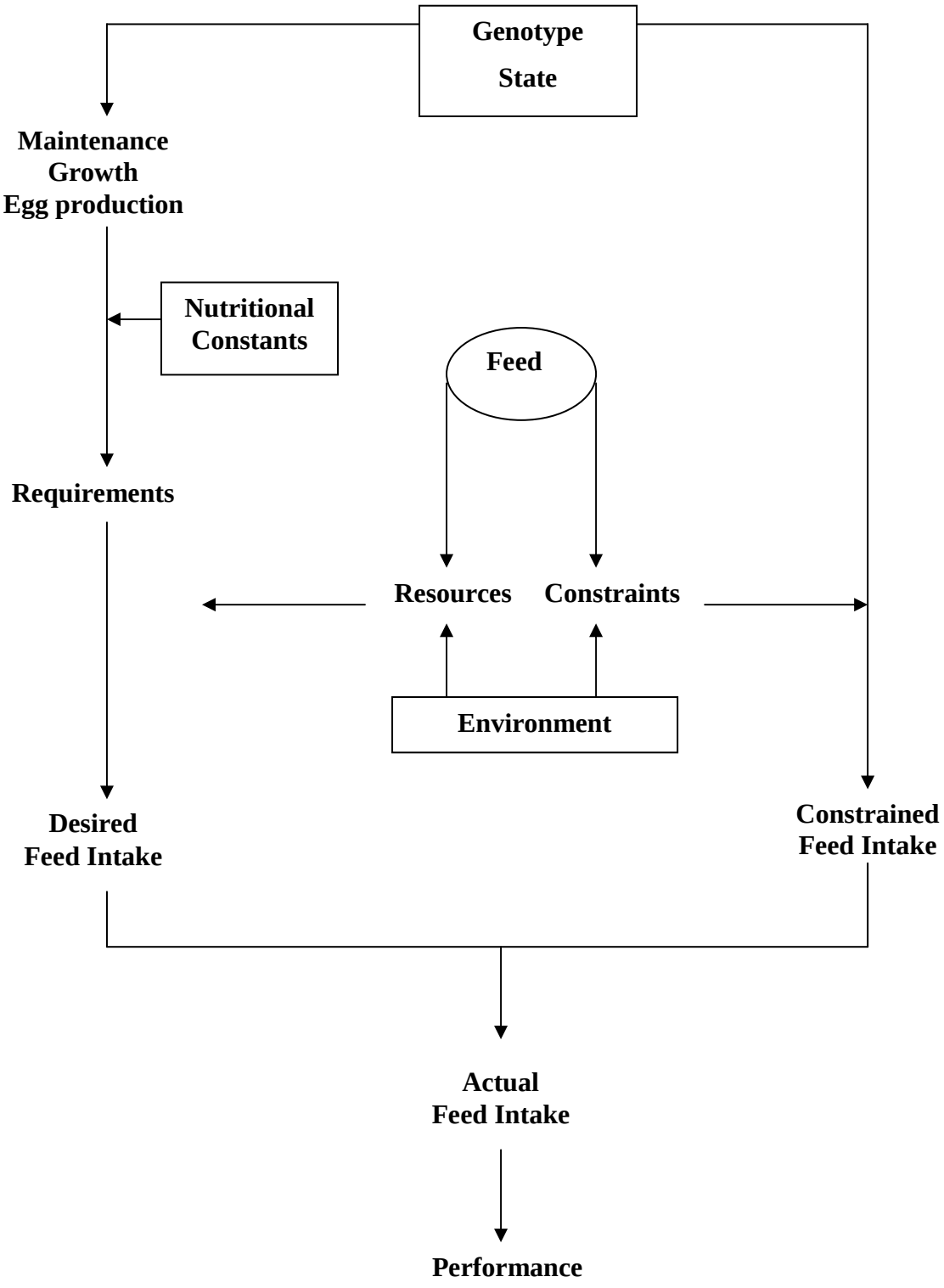


Figure 1.2 A systems approach to predicting nutrient requirements and performance of laying birds (as adapted from Emmans and Oldham, 1988, for growing animals)

1.3.2 Description of the genotype – the potential egg output

Emmans (1987) suggested that there are two obvious ways in which genotypes vary in growing birds. The first is what they are like when mature and the second is the path of development to get there. In the case of a laying hen it would be necessary, in addition, to allow for differences in potential age at sexual maturity, rate of laying and egg weight.

1.3.2.1 *Mature size*

It is essential to describe adequately the mature size of a laying hen or broiler breeder. This could be described in terms of body weight and composition. To avoid problems resulting from differences in lipid content at maturity brought about, in turn, by different feeding regimes applied during growth, mature size should be measured, not as total weight, but as body protein weight. For a bird to maintain its body composition and form it needs a minimum rate of supply of resources. The problem is to quantify the relationship between the rate of supply and its state or to provide a rate function that will scale maintenance to cover all ages or weights on the basis of the current state of the bird. The body of a bird may contain appreciable amounts of lipid, which may act as an energy source, and there may also be some reserve of protein. If its daily intake of protein is sufficient for maintenance and its potential rate of egg production, but its daily intake of energy is insufficient, it may be expected to deplete its lipid reserves to support maintenance and egg production (Emmans and Fisher, 1986). The second problem is to determine the extent to which birds could be made to utilise their excess body lipid reserves whilst maintaining laying performance.

In hens in lay, the question arises whether they are, or need to be, growing and if so, whether this growth is in lipid, protein or both. By definition, egg production is a function of sexually (but not necessarily somatically) mature birds so the assumption can be made that, at first egg, the bird stops growing and after this it may gain or lose lipid or protein and ash but it would not be expected to show a net gain of protein or ash (Emmans, 1981). Laying pullets, fed *ad libitum*, do not grow body protein, only lipid, once they start laying. However, protein growth of broiler breeders has been restricted throughout their lives. Hence, they may still have the capacity to grow body protein and lipid once they have started laying.

Where growth of protein or lipid takes place, the process of simulating this and of subsequently determining the nutrient requirements and the desired, constrained and actual food intakes has been well described by Emmans (1987), these processes having been incorporated into a broiler growth model (EFG Software). Of greater interest in this thesis are the processes required in predicting the nutrient requirements for egg production.

1.3.2.2 *Potential egg output*

The concept of a potential egg output (rate of lay x egg weight) could be described as the maximum possible egg output that the genotype can achieve when given perfect nutritional and husbandry conditions. The performance standards provided by the breeding companies represent the level of performance to which most producers aspire. Emmans and Fisher (1986) described egg as a mixture of yolk, albumen and shell, each of which, in nutritional terms can be regarded as having a constant composition. Given this, it may be possible to solve the problem of predicting the rate of production in three steps: 1) predict the rate of production of yolk material; 2) predict the partitioning of yolk material into individual yolks; and 3) predict the albumen and shell weights from yolk weight. The prediction of yolk production may be predicted from the equation 1.1:

$$y = a\, e^{-ct} \exp - (\exp (G_0 - bt)) \qquad \text{(Equation 1.1)}$$

where the parameters are a scalar, a, a decay parameter, c, the initial state parameter at t = 0, G_0, and a growth parameter, b. The form of the prediction obtained is shown in Figure 1.3.

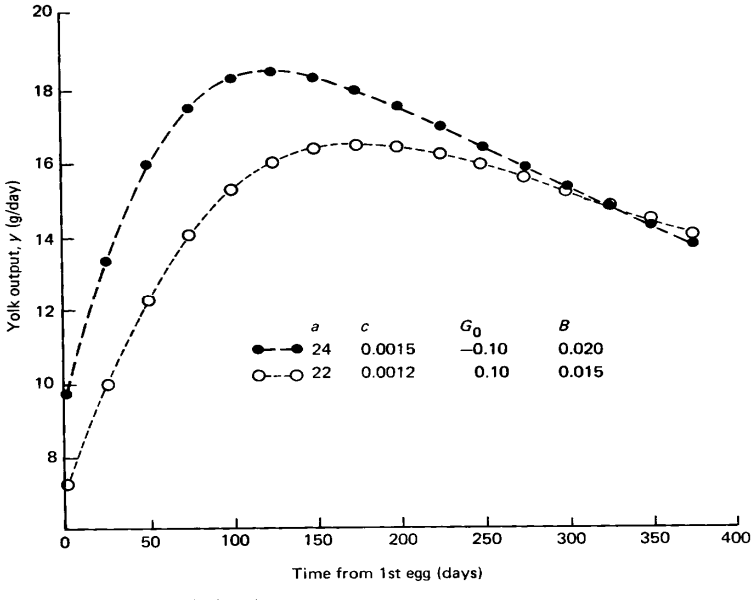


Figure 1.3 Examples of a function to describe the rate of yolk output, y (g/d) in terms of time from first egg, t days (after Emmans and Fisher, 1986)

Mean yolk weight (MYW) is given by yolk output (y) divided by the rate of ovulation and lay (R) (Equation 1.2).

$$MYW = y / R \qquad \text{(Equation 1.2)}$$

Emmans and Fisher (1986) pointed out that a given hen at a given time has an internal cycle of length ICL hours and the environment has a cycle, usually defined by light, of length EXCL hours. Johnston (2004) defined internal cycle length as representing the interval between successive ovulations. This interval is determined by the synchrony between the follicle hierarchy and the circadian rhythm of LH release. A hen that has a properly maintained hierarchy containing sufficient follicles, each capable of maturing every 24 hours, will have an internal cycle length of about 24 hours and will therefore lay an egg a day. With advancing age the follicles take longer to mature with the result that the internal cycle length increases. Emmans and Fisher (1986) proposed that the change in a hen's internal cycle length (ICL) over time may be calculated from the following equation 1.3.

$$ICL = ICLo – Lag + 1 / ((1/Lag) – kt) \qquad \text{(Equation 1.3)}$$

where ICLo = initial internal cycle length, k = a decay factor and t = time from first egg, in days. If the internal cycle length is less than or equal to the 24-hour daylength or external cycle length (EXCL), rate of lay (R) is given by equation 1.4.

$$R = 24 / EXCL \quad \text{(Equation 1.4)}$$

If the internal cycle length is greater than the external cycle length:

$$R = Lag / ((ICL - EXCL)(1 + (Lag / (ICL-EXCL)))) \quad \text{(Equation 1.5)}$$

Then, albumen and shell weights may be predicted from these allometric functions:

$$AW = a_1 . YW^{b1} \quad \text{(Equation 1.6)}$$

and

$$SW = a_2 . ECW^{b2} \quad \text{(Equation 1.7)}$$

where AW = albumen weight, YW = yolk weight, SW = shell weight and ECW = the weight of the egg contents, yolk plus albumen. Egg weight is given by YW + AW+ SW and mean egg output will be MEW . R.

Johnston (2004), who developed a stochastic model to predict annual egg production of a flock of laying hens, pointed out that these functions suggesting by Emmans and Fisher (1986) allow a decrease in egg production with advancing hen age, but they do not permit the simulation of the shorter egg sequences produced by many hens at the onset of lay. In order to reproduce these, the internal cycle length needs to be longer than 24 hours initially, before decreasing with advancing time from first egg to below the daylength and subsequently increasing above 24 hours. The required curvilinear shape may be simulated with the use of the following quadratic-by-linear equations of the form:

$$y = A + B / (1 + D. x) + C. x$$

where y = ICL and x = time from first egg. If each of the four parameters is assumed to be normally distributed and is given a mean and standard deviation then each hen in the flock may be allocated its own function to predict internal cycle length at a given time.

1.2.3 Nutritional constants

To transform maintenance, growth and egg production into quantitative requirements for amino acids and energy, the values of a set of nutritional constants are needed (Table 1.1).

Table 1.1 Nutritional constants required for determining nutrient requirements of broiler breeder hens

Protein	amino acid composition of body protein, for protein growth
	amino acid composition of yolk and albumen protein, for egg production
	amino acids required for maintenance
	nett efficiencies of utilisation of each amino acid for growth and egg production
Energy	energy for maintenance
	energy for yolk and albumen production (lipid and protein)
	energy for body protein gain
	energy for body lipid retention

The amino acid composition of the body and the egg components (yolk and albumen) need to be known, together with the scaling rules for maintenance and egg production and the quantities of each resource (or nutrient) needed per unit of function. The definition of an energy and protein scales are needed. Egg production can be defined as the rate of production of whole egg but this description is inadequate as the composition of eggs varies over time in terms of yolk, albumen and shell, and also in terms of nutrient contents.

1.3.4 Predicting nutrient requirements

Once the values of the nutritional constants are known, it would be possible to predict the requirements of any genotype in any state kept in a thermoneutral environment. The problem of predicting requirements is to bring together the genetic variables and the values of the nutritional constants, and then the composition of the feed will determine the desired feed intake. The desired feed intake is the intake that will allow the potential egg output to be attained. However, with broiler breeders, the question is not how much food the bird will consume voluntarily, but what the content of nutrients in the feed should be, given that a fixed amount of food would be allocated to each hen daily.

1.3.5 Negative aspects of feed composition and environment

What will happen if an unbalanced food is given to the bird or if the bird is kept in an unfavorable environment? In practice, common causes of egg production failing to reach the potential rate are temperatures that are too high, or feeds of too low a nutrient: energy ration, or both in combination, due in both case to an upper limit to the bird's capacity to lose heat in a given environment (Emmans, 1989).

The consequences of deviations from the optimum nutritional and environmental conditions will have to be predicted. This will require an understanding of the heat generated by the hen in maintaining itself, in processing the food that has been consumed, in constructing the yolk, albumen and shell, and of the heat lost through panting, conduction, convection, and through laying an egg. This is a critical aspect of a model in which the nutrient requirements for egg production are predicted, as this is possibly the most important constraint preventing the hen from achieving its potential.

1.4 DEALING WITH POPULATIONS RATHER THAN INDIVIDUALS

The theories discussed in the early part of this chapter describe events for one animal in one state, i.e. at one time. However, the requirement of an individual varies with time and is described by assigning values to its inherent parameters (Emmans, 1989). Another source of variation is that between individuals within a flock. Each bird will have its own characteristic values for the inherited parameters that describe its potential. Systematic errors will occur if the average individual in a population is used as the basis for generating individuals from which a population response is to be simulated, although these may be small in some cases (Emmans and Fisher, 1986; Emmans, 1989). This is due mainly to variation in the bird characteristics, including variations in feedstuff utilisation and in nett efficiencies of nutrient utilisation (Emmans and Fisher, 1986). These authors pointed out the two stages that require more attention when predicting a population response: 1) theories of individuals and 2) theories of population structures. In the final stage both sets of theories are used in combination. The problem of using theories related to a group and not to individuals is that the relationships between outputs and inputs for groups are curvilinear whilst the reasonable assumption of constant efficiencies for nutrient utilisation leads to curves (Fisher *et al.*, 1973). The problem of predicting the nutrient requirements of

a population of birds may be approached by considering firstly the requirements of an individual and then the variation between the individuals, which comprise the population.

Because broiler breeders are fed a restricted amount of food each day it is likely that there will be competition for this food at feeding time, which will result in differences in the amount of food that each hen consumes each day. The consequences of such variation should be investigated, this being one of the advantages of a stochastic model.

1.5 OPTIMISING THE FEEDING PROGRAMME OF LAYING BIRDS

Having obtained accurate data of the requirements of an individual or group of birds, and being able to quantify the value of egg output, the next step would be to optimise the feeding strategy for a flock of birds. The optimum feeding programme for a flock of birds is that which will result in the highest profit for the enterprise (Gous, 2002).

Two optimisers have been produced by the poultry group at the University of KwaZulu-Natal, one dealing with broilers and the other with laying hens. The latter is based on the Reading Model (Fisher *et al.*, 1973). This programme optimises the amino acid intake and balance in the feed for a flock of laying hens, and simultaneously optimises the nutrient density of the feed, thereby maximising the profitability of the enterprise. The feeds are designed according to the characteristics of the laying flock, including body size, feather cover, size and quantity of eggs being laid, and the characteristic intake of the flock. In addition, the marginal cost of each amino acid is considered, as is the marginal revenue for eggs. This optimiser, fully integrated with a feed formulation programme, performs a number of functions associated with the amino acid and energy nutrition of laying hens: 1) it predicts the intake of each amino acid that would be required to sustain a given egg output; 2) it calculates the first-limiting amino acid of the feed, based on prevailing marginal costs of the different amino acids, and the prevailing marginal revenue for eggs, and hence the economic optimum egg output; 3) it calculates the optimum amino acid mixture that would sustain performance of the flock at the economic egg output; and 4) it calculates the optimum nutrient density of the food, given the characteristic intake of energy by the flock and the cost of supplying energy in the food.

The objective of the simulation model for broiler breeders is not to predict voluntary food intake, as they are given a restricted amount of food each day and not allowed to eat *ad libitum*, but to determine the optimum combination of energy and amino acids in the feed, as well as the optimum daily allocation of feed per bird. Questions such as the ideal energy to amino acid ratios, the optimum number of feeds with their length of time that they should be fed, the optimum nutrient density and daily feed allocation for each day of the laying period need to be addressed, bearing in mind the cost of ingredients and the revenue derived from the sale of fertile hatching eggs. Because the major costs are usually obtained from the breeding farm and the feed supplier, the only persistent problem in optimisation is the definition of the bird response (Gous, 2002).

Once the nutritional strategy for any given flock of birds has been optimised, it is then necessary to investigate the different management systems which may be applied to that flock with regard to strain of bird and possibly environmental conditions which would result in maximum economics returns. The nutritional strategy here would imply the composition of the feed, the daily amount to be allocated per bird, and the length of time that each feed should be given before changing to a different feed composition. Management strategies might include whether mash or pellets are fed, and the feeding system to be used, both of which would be directed at reducing the variation in the amount of food consumed by each bird in the population.

1.6 CONCLUSION

In the case of an egg production enterprise, the individual hens are the sub-systems, which comprise each system (flock) of birds. The individual flocks are the components of the production enterprise as a whole. The major stimuli acting upon the system of egg production can be broadly defined under three major headings: 1) biological stimuli such as the environment, the genetic characteristics of the bird and the daily allocation of nutrients to the birds; 2) the economic aspects such as the fixed and variable costs of production and the price which the output will demand and 3) the influence of time on the system (Kleyn, 1987). The problem of predicting nutrient requirements of a laying hen is that it involves so many interactive factors, which need to be combined to produce a response to specific conditions. The nutrient requirements of a flock have to be determined in response to its environment, to the feed being offered it, as well as to the genotype, so

the factors to be considered include the potential egg output of the genotype, the differences between individuals at a time and within individuals over time, the carcass composition and the protein gains, the effects of differences between genotypes in the amount of excess energy that may be stored as body lipid, the effect of constraints placed by the environment and the feed on the nutrient requirements of birds. Sufficient accurate information on the response of broiler breeders to various essential nutrients are needed such that their responses to nutrients can be modelled. It is through the development of an accurate theory, and the use of computers, that it has been possible to ingrate all of these factors into a workable form and to create the Breeder Model..

The following chapter deals with the review of information necessary to develop such a theory or model

CHAPTER 2

MEETING THE ENERGY AND AMINO ACID REQUIREMENTS OF BROILER BREEDER HENS DURING THE LAYING PERIOD: A REVIEW

2.1 INTRODUCTION

If the daily food intake of broiler breeders were not restricted throughout their lives, these birds would be able to achieve a mature size of 5.4kg by 24 weeks of age (Heck *et al.*, 2004). Such a practice would be highly uneconomical, as food consumption throughout the growing and the laying periods would be excessive and the egg output of the female would not be near its potential. Egg output would be reduced, as well as fertility and hatchability (Pearson and Herron, 1981). Their welfare would also be compromised, given that such large birds would suffer thermal discomfort, a high incidence of lameness, and high mortality due to skeletal disorder and heart failure (Katanbaf *et al*. 1989; Savory *et al*. 1993). It is therefore essential to control the daily food consumption of broiler breeders, and consequently the management of these birds is more difficult and demanding than of other types of commercial poultry. Control over the food consumed is enforced via a restricted feeding programme where the daily allowances of energy and protein have to be adequate but not excessive, in order to attain maximum production.

Poultry require six classes of nutrients. These included water, protein/amino acids, minerals, vitamins, energy and fatty acids. The diet should ideally be formulated to contain adequate amounts of 10 amino acids, 12 minerals, 13 vitamins and energy in the exact proportions to meet the bird's need for growth, maintenance and reproduction (Dozier, 2003). The requirement for a given nutrient is the minimum quantity of that nutrient, when all other nutrients are supplied in adequate quantities that will maintain normal growth and reproduction and, at the same time, prevent the development of symptoms of nutritional deficiency. The accurate way to express nutrient requirements is in terms of an amount per day per animal. There are various sources of information on nutrient recommendations, allowance, levels and specifications. These arise from data presented in the scientific literature, in publications on nutrient requirements by national bodies (ARC, 1975; NRC, 1994), commercial producers of products (amino acids, vitamins…) for inclusion in diets and information published by producers of birds. Information from diet manufacturers and

integrated companies is highly relevant but almost impossible to access because of the commercially confidential nature of the information.

The nutritional requirements of broiler breeders are influenced to a considerable extent by the genotype, the environment and the stage of reproduction (the state) of the bird. The optimum inclusion of a nutrient should be defined by economic factors rather than solely on the specific requirement for a particular nutrient, but this is not often done. The majority of researchers working on the nutrition of broiler breeders in the past expressed the requirement as a fixed concentration in the diet, ideal for making tables of requirements, but it is difficult to apply an accurate cost analysis to such numbers. The conclusions drawn by those researchers are of little value in developing a strategy for determining the optimum economic daily intake of nutrients for a given genotype and enterprise using nutrient responses and marginal costs and returns. The available literature on broiler breeder nutrition has been reviewed below with the goal being to obtain sufficient accurate information on the response of these birds to various essential nutrients such that their responses to nutrients can be modelled. This approach requires information on the requirement of a broiler breeder for maintenance (mg amino acid or kJ energy/g body protein) and for egg output (mg amino acid/g egg output), on the mean body protein weight and egg output, with variances, in a population of broiler breeders and the marginal cost of the nutrients and marginal revenue for the hatching eggs. With such information it would be possible to determine the optimum economic intake of each nutrient for the flock. This would also involve determining the optimum nutrient density in the feed, as the daily allocation of nutrients could be supplied in a nutrient-dense feed, costing more than a diluted feed, but with the daily allocation of this feed being less than that of a bulky feed. It would also be possible to determine at what stage of production the feed composition of allocation should be changed, on biological and economic grounds. This approach has not been used in broiler breeder nutrition, which up to now has lacked a comprehensive theory with which to deal with the above possibilities. The review of literature that follows is aimed at extracting the information necessary to develop such a theory or model.

2.2 MEETING THE ENERGY REQUIREMENTS

2.2.1 Energy requirements

The recommended energy requirements for strains of broiler breeders at 28 weeks by the respective breeding companies are shown in Table 2.1.

Table 2.1 Recommended dietary ME concentrations for six strains of broiler breeder at 28 weeks (after Leeson and Summers, 2000)

Breed	Hubbard	Cobb	Ross	Hybro	Abor Acres	Shaver
ME (MJ/kg)	1916	1962	2000	1895	1937	1958
Feed intake (g)	160	161	167	165	162	170

The daily nutrient intake is merely a factor of feed intake X diet concentration. A fairly consistent pattern of recommendation for the various strains is shown taking into account feed intake together with diet specifications.

In the literature, reports regarding the amount of energy required for broiler breeders are contradictory and vary from 1610 to 2090kJ AME/d for maximum egg production (Table 2.2). The requirement seems to be higher (by 10%) for birds housed on the floor rather than those kept in cages, with the exception of Bowmaker (1986) who found an energy requirement of 2000kJ/d for birds kept in individual cages.

Table 2.2 Recommended dietary ME concentrations for maximum egg production

Author(s)	Floor or cage	Energy requirement (kJ/d)
Bornstein *et al.* (1979)	Floor	1840-1890
Pearson and Herron (1981)	Floor	1730
Pearson and Herron (1982)	Cage	1610-1880
Wilson and Harms (1986)	Floor	2090
Bowmaker (1986)	Cage	2000
Spratt and Leeson (1987)	Cage	1610
NRC (1994)	Floor	1800-1940

The accurate prediction of energy intake is important to formulate diets for broiler breeders and to make economic decisions. Many people spend time discussing whether their hens should receive 150, 165 or 185g of feed per day at peak. This is a typical non-sense proposition. In fact, any of these figures may be right, but at the same time they may

all be wrong, depending on the specific situation of each flock – body weight, egg output, house temperature and energy content of the ration. In any case, there is only one accurate way of feeding broiler breeders and that is according to their energy requirements. In full-fed laying hens, birds have the chance to adjust their individual feed intakes in order to meet the specific energy requirements. However, with controlled feeding of heavy broiler breeders, meeting the energy requirement of the birds is up to the poultry nutritionist. The birds eat what they are given and the amount of energy provided must be accurately calculated. For this reason, several models have been suggested to predict the metabolisable energy requirement of broiler breeders.

2.2.2 Models predicting energy requirements

The metabolisable energy (ME) partitioning model has been the most promising for imminent application. Indeed, the energy demanding processes of the body appear to be divided into 1) inevitable and primary expenditures: maintenance and thermoregulation; 2) syntheses which are usually performed when food intake is in excess of that required to meet primary expenditures: egg production and 3) deposition of body lipid which occurs when food is supplied in excess of the needs for primary expenditures and egg production (De Groote, 1974; Emmans, 1974).

The factorial approach has been used to partition the ME requirements into maintenance, growth and production and can be expressed by the model: $ME = aW^b(T) + c\Delta W + dEM$ where MEI is ME daily intake, W^b is metabolic body weight, ΔW is body weight change, EM is egg mass output, T is environmental temperature, a, c and d are the maintenance, growth and production requirements coefficients, respectively (Sakomura, 2004). These coefficients are important to elaborate mathematical models in order to estimate energy requirements. The application of predicting daily nutrient requirements models can help to establish better and more profitable feeding programs for poultry. However, for poultry, basically most models have been developed for laying hens (Emmans, 1974, NRC, 1981; Peguri and Coon, 1988, as cited by Rabello, in press; Sakomura *et al.*, in press, as cited by Sakomura, 2004; NRC, 1994). The accuracy of these models depends on the estimation of the coefficients for maintenance, growth and production. Unfortunately, they vary greatly in the literature, as seen in Tables 2.3 and 2.4, and large variations in the predicted ME

intakes result when using some of these equations with different temperatures and egg mass output, as noted by Zhang and Coon (1994).

Table 2.3 Metabolisable energy intake (kJ/bird d) prediction equations for laying hens

Source		Equation
Emmans (1974)	White strains	$MEI = W(711\text{-}9.2T) + 8.4E + 20.9\Delta W$
	Brown strains	$MEI = W(586\text{-}8.4T) + 8.4E + 20.9\Delta W$
NRC (1981)		$MEI = 544w^{0.75}(4.3)^{\Delta t} + 8.7EM + 23.0\Delta W$
Peguri and Coon (1988)		$MEI = W(1057 - 7.5T - 0.3T^2) + PF(-6.2 + 0.06T + 0.004T^2) + 12.0EM + 25.1\Delta W$
NRC (1984, 1994)		$MEI = W^{0.75}(724 - 8.2T) + 8.7EM + 23.0\Delta W$
Sakomura *et al.* (in press)		$MEI = W^{0.75}(694 - 9.9T) + 10.0EM + 28.0\ \Delta W$

W = Body weight (kg/bird), ΔW = Body weight change (g/bird/day), EM = Egg mass production (g/bird/day), T = Environmental temperature (ºC) and PF = Percent feather cover (0-100).

Beside the difference in genetics and environmental conditions, the limitations in the methodologies employed also have an influence on the varied estimated coefficients in the literature (Chwalibog, 1992). The estimated coefficients and their efficiencies are always obtained under specific environmental and nutritional conditions, and with the different exponential values for metabolic size, they contribute to the variation. These partition equations have also been developed from the results of feeding one feed *ad libitum* to birds, whereas it might be expected that birds partition energy differently when fed adequate versus inadequate amino acid levels. When inadequate levels are used, feed intake is increased to compensate for the deficiency (Emmans, 1974) with a resultant wastage of energy. Birds utilise energy more efficiently when feed is restricted rather than fed *ad libitum*. According to Blaxter (1989), the increment in lipid deposition in mature birds provided a decrease in ME for maintenance because the metabolic ratio in fat tends to be lower than in other tissues. Hence, body composition should be considered when predicting or measuring the maintenance energy requirements. For the above reasons, laying hens models should not be used to define the energy requirement of broiler breeder hens due mainly to difference in the basis on which maintenance requirements are measured.

Rabello (2001), as cited by Sakomura (2004), and Rabello *et al.* (in press) determined ME requirement model for broiler breeder hens kept in cages and on the floor, respectively, using the factorial method (Table 2.4).

Table 2.4 Metabolisable energy intake (kJ/bird d) prediction equations for broiler breeder hens

	Equation
Broiler breeder hen - floor	$ME = W^{0.75}(807 – 26.4T + 0.5T^2) + 10.0EM + 31.9WG$
Broiler breeder hen - cage	$ME = W^{0.75}(800 – 34.1T + 0.7T^2) + 10.0EM + 31.9WG$

W = Body weight (kg/bird), WG = Body weight change (g/bird/day), EM = Egg mass production (g/bird/day) and T = Environmental temperature (ºC).

The influence of temperature on ME requirements for maintenance was determined in experiments conducted in three environmental rooms with temperature kept constant at 13, 21 and 30ºC using the comparative slaughter technique. The energy requirements for weigh gain were determined based upon body energy content and efficiency of energy utilisation for weight gain. The energy requirements for egg production were determined based on egg energy content and efficiency of energy deposition in the eggs.

2.2.3 Energy requirement for maintenance

Most of the energy consumed by a laying bird is used to meet maintenance requirements; only about one third is available for production (Pearson and Herron, 1981). Maintenance needs of birds include temperature regulation, tissue repair, feed digestion and to support normal activity such as breathing, consuming feed and water, moving and breeding (Dozier, 2003). Energy maintenance requirement (MEm) has been determined in feeding trials or by calorimetric measurements, and by using regression equations of energetic balance components. The energetic balance components can be determined by direct calorimetry (using calorimeters), indirect calorimetry, and by carcass analysis. The indirect calorimetry method measures the heat production by determining the O_2 consumed and CO_2 produced in respiration chambers, and has been used in several studies (Johnson and Farrell, 1983; Spratt *et al.*, 1990). At 21°C, for caged Hubbard broiler breeder hens, the MEm was 292kJ per kg d (367kJ per $kg^{0.75}$ d) (Spratt *et al.*, 1990) and for caged Hy Line broiler breeder hens, 266kJ per kg d (365kJ per $kg^{0.75}$ d) (Johnson and Farrell, 1983). Rabello (2001), as cited by Sakomura (2004), and Rabello (in press), determined regression equations of MEm as a function of ambient temperature for broiler breeder hens kept on the floor and in cages, found that the requirement of breeders raised on the ground was 20% higher than that in cages (603, 566, 572 and 326, 273, 248kJ/$kg^{0.75}$day at 13, 21 and 30ºC, respectively). This was explained by the higher energy spent on activity. These

results are important because most of the maintenance energy requirements for broiler breeders have been studies in metabolic chambers or cages, which clearly underestimate the requirements for breeders raised on the ground.

2.2.3.1 *Temperature*

Birds have a zone of thermoneutrality, over which metabolism is minimal. Within this zone birds control their heat loss by physical means. When the temperature falls below this zone the birds maintain their body temperature by increasing heat production, mainly by chemical means, and this increases their requirement for energy. The maintenance energy of cockerels increases by approximately 8.4kJ/kg d °C when the temperature decreases from 34 °C to 15°C (Emmans, 1974). Measurement of total heat production includes the energy required for maintenance, and energy spent in response to changes in environment. The major environmental factor that influences heat production is temperature. Regression equations of MEm as a function of ambient temperature for laying hens and broiler breeder hens are shown in Tables 2 and 3, respectively. The difference observed between the genotypes is probably due to variation in body weight and body composition. Most of the models of energy requirement for laying hens consider a linear effect of temperature on maintenance requirements. Peguri and Coon (1988), as cited by Rabello (in press), found a quadratic effect in energy requirements for laying hens over a range of temperatures from 7.0 to 37.2°C. A quadratic effect was observed for broiler breeder hens (Rabello *et al.*, in press). There was a decrease in MEm when the temperature increased to 26ºC, and above that temperature the MEm increased once more. According to Hurwitz *et al.* (1980), the effect of temperature on energy metabolism is very complex and the responses are non-linear. He suggested that the energy requirement for maintenance decreases at a constant rate with an increase in temperature to 24°C. It continues to decrease but at a minimal rate between 24 and 28°C and then it increases to 34°C. Leeson and Summers (1997) observed a small variation in heat production in birds kept at temperatures ranging from 19 to 27ºC, but below the lower critical temperature birds need to produce heat to maintain their body temperature, whilst above 27ºC they require energy to dissipate heat. However, these temperature limits are not the same for all birds because body weight, feed intake, feathering, and activities can affect bird response to temperature changes.

2.2.4 Energy requirements for growth and egg production

Energy is required for tissues deposition, egg formation and embryo development. During the pre-peak period, when flock egg production is low and growth rate is still relatively high, the energy required for growth may appear to be high, but if it is assumed that a hen stops growing the moment it begins to lay eggs, the energy requirement for growth will be zero after the hen starts laying. This is why it is more accurate to model the requirements for each hen and then to build up a population from the mean and variance when modelling the energy requirements of a flock. Suggested ME requirements for growth vary considerably in the literature: examples are 18.45 (Davis *et al.*, 1972), 20.04 (Leeson and Lewis, (1973), 20.92 (Emmans, 1974), 23.01 (NRC, 1981), 27.95 (Sakomura *et al.* (in press), as cited by Sakomura, 2004) for white layer hens and 31.88kJ/g (Rabello *et al.*, in press) for broiler breeder hens. These values differ presumably because the tissues being formed (whether protein or lipid) differ in composition, and because of differences in the efficiency of ME utilisation (see 2.2.4.1).

Energy needs for reproduction are a function of requirements for egg numbers and egg size. Frequently, this concept is described as energy needed for egg output. Rabello (2001) and Sakomura *et al*. (in press), as cited by Sakomura (2004), found similar egg energy content in the broiler breeder's (6.44kJ/kg egg) and laying hens' (6.23kJ/kg) eggs. The same authors found similar efficiencies of ME utilisation for energy deposition in eggs of broiler breeder (64%) and laying hens (62%). In this way, the ME requirement for egg production was similar for broiler breeders and laying hens (10.04kJ/g egg). Thus, the same coefficient could be used to determine the energy requirement for egg production for broiler breeder and laying hens. The energy content of eggs ranges from 5.56kJ/g (Sibbald, 1979) to 7.49kJ/g (Chwalibog (1992). On the other hand, the energy efficiency ranges from 60 to 85% (Luiting *et al.*, 1990; Chwalibog, 1995) depending upon genotype, bird's age, lighting pattern, egg size, and egg composition (Chwalibog, 1992). Consequently, the ME requirement ranges from 8.03 to 13.18kJ/g of egg.

2.2.5 Efficiencies for growth and egg production

The efficiencies of energy utilisation have been determined for growth (65 and 47%) and egg production (62 and 64%) in laying hens and broiler breeder hens, respectively

(Sakomura *et al.*, in press; Rabello, 2001, as cited by Sakomura (2004)). However, the majority of researchers take into account the efficiency for growth and for egg production together due to the difficulty in determining partial efficiencies for laying and broiler breeder hens. According to De Groote (1974), the efficiencies vary from 64 to 86% in studies with laying hens. On the other hand, Emmans (1974) assumed an efficiency of converting dietary ME to egg and carcass energy of 80%

The differences in efficiency may be due to differences in the proportions of protein and lipid being deposited in the gain, and to the fact that some birds will not be growing (those who are laying) whilst others will, and the proportions will change as more birds begin to lay. The uniformity in body weight of the flock will influence this, as will the lighting programme used to bring the birds into lay – a strongly stimulatory programme that causes most birds to start laying simultaneously (resulting in a sharp rise to peak production) will result in a different rate of growth to that in a flock that is un-uniform and which reaches a lower peak over a longer period of time. Then later, the rate at which the birds go out of lay will influence the amount of growth that takes place, as will the amount of body lipid that is available for maintenance and egg production. There is no wonder that the efficiencies appear to differ!

2.3 MEETING THE PROTEIN AND AMINO ACID REQUIREMENTS

2.3.1 Protein and amino acid requirements

The NRC (1994) stated that “chickens do not require a specific level of crude protein per se; rather, they have a requirement for specific amino acids plus sufficient protein to supply either the nonessential amino acids themselves or amino nitrogen for their synthesis. In the instance of meat-type breeder hens, there is a paucity of research directed toward determining specific requirements for essential amino acids. Therefore a minimum crude protein intake is generally designated to provide adequate amounts of essential amino acids whose requirements are not adequately known.” As in the case of energy, the suggested (recommended) protein and amino acid requirements differ markedly from one source to another. Leeson and Summers (2000) showed how the dietary protein and lysine levels recommended by the various suppliers of genetic material differ (Table 2.5).

Table 2.5 Dietary protein and lysine recommendations and intakes for broiler breeders (Management Guide Data) (after Leeson and Summers, 2000)

Breed	Hubbard	Cobb	Hybro	Ross 1997	Ross	Ross 2001
ME (MJ/kg)	12	11.97	11.5	11.5	11.97	11.5
Crude Protein (g/kg)	155	160	170	150-160	160	170-175
Lysine Total (g/kg)	7.1	7.8	7.5	7.0	8.3	8.1
Feed intake (g/bird)	160	161	165	174	167	174
Crude protein intake (g/bird d)	24.8	25.76	28.05	26.1	26.72	29.58
Lysine intake (mg/bird d)	1136	1256	1238	1218	1336	1409
Lysine (g/kg crude protein)	45.8	48.8	44.1	46.7	51.8	46.6
Lysine (g/MJ ME)	0.59	0.65	0.71	0.61	0.75	0.77

Leeson and Summers (2000) suggested that the differences shown above could be true breed differences but that it would be difficult to rationalize this, considering the breed-nutrition interactions.

Daily crude protein intakes of 18 to 22g per hen seem adequate for broiler breeders in floor-pens receiving a diet without supplemental amino acids (Waldroup et al., 1976a; Harms and Russell, 1995), although lower crude protein intakes of 16g per day may be satisfactory if additional amino acid supplementation is practiced (Harms and Russell, 1995; Lopez and Leeson, 1995). Excessive crude protein intakes are to be avoided. Daily intakes of 27g per hen had adverse effects on hatchability (Pearson and Herron, 1981, 1982). For individually-caged breeders, protein intakes between 16.5g and 19g were adequate to maintain reproductive performance through peak egg production (Pearson and Herron, 1982; Spratt and Leeson, 1987; respectively).

The NRC (1994) suggested a daily intake of 765, 450, 700 and 190mg of lysine, methionine, sulfur amino acids and tryptophan, respectively, with an intake of 19.5g protein. They previously suggested 765, 450 and 700mg of lysine, methionine and sulfur amino acids, respectively, with a protein intake of 22g (NRC, 1984). Few trials have been conducted to determine specific amino acid requirements. Pearson and Herron (1981) reported that 19.5g protein per day was adequate for breeders in floor pens when it provided 970mg of lysine, 570mg of methionine, 300mg of cystine and 120mg of tryptophan. Wilson and Harms (1984) obtained satisfactory performance with daily intakes per hen on litter of 808mg of lysine, 361mg of methionine, 682mg of sulfur amino acids, 1 226mg of arginine and 223mg of tryptophan, with 18.6g of crude protein per day. Harms and Ivey (1992) reported the requirements of breeders on floor pens for dietary lysine as

determined from empirical data ranges from 824mg for egg production, 806mg for egg weight and 819mg per day for egg mass when the daily protein intake was at least 18.6g. Harms and Russell (1995) re-evaluated the requirements for lysine in order to separate the effects of lysine and protein intake on egg output of 32-wk-old breeders on floor-pen. They determined that 845mg lysine per day was required for maximum egg production, egg mass and egg content. The simulated requirement for lysine and methionine using the response coefficients of Bowmaker and Gous (1991) for a 3kg breeder producing 45g egg mass per day is 793 and 321mg daily, respectively.

Many past research reports have discussed amino acids needs from empirical data mainly done with birds in floor-pen without separating the requirements into components for maintenance, body weight gain and egg production. Broiler breeders potentially have more profound changes in these parameters than commercial layers, which enhance the need for a factorial approach to determining the amino acid requirement of breeding birds.

2.3.2 Models predicting amino acid requirements

Waldroup *et al.* (1976b) estimated the daily amino acid requirements of broiler breeders using the Model B reported by Hurwitz and Bornstein (1973) as AAR (g/d) = 1.85 W Am + 0.21 G At + EM (62Ay + 59Ao + 52At) where W, G and EM are the body weight (kg), weight gain (g/d) and egg mass (g/d), respectively; and Am, At, Ay and Ao are the fractions of the respective amino acid in protein for maintenance, tissue, egg yolk and ovomucoid, respectively (Table 2.6). The researchers utilised a production model based on several breeder guides. They developed growth and egg production curves for different ages of breeders and the average change in body weight was calculated.

Table 2.6 Model predicted protein and amino acid needs of breeder hens (Leeson and Summers (1999) as adapted from Waldroup et al. (1976b))

Age (weeks)	CP (g/d)	Amino acid (mg/hen d)				
		Lys.	Trp.	Met.	Met. + Cys.	Thr.
22	7.2	282	79	258	362	320
24	7.4	282	84	275	382	335
26	9.8	400	110	341	485	428
28	13.2	608	153	450	652	580
30	15.1	742	183	530	770	690
40	15.5	722	187	552	809	695
50	14.4	625	173	528	750	650
60	13.2	542	160	495	698	600
70	12.5	497	152	480	664	570

The main observation made by Leeson (1999) of the adapted data presented by Waldroup *et al.* (1976b) is the low calculated amount of protein required by the breeders during the various stages of production. Leeson suggested that, in practice, breeders are fed higher levels of protein as an economical way of providing the necessary amino acids and reported that most breeder flocks will be over-fed rather than under-fed crude protein because it is difficult to justify more than 23-25g protein per day.

Bornstein *et al.* (1979) tested the applicability of the laying hen Models A and B (Hurwitz and Bornstein, 1973) for predicting the amino acid requirements of broiler breeders. The researchers completed three feeding trials with 1000 broiler breeders in each trial and suggested the experiments verified the applicability of Model B, developed for laying hens, for the purpose of predicting amino acid requirements for the most limiting amino acids for broiler breeders. They suggested that a hen weighing 3.5kg, gaining 4g per day and producing a daily egg mass of 52.7g had daily lysine, methionine and sulfur amino acids requirements of 830, 570 and 830mg per day, respectively.

The Reading Model (Fisher, 1973) was designed to describe the response of groups of laying hens to increasing intakes of amino acid. The model is based on the assumption that a bird's required intake of amino acid is proportional to its body weight and its potential egg output. It is assumed that each bird has a characteristic maximum egg output (Emax) and that, for each bird, when E<Emax,

$I = aE + bW$

where I = amino acid intake (mg/d); E = egg output (g/d); W = body weight (kg); a = amount of amino acid in mg required to produce 1g of egg output and b = amount of amino acid in mg required to maintain 1 kg of body weight. After rearrangement,

$E = (A - bW) / a$

In order to avoid negative rates of egg production, when A<bW, E is set to zero. The response curve for a flock of hens has a characteristic sigmoid shape (Figure 2.1a).

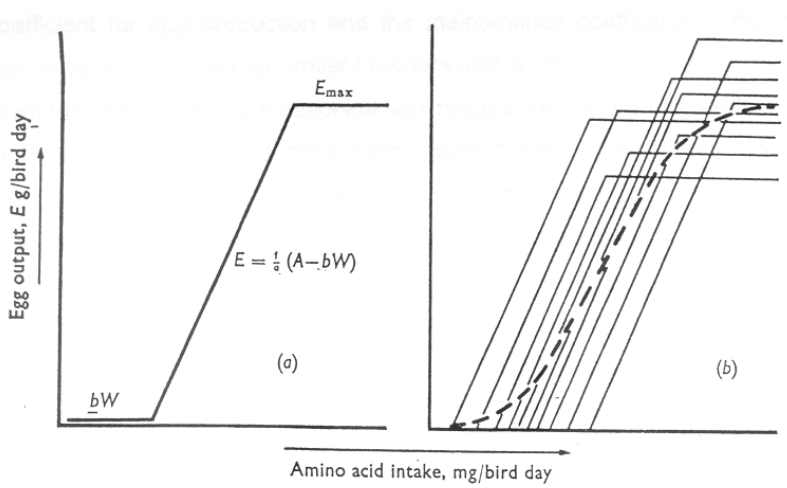


Figure 2.1 The model for the response of laying hens to amino acid intake (a) the response of an individual bird (b) individual (-) and mean (- -) responses for a small group of birds. See text from meaning of symbols (Fisher et al., 1973)

As can be seen from Fig. 1a, the response of an individual is represented by two straight lines: once the maintenance requirement (bW) has been met, egg output increases linearly (aE) until the genetic potential of the hen (Emax) is reached, whereafter no further increase in output is possible. The flock response is an integrated average of a large number of individual responses (Figure 1b). Based on the assumption that W and Emax vary normally among birds in a flock, the performance of a flock can be simulated by defining the mean maximum output ($\bar{E}max$) and its variance ($\sigma_{\bar{E}max}$), mean body weight (W) and its variance (σ_W), the correlation between E and W (r_{EW}) and the values of a and b, the quantities of amino acid associated with each unit of E and W, respectively. Random sampling can then be used to draw large samples of birds from a flock with experimentally or otherwise defined values for $\bar{E}max$, W and the other five parameters. When this has

been done, response profiles for each bird can be computed and these data used to calculate the predicted curvilinear response profile for the flock (Curnow, 1973).

This model allows one to determine the intake of each amino acid that maximises income over feed cost. By taking account of the marginal cost of each amino acid and the marginal revenue for eggs, the additional amount of each amino acid worth feeding, above that required for the mean individual in the population, is calculated. This is the first model to address amino acid 'requirements' in both biological and economic terms.

Some estimates of a and b have been outlined from flocks at or near peak output because at this time minimum amounts of amino acids are being diverted for tissue and feather production, and there is a minimum number of non-producing hens. Bowmaker and Gous (1991) used the Reading Model (Fisher, 1973) to determine the coefficients of response for lysine and methionine for egg mass and maintenance in broiler breeders (Table 2.7).

Table 2.7 Requirements for lysine and methionine obtained from fitting the Reading Model (Fisher, 1973) for laying hens (LH) and broiler breeders (BB)

		Lysine intake	Lysine requirement (mg)
McDonald and Morris (1985)	LH	9.99E + 73W	669
Bowmaker and Gous (1991)	BB	16.88E + 11.2W	793
		Methionine intake	Methionine requirement (mg)
McDonald and Morris (1985)	LH	4.77E + 31W	306
Bowmaker and Gous (1991)	BB	7.03E + 1.52W	321

The researchers reported the coefficients of response for maintenance and egg output were significantly different than the coefficients for amino acid requirements for laying hens (McDonald and Morris, 1985). The coefficients of response per kg BW for breeder maintenance amino acid requirements are lower and the coefficients for egg output are higher than those for laying hens. Bowmaker and Gous (1991) suggested the lipid reserve making up a large portion of breeder body weight, and not requiring amino acids for maintenance, may cause the coefficient for maintenance to be lower for broiler breeders. They also noted that broiler breeders have a much poorer rate of laying (more pause days) than laying hens, i.e. the efficiency of utilisation of amino acid is poorer and therefore they appear to require more of the amino acid per gram of egg output. The simulated requirement for lysine and methionine using the response coefficients of Bowmaker and

Gous (1991) for a 3kg breeder producing 45g egg mass per day is 793 and 321mg daily, respectively.

Leeson and Lopez (1994) computed the amino acid requirement of two different types of breeders using the maintenance requirement estimation of Leveille *et al.* (1960) and tissue gain and egg production requirements from the Model B of Hurwitz and Bornstein (1973). The researchers simulated a peaking breeder with a body weight of 2.5kg, gaining 100g /7 days and producing 50g egg mass/day and a 40 week-old breeder with a 3.5 body weight, gaining 30g /7 days and producing 40g egg mass/day. The requirements predicted in this way do not change much as the breeder ages (Table 2.8).

Table 2.8 Metabolisable amino acid requirements (g/hen d) of female broiler breeders (after Leeson and Lopez, 1994)

Breeders at peak production

	Maintenance (2.5kg BW)	Egg mass (50g/d)	Growth (100g/week)	Total (g/d)
CYS	0.100	0.15	0.070	0.32
MET	0.180	0.21	0.070	0.47
THR	0.190	0.31	0.070	0.57
VAL	0.150	0.44	0.110	0.70
ISO	0.180	0.40	0.070	0.65
LEU	0.310	0.52	0.110	0.94
LYS	0.070	0.38	0.130	0.58
ARG	0.300	0.40	0.110	0.81
HIS	-	0.15	0.030	0.18
TRP	0.050	0.08	0.010	0.14
PHE	0.150	0.31	0.070	0.53

Breeders at 40 weeks of production

	Maintenance (3.5kg BW)	Egg mass (40g/d)	Growth (30g/week)	Total (g/day)
CYS	0.160	0.17	0.020	0.35
MET	0.240	0.17	0.020	0.43
THR	0.260	0.24	0.020	0.52
VAL	0.210	0.36	0.030	0.60
ISO	0.250	0.32	0.020	0.59
LEU	0.430	0.42	0.030	0.88
LYS	0.100	0.30	0.040	0.44
ARG	0.420	0.32	0.030	0.77
HIS	-	0.10	0.010	0.11
TRP	0.070	0.07	-	0.14
PHE	0.210	0.25	0.020	0.48

Although the rate of egg production declines as the breeders' age, the egg size and maintenance requirements usually increase. Leeson suggested the predicted requirements justify a one feed system because the requirements decline approximately 9.5% for the two

bird types which coincides with an amino acid reduction of 11.6% when reducing feed intake from 154g at peak production to 136g toward the end of lay. The predicted lysine requirements for an average breeding hen using suggested body weights and egg output (Leeson and Lopez, 1994) that represent a typical peaking (2.5kg BW and 50g egg mass) and older breeder (3.5kg BW and 40g egg mass) were 872mg/day and 714mg/day, respectively.

Fisher (1998) predicted the amino acid requirements of modern broiler breeders using the suggested target performance goals for the Ross 308 female parent. The main components of the simple factorial equation utilised by Fisher were:

$$Raai = aE + bW^{n} + C\delta w$$

where Raai = amino acid intake requirement (mg/day); aE = requirement for egg production as a function of E (g egg output/d); bW^{n} = requirement for maintenance as a function of body or tissue weight and $c\Delta W$ = requirement for tissue growth as a function of weight change.

Fisher utilised the composition of eggs, body tissue and maintenance value listed in Table 2.9 to predict the amino acid requirements.

Table 2.9 Amino acid compositions utilised for estimating amino acid requirements for breeders (after Fisher, 1998)

	Body protein A	Egg protein B	Maintenance C	Egg D
ARG	6.8	6.036	50	7.387
HIS	2.6	2.228	10	2.739
ILEU	4.0	5.420	50	6.615
LEU	7.1	8.532	32	10.375
LYS	7.5	6.768	73	8.300
MET	2.5	3.367	25	3.959
MET+CYS	3.6	6.106	60	6.889
PHE	4.0	5.110	16	6.308
PHE+TYR	7.1	9.193	32	11.205
THR	4.2	4.650	40	5.727
TRP	1.0	1.892	10	2.175
VAL	4.4	6.493	60	7.387

Derived and used in the calculations as follow:

A: From summary of published data. Utilised for body protein growth with an efficiency of 0.80. Assumed composition of protein maintenance.

B: Based on amino acid composition of egg components as listed by Fisher (1994) and assuming 31.8, 57.2 and 11.0 g/100g weight and 27, 17 and 5.3 g N/kg for yolk, albumen and shell, respectively.

C: From Fisher (1983) based on a review of available evidence. Figure used only in calculation of standard deviation of requirement.

D: As for B with additional assumption that egg contains 1.89 gN/100g. Used as C only.

Fisher (1998) determined the maintenance requirements for amino acids for breeders using the following equation: $MPr = BPm^{-0.27}$. BP. X where MPr = maintenance protein requirement, g/d, expressed as ideal protein; BPm = feather-free body protein mass at maturity (=0.863kg utilised for illustration); BP = feather-free body protein mass and X = a constant, a value of 8g/kg. Fisher assumed that an adult breeder female would have 18% protein in the body and that the gain would be 14% protein. He also assumed that the amino acid composition of ideal protein for maintenance was the same as the amino acid composition of the body. The amino acids required for growth were estimated by using the body protein composition with a coefficient of utilization of 0.8 for all amino acids. Fisher's equation for predicting amino acid requirements is for the average single bird in the breeder flock. Indeed, he utilised a correction for variation and added 1.8 standard deviation in requirement to the mean to establish the flock requirements for amino acids. Fisher suggested that adding 1.8 standard deviations to the requirements would cover about 97.5% of the flock. This component is the unique feature of the Reading Model that was reported by Fisher *et al.* (1973) for predicting amino acid requirements for laying hens.

Fisher (1998) reported that the available lysine requirement for breeders ranges from 1080mg/d at 28-29 weeks to a slightly lower intake of 975mg/d at the end of the laying period. Since the daily requirement for lysine only decreased 105mg from peak production to the end of lay and that the normal practice is to reduce feed intake and dietary energy to control body weight, Fisher suggested that the percentage of lysine needed in breeder diets actually increases from 0.65% available lysine at peak lay to 0.74% available lysine at the end of lay. The requirements (as percent of the feed) for a flock being fed and producing as specified in a commercial manual (Ross Breeders Limited, 1995) reached a maximum requirement at about 55 weeks of age and not at peak production as commonly supposed. The finding by Fisher (1998) are very similar to the findings of Leeson (1999) in that both believed that the small reduction in required amino acids per day during the laying period do not justify a reduction in amino acid concentration due to the decrease in feed intake. Fisher (1998) compared the predicted amino acid requirements of average individual breeders and for a flock of 27-33 week-old breeders to the NRC (1994) suggested amino acid requirements. Although, the requirements presented by Fisher are expressed as available amino acid requirements and by the NRC (1994) as total amino acid requirements, the predicted amino acid requirements of Fisher were generally higher than the NRC requirements, mainly for lysine and histidine, due to the fact that Fisher utilised a larger maintenance requirement for lysine than the suggested maintenance requirement of Leveille and Fisher (1960) and to flock variability that were not used in some of the model calculations that Waldroup *et al.* (1976b) and Bornstein *et al.* (1979) used to develop some of the NRC (1994) requirements. Fisher (1998) concluded that questions about amino acid utilisation and about the lysine requirement for maintenance required further investigation.

2.3.3 Maintenance requirement

The amino acids required for maintenance by laying hens have been estimated from the research by Leveille and Fisher. (1959, 1960) using adult White Leghorn roosters. Coon (2004) pointed out that the extrapolation of these requirements to deal with broiler breeder females may not be accurate. Indeed, Cave *et al.* (1990) reported that the maintenance requirement of TSAA for broiler breeder females determined with balance studies was three times greater per kg body weight than minimum maintenance level of protein-depleted White Leghorn males predicted by the model of Leveille and Fisher (1960). They also suggested that the difference in maintenance requirements may be related to sex

differences. McDonald and Morris (1985), using the Reading Model to predict the maintenance requirements of laying hens, reported that the maintenance requirement of light and medium weight laying hens was 1.6 times greater, when predicted in this way, than the maintenance requirement of White Leghorn males reported by Ishibashi (1972). It is more likely that the differences are due to the methods of prediction and measurement than to sex differences. The maintenance requirement of 73mg/kg BW/d (McDonald and Morris, 1985), 11.2mg/kg BW/d (Bowmaker and Gous, 1991) and 0.01mg/kg BW/d (Goddard, 1997) for lysine, 60mg/kg BW/d (Burnham and Gous, 1992) and 45.5mg/kg BW/d (Huyghetaert *et al.*, 1991a) for isoleucine and 44.4mg/kg BW/d (Huyghetaert *et al.*, 1991b) for threonine, either calculated at zero N-balance or by extrapolation of response curves, are probably considered more robust than the estimated maintenance requirements of Leveille and Fisher (1959, 1960). Because the maintenance requirements published in the literature are so variable, and because the methods used to determine these requirements are generally subject to criticism (Gous *et al*., 1984) there is good reason to suggest that more accurate measurements should be made, given that the maintenance requirements make up a large proportion of the total amino acid requirement of the broiler breeder hen.

2.3.4 Efficiency of amino acid utilisation

The efficiency of amino acid utilisation for egg production can be determined by comparing the estimates of the coefficient for egg output with the amount of amino acid deposited in the egg (Table 2.10).

Table 2.10 Efficiency of utilisation of amino acids for laying hens and broiler breeders

	Bird	Amino acid	'a' (mg/g egg)	Egg (mg/g)	Efficiency
McDonald and Morris (1985)	Layers	Lysine	9.99	7.90	0.79
McDonald and Morris (1985)	Layers	Methionine	4.77	3.51	0.74
Fisher (1980)	Layers	Methionine	4.36	3.67	0.84
Fisher (1993)	Layers	Lysine			0.83
Bowmaker and Gous (1991)	Breeders	Lysine	16.88	7.90	0.47
Bowmaker and Gous (1991)	Breeders	Methionine	7.03	3.51	0.50
Goddard (1997) 26 weeks	Breeders	Lysine	14.04	8.30	0.59
Goddard (1997) 37 weeks	Breeders	Lysine	14.25	8.30	0.58
Goddard (1997) 48 weeks	Breeders	Lysine	14.23	8.30	0.58
Goddard (1997) 60 weeks	Breeders	lysine	12.19	8.30	0.68

The efficiency of conversion of dietary amino acid to egg protein for laying hens has been calculated to range between 0.74 and 0.85 (Fisher, 1980; McDonald and Morris, 1985; Emmans and Fisher, 1986). The efficiency of utilisation for broiler breeders was found to be much lower and to range between 0.47 and 0.68 (Bowmaker and Gous, 1991; Goddard, 1997), but not all the birds were laying at a rate of > 50%. In order to test the hypothesis that broiler breeders laying in closed cycles have the same net efficiency for egg production as laying hens, Bowmaker and Gous (1991) performed an analysis in which birds laying fewer than 14 eggs in the 28 day period i.e. birds laying at less than 50%, were excluded. For lysine, the coefficient for egg production decreased from 16.88 to 13.9 and the maintenance coefficient also decreased from 11.2 to 0.56. For methionine, the coefficient for egg production decreased from 7.03 to 5.36 and the maintenance coefficient increased from 1.52 to 1.87. These adjusted coefficients give an efficiency of 0.57 for lysine and 0.65 for methionine, values closer to those suggested above for laying hens but still considerably lower.

The efficiency of utilisation of the limiting amino acids for egg production appears to be relatively constant when different breeds of laying fowl are compared at the same age. As laying flocks age, the efficiency of utilisation of protein for egg production declines (Fisher and Morris, 1967; Jennings *et al.*, 1972; Wethli and Morris, 1978) and in broiler breeder hens (Goddard, 1997). The efficiency of utilisation declines when the rate of lay drops below 50% because the deposition of egg albumen is more discontinuous or because yolk protein synthesis itself becomes phasic (Fisher, 1980). Evidence that yolk protein synthesis becomes phasic can be seen by the fact that poor production in older broiler breeders has been attributed to birds with fewer developing yellow follicles (Hocking *et al.*, 1987). This is very important when considering broiler breeders because they have much lower rates of egg production than laying hens (Fisher, 1980), the food intake is restricted and the food allowance is manipulated in accordance with the changing requirements for egg production. It is therefore imperative to establish the amino acid requirements for all stages of their production cycle because if amino acids are limiting there will be a decrease in the rate of lay (Bowmaker and Gous, 1991).

2.3.5 Synthetic amino acids

Proteins are one of the most costly major items in broiler breeder feeds. Therefore, it is worth trying to maximize the efficiency of protein and amino acids utilisation in order to minimise the cost of production whilst achieving maximum performance. In some cases this could be achieved by reducing the excessive contents of some amino acids, thereby improving amino acid balance. A simple means of achieving this is to partially replace some of the standard protein sources (e.g. soybean meal) with purified synthetic amino acids (Han and Lee, 2000). Nowadays, the use of crystalline amino acids is widespread in manufacturing of feed for animals. L-lysine, DL-methionine and DL-threonine are commonly used to replace or supplement natural protein sources of these three amino acids.

Many researchers have clearly shown the protein-sparing effect of using synthetic amino acids to balance low protein diets. In a review of literature, Han and Lee (2000) concluded that the supplementation of limited amounts of synthetic amino acids (0.1 to 0.3%) to feeds for swine and poultry could spare 2 to 4 percentages units of dietary protein with no decrease in weight gain or feed conversion. When 0.07% lysine was added to the diets of layers, egg mass and efficiency of egg production were not affected by a lowering in the protein level by 2 percentage units. Reducing the protein content of broiler breeder feed by 6 percentage units, when supplementing 0.28% methionine and 0.68% lysine to compensate for lowered methionine and lysine content supplied by protein, had no effect on performance (Lopez and Leeson, 1995).

The protein-sparing effect originated from the concept of a low-pollution diet. An excess of dietary protein or deficiency in calories from carbohydrates and/or fat will cause a proportion of proteins to be used for energy. In either case, protein will be broken down and carbon used for energy, thus nitrogen will be excreted as uric acid (in poultry) (Han and Lee, 2000). Han and Lee (2000) pointed out that reducing the protein level by more than 2 percentage units substantially lowered nitrogen excretion by more than 10% in pigs and broilers. Feed was supplemented with lysine, methionine and, in most cases, also with threonine and tryptophan. In one layer study, Kim and Han (1996), as cited by Han and Lee (2000), stated that by lowering the crude protein level by 2 percentage units, nitrogen excretion was decreased by 13.6%.

Supplements of synthetic amino acids to animal diets are important not only on nutritional and economic grounds, but also for environmental purposes. However, the *in vivo* utilization of added free synthetic amino acids is still open to considerable discussion. Possible upper limits to the use of synthetic amino acids to replace protein have been discussed by Bach-Knudsen and Jorgensen (1986). Concern arises mainly from the demonstration by Batterham's group in Australia (Batterham, 1974; Batterham and O'Neill, 1978; Batterham and Murison, 1981) that growing pigs meal-fed once daily utilise crystalline lysine, added at a level of 2g L-lysine/kg diet, no better than 43 to 67% of that achieved by pigs meal-fed six times daily. In those trials no improvement in performance was seen when feeding the control diet six times compared with once daily. In contrast, Walz (1981; 1983), as cited by Bach-Knudsen and Jorgensen (1986), could not verify any improvement in pig performance by frequent administration of free synthetic lysine. The absorption of free amino acids is more rapid than that of protein-bound amino acids due to the fact that the added free amino acids pass the stomach together with the easily hydrolysable nitrogen fraction very shortly after feeding (Bach-Knudsen and Jorgensen, 1986), thereby being available at sites of protein synthesis before the remaining amino acids from gut protein hydrolysis reach these same sites. On the other hand, with frequent meals, one would assume equilibrium to be established between gut, blood and tissues with regard to lysine utilisation for protein synthesis (Baker and Izquierdo, 1985). These latter authors found that twice-daily feeding of diets supplemented with 0.08% and 0.16% of lysine to chicks showed no evidence of diminished lysine utilisation. (63.2% and 64.7% meal fed versus 67.8% and 66.7% *ad libitum* fed). The efficiency of crystalline lysine supplement was virtually the same whether chicks were meal fed or *ad libitum* fed. It would appear that pigs or chicks on meal-feeding regimens should be fed at least twice daily, and perhaps thrice daily, in order to maximise the efficiency of lysine and protein amino acid utilisation. Moreover, it should not be assumed that results with lysine-supplemented diets would parallel those with diets supplemented with crystalline amino acids other than lysine (Baker and Izquierdo, 1985). In laying hens, Shannon (1981 and unpublished), as cited by Fisher (2000), used variable levels of methionine, lysine and intact protein in different daily sequences of supplementation. All sequences supplied the same average amino acid or protein levels in the feed. With both free amino acid and intact protein, 24 hours variations in supply gave poorer production than continual levels. Variations over shorter time periods were not tested. These results leave open the question as to whether broiler breeder hens, which are fed once per day or, in "skip-a-day" rearing

systems, even less frequently are likely to show reduced protein or amino acid utilization; the question seems to merit further investigation.

2.4 BODY WEIGHT AND BODY COMPOSITION

Feed restriction is used almost universally to control the body weight of immature and mature broiler breeders. The effect of feed restriction on body weight is well documented. Birds fed different protein and energy intakes show increased body weight gain with increased energy intake. Body weight gain increases linearly with increased energy allowance (Pearson and Herron, 1980, 1981, 1982; Spratt and Leeson, 1987; Attia *et al.*, 1995). However, protein intake during lay did not affect body weight or weight gain in a trial by Pearson and Herron (1981; 1982).

While the effect of feed restriction on body weight is well documented, much less is known about its effect on the body composition of the laying broiler breeder. When body composition has been considered, it has been measured during the rearing period (Bennett and Leeson, 1990), at the end of the rearing period (Blair *et al.*, 1976; Pearson and Herron, 1980, 1981, 1982; Spratt and Leeson, 1987; Renema *et al.*, 1999) or at the end of the laying period (Blair *et al.*, 1976; Pearson and Herron, 1980, 1981, 1982; Spratt and Leeson, 1987; Attia *et al.*, 1995; Wilson *et al.*, 1995), but not whilst the laying period progresses.

Most of the body weight gain in the breeding period occurs in the early part of lay as food allowance is increased and prior to the birds coming into lay. Pearson and Herron (1980) studied the effects of increasing or decreasing the intakes of nutrients of broiler breeders placed on the floor during the laying period. The comparison of the carcass constituents at 34 weeks with those of a sample of pullets killed at 22 weeks of age showed significant growth in all constituents between 22 and 34 weeks of age. The researchers showed that an increase in carcass protein (281g vs. 362g and 326g) that had occurred by 34 weeks of age suggesting that at 22 weeks of age birds restricted during the rearing had not reached maximum lipid-free body size but continued to lay down muscle tissue as well as lipid during the early part of the breeding period. However, at 22 weeks of age, birds were probably not laying and so there would have been a period when they continued to grow in protein before they started to lay. There may have been no further growth of protein once the hens started laying.

Several authors have shown that the percentage of body lipid was affected by energy restriction and live weight during the growing period, but females were able to achieve sexual maturity as measured by age at first egg with a wide range of body lipid contents. In contrast, the proportion of protein in the body remained remarkably constant, not apparently affected either by age, live weight or age at first egg (Bennett and Leeson, 1990; Soller *et al.*, 1984). During the laying period, the results obtained were quite contradictory mainly with respect to body protein content. Not surprisingly, increasing the energy allowances of broiler breeders during the laying period increased body weight, with differences in body weights being due mainly to differences in lipid deposition. Blair *et al*. (1976) showed that regulating the amount of food to achieve 90, 100 and 110% of a target weight during the growing period did not influence the carcass composition at 22 weeks of age (185, 183 and 190g/kg carcass protein, 162, 178 and 164g/kg carcass fat, respectively). However, at 66 weeks, the carcass composition was markedly influenced by the amount of food allowed during the laying period (80% or 100% of a set allowance). The carcasses of the restricted hens contained significantly more moisture and protein (631 vs. 585g/kg carcass moisture, 195 vs. 179g/kg carcass protein, respectively) and significantly less fat (136 vs. 200g/kg carcass fat, respectively). Pearson and Herron (1981) fed broiler breeders in floor-pens with 1.88, 1.73 or 1.52MJ AME per bird at two protein intakes (27 or 21.3g crude protein (CP) per bird) or daily protein intakes of 24.6 and 19.4g CP per bird at a daily energy intake of 1.88MJ AME per bird from 21 to 64 weeks. The differences in live weight of birds at 64 weeks associated with energy allowance were found to be due mainly to differences in lipid and water content of the carcass. No significant differences in protein or ash content were observed in these birds (average of 170g/kg protein and 43g/kg ash). The protein intake during the laying period had no significant effect on carcass composition at 64 weeks, which is in agreement with Pearson and Herron (1982) with birds placed in cages. Attia *et al.* (1995), who determined the effect of reducing the daily energy intake of broiler breeders placed on the floor while maintaining a constant intake of other nutrients, found a highly significant positive relationship between daily energy allotment and carcass lipid at 61 weeks, while carcass ash and protein were negatively correlated with energy intakes. Spratt and Leeson (1987) found that the increase in carcass fat at 41 weeks, of broiler breeders placed in cages, due to the increase in energy intake occurred at the expense of both carcass protein and moisture. Carcass fat increased as protein intake increased. Wilson *et al* (1995) undertook a study to investigate whether the growth curve of breeder pullets to 24 weeks influenced subsequent flock performance.

Pullets were reared to 20 weeks in litter floor pens and were subjected to one of three feeding programmes: a standard skip-a-day program; an ‘early slow’ programme in which pullets were fed a lower than standard amount of feed to 20 weeks, and an ‘early fast’ treatment, with birds being fed a larger amount of feed to 20 weeks. At this time 25 birds from each growing treatment were placed in individual laying cages where they were kept to 58 weeks of age. Feed was increased for the ’early slow‘ birds and decreased for the ’early fast‘ birds in an attempt to have birds of similar body weight at onset of production. The carcass composition data at 58 weeks suggests that breeders, of similar weight at the onset of lay and subjected to the same feeding program, have similar carcass compositions throughout the reproductive cycle, regardless of the type of growth curve to 24 weeks of age (Table 2.11).

Table 2.11 Influence of feed allotment on body compositions (g/kg) of broiler breeders at 25 and 58 weeks of age (as adapted from Wilson et al., 1995)

Variable	Early slow	Standard	Early fast
Carcass composition at 25 weeks			
Body weight	2652	2690	2684
Carcass moisture	649	645	647
Carcass protein	179[a]	182[ab]	190[b]
Carcass fat	142	139	130
Carcass composition at 58 weeks			
Body weight	3556[a]	3368[b]	3450[ab]
Carcass moisture	555	571	567
Carcass protein	208	190	191
Carcass fat	156	164	164

The changes in body composition during rearing and lay are clearly influenced by the amount of each nutrient, and energy, supplied to the birds, the potential rate of growth and egg output of each bird, the competition at the feed trough, which prevents all birds from consuming the same amount of feed daily, the fluctuations in environmental temperature and many other factors. These factors would all have had some impact on the results presented above, making it impossible to understand the mechanisms involved by reading the literature.

2.5 RATE OF LAY AND EGG WEIGHT

The separation of amino acid requirements for egg production and egg weight (egg mass, or output, is the product of production and weight) as reported by Harms and Ivey (1992) may be a difficult approach because it has been shown that laying hens and broiler breeders partition amino acids for egg production and egg weight depending upon the severity of the deficiency (Morris and Gous, 1988; Bowmaker and Gous, 1991). These researchers showed that both rate of lay and egg weight decreased to the same extend until the amino acid supply was reduced to 0.9 for laying hens and 0.64 for broiler breeders of that required for maximum output. As amino acid supply was reduced further, rate of lay declined almost linearly to a low of 0.7 and 0.2, whereas egg weight was 0.9 and 0.8 of its maximum value for laying hens and broiler breeders, respectively. It seems that when the protein and amino acid intakes are low, birds tend to adjust first their egg production and secondly their egg weight (Figure 2.2).

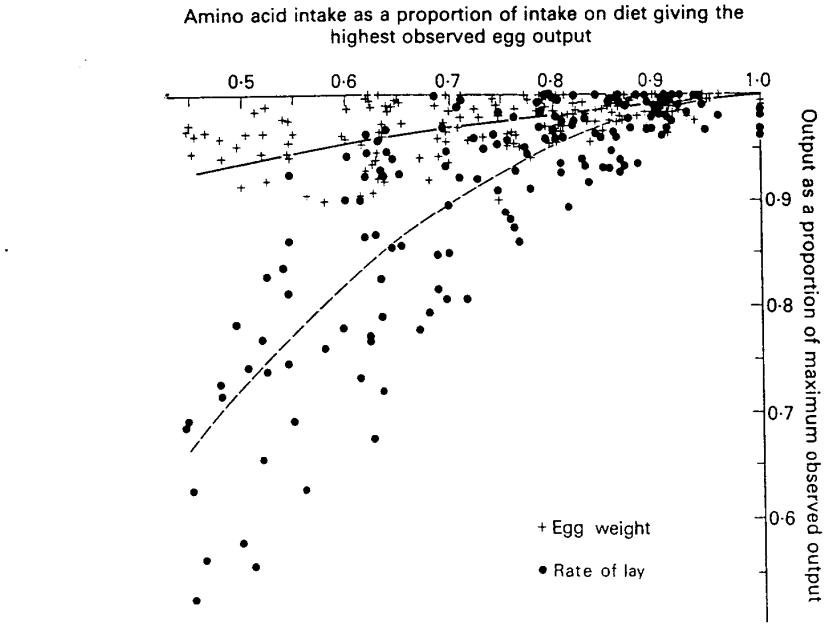


Figure 2.2 The relationship between intake of limiting amino acid and rate of lay (---) or egg weight (-) (From Morris and Gous, 1988)

2.6 EGG COMPOSITION

Knowledge of the chemical composition and physiological processes of yolk and albumen formation has been obtained mostly from work with commercial layers. This information has been applied when interpreting factors influencing egg composition of broiler breeder hens. The ratio of yolk to albumen in an egg is a useful measure of the change that can occur in egg composition. Some results indicate that egg weight, shell weight and percent yolk increase, while albumen and shell percentages of total egg weight decrease as a result of increasing bird age (Marion, 1964; Fletcher *et al.*, 1981; Fletcher *et al.*, 1983, Rossi and Pompei, 1995; Viera and Moran, 1998). Increase in yolk weight is usually correlated with an increase in egg weight (Fletcher *et al.*, 1983). The effect of bird age on egg composition has been described by Williams and Sharp (1978), who investigated the ovarian development and morphology in both broiler breeder hens and commercial layers. They reported that smaller and more numerous yellow-yolky ovarian follicles are observed in 26-week old than in 82-wk-old hens. As laying hens get older, the initial decrease in egg production and increase in egg weight is due to a reduction in the rate of recruitment of yellow-yolky follicles, which grow to a larger size before ovulation.

Egg composition is largely determined by the proportion of yolk, albumen and shell, and by the dry matter content of these components (Fisher, 1998). As previously reported, the energy content of eggs ranged from 1.33kcal/g (Sibbald, 1979) to 1.7kcal/g (Chwalibog, 1992). A typical egg weighs about 58 to 60g and contains 7 to 7.5g (11 to 12%) protein. About 3.1g (42%) is yolk protein, synthesized in the liver, and about 4g (54%) is albumen protein synthesized mainly in the magnum region of the oviduct. The remaining 3 to 4% of the protein is in the shell and its associated membranes (Fisher, 1980; McDonald and Morris, 1985). Lunven *et al.* (1973) measured the amino acid composition of hen's egg, and the results for lysine and methionine are given in Table 2.12.

Table 2.12 Lysine and methionine contents of yolk, albumen and egg (mg/g N) (Lunven et al., 1973)

Variable	Yolk	Albumen	Egg
mg lysine/g N	477	378	439
mg methionine/g N	175	240	195

Amino acid composition of eggs has been assumed to be constant across ages and different strains (Lunven *et al.*, 1973; Spratt and Leeson, 1987). Much of the research conducted during the past 50 years confirms the findings of Romanoff and Romanoff (1949) in terms of the proportional changes in the components with increasing egg weight and hen age. More recently, the emphasis has shifted towards quantifying the various relationships. Linear functions, which predict the yolk:albumen ratio from egg weight (Hussein *et al*., 1993; Harms and Hussein, 1993; Yannakopoulos *et al.*, 1998); albumen and yolk weight from egg weight (Hussein *et al*., 1993); and % albumen and % yolk from egg weight (Ahn *et al*., 1997) have been published. Fletcher *et al*. (1983) produced multiple linear regression equations to predict component weight from egg weight and flock age for Shaver hens. The changes in egg composition taking place over time in laying hens have been adequately modelled by Johnston (2004). However, most of the work has been done with commercial layers, and so examining the relationships between yolk, albumen and shell weights at different egg weights and ages of broiler breeder hens will need to be investigated.

2.7 DISCUSSION

The subject covered in this chapter, dealing with the nutrient requirements of broiler breeders, has suffered from a lack of a systems approach to the subject; with some empirical experiments having been done in some areas, whilst in others reliance has been placed on the information obtained for commercial laying hens. This has resulted in a paucity of information specific to the way in which broiler breeders should be fed in order to maximise performance and profit. Because the purpose of this thesis is to model the performance of broiler breeders with a view to improving the basis of making nutritional decisions, the literature relevant to this goal has been searched for, but found wanting. Many of the results quoted are contradictory, confusing and, hence, unhelpful. There is no doubt that by adopting a modelling approach to the problem, a great deal more progress can be made than has been the case in the past 50 years.

Compared with the modelling of meat-type animals (e.g., broilers, pigs and beef), model development for laying hens is still in its infancy, as well as being more complex in some respects. Not only must body weight gain be considered, as in the case when modelling broilers, but so must egg output, which is both discontinuous and accompanied by changes

in composition with time. But some progress has been made in modelling the laying patterns of commercial laying hens (Johnston, 2004) and this same approach can certainly be applied to broiler breeders. With this knowledge, the daily nutrient requirements of each hen can be determined more precisely, leading to the successful modelling of performance given a daily allocation of nutrients and energy.

There are a limited number of papers describing the factorial requirements for energy and amino acids for broiler breeders. Past research reports have based the feed requirements of broiler breeder hens mainly on the principles designed for the feeding of commercial laying hens and have either evaluated dietary energy and protein levels or have discussed amino acid needs using linear regression analysis of empirical data or by deriving partition equations, which assume linear relationships between inputs and outputs. The major concerns associated with these methods is that no provision is made to accommodate the considerable variance associated with genetic differences among breeds and strains, environmental (including social) effects and effects of other diet components (fat versus carbohydrate). Of course, it is necessary to have data available from empirical studies with specific strains fed specific diets in specific environments in order to produce a mechanistic model. However, the point of the above comments is to emphasize that, depending on how the experiment has been conducted, the coefficients resulting from these trials may have no essential biological meaning and might not be applied to situations beyond those defined by the data set used to estimate the values of the parameters in the equation. Examples are the lack of agreement on an egg GE value and the use of non-standardized methods for determining the relative efficiencies of egg output and body weight change, both of which have lead to different coefficients being used in prediction models. The requirements suggested by some researchers in past research may reflect egg production that would be less than optimum with the present breeder hen. Nutrient requirements for breeders need to be expressed on a factorial basis so that data can be extrapolated for differences in strains, ages, body weight, mature protein weight, body composition, egg size and egg composition. Broiler breeders potentially may make more profound changes in body weight, egg weight and egg mass than a commercial-laying hen, which enhances the need for developing a factorial model.

The Reading Model (Fisher, 1973) is based on simple factorial equations and provides an excellent method of determining the economic optimum amino acid supply for a flock of

laying hens, resolving the problem of diminishing returns and variability and characterized by the ability to combine the results of different experiments. One limitation to the Reading Model is the need for maintaining a normal distribution for production among the individuals of the flock. If the egg output of a flock of broiler breeders followed a normal frequency distribution, then the nutritionist would be justified in using the Reading Model to determine the optimum daily intake of each amino acid to be fed to the flock and because a measured amount of feed is allocated to the birds daily, it would be a simple matter to determine the concentration of each amino acid to be included in the feed. Gous (personal communication) pointed out that research with broiler breeder hens placed in individual cages has proved that the frequency distribution of egg outputs is decidedly non-normal. There is a large group of birds whose egg output, even on the most generous feeds, is zero, or up to a maximum of about 10g per day (i.e. one egg every seven days). If these birds were excluded from the analysis, the mean egg output of a flock would increase by about 5g per day, which is a considerable correction if this variable is used in calculating the optimum amino acid intake of the flock. A second limitation in the application of the Reading Model is that differences in efficiency of utilisation of amino acids are not considered. Birds that are not laying in close cycles, i.e. those birds that produce fewer than one egg every two days, have been shown to utilise their dietary nutrients less-efficiency than do birds that lay in closed cycles. Fisher (1980) demonstrated this with laying hens and Bowmaker and Gous (1991) found the same tendency with broiler breeder hens. There is a significant decline in efficiency as the rate of laying drops below 0.5. A third limitation of the Reading Model is its static nature. The possibility exists that a portion of individuals in a population will not be satisfying their need for limiting amino acid when a flock of hens receives the optimum amino acid requirement as determined by the Reading Model. The underfed hens may mobilise body protein, which may serve as an amino acid reserve to maintain the level of egg production they are capable of. However, how long can the amino acid reserve sustain the level of production? What production will be expected after depletion of this reserve? Would the hen go out of production or partition the limited amino acid intake between egg number and egg weight? The Reading Model appears to be increasingly inappropriate for flocks of broiler breeder hens. A mechanistic approach to the question of feeding broiler breeders efficiently seems to be a more sensible approach, given the above arguments.

Another question regarding the amino acid nutrition of broiler breeder hens that requires closer scrutiny is the extent to which the maintenance requirements are related to body weight as opposed to body protein content. Because these birds have considerable lipid reserves, especially the poor layers in the flock, and because it can be argued that there is no energy cost in maintaining such lipid reserves (Emmans and Oldham, 1989), it is unlikely that the amino acids required for maintenance (as defined by the **b** value of the Reading Model) would be related to the body weight of the bird. A more accurate estimate of the amount required for maintenance, when comparing broiler breeder hens of different size and body composition, would be that related to the protein content of the body, as has been suggested by Emmans and Fisher (1986) for broilers. Very little work on the body composition of broiler breeder hens on a feed restricted programme has been reported. The body composition of broiler breeders in lay has been measured mainly at the end of the laying period. The pattern of changes in body composition over time in the mature broiler breeder hen has not been rigorously investigated. The bird's body composition should be more studied, because knowledge of the changes that take place in the protein content of broiler breeders at different stage of the laying period will be useful when calculating the maintenance requirement.

In the literature, the response of broiler breeder hens to protein has often been confounded by intakes of limiting amino acids. For example, although some researchers have reported good egg production by feeding 27.7g CP and 1 272 mg of lysine per bird d (Bowmaker and Gous, 1981), others have reported CP needs as low as 18.6g CP when combined with 808 mg lysine (Wilson and Harms, 1984). This suggests that the efficiency of protein utilisation depends to a large extent upon the amino acid composition of the diet. Thus, lower protein requirements could only be achieved by ensuring that the amino acid requirements of the bird are met. The availability of synthetic amino acids now permits the use of lower dietary crude protein content while meeting the amino acid requirements. However, the general experience with Leghorns, pigs and broilers is that such diet modifications are only partly successful. As natural protein sources are replaced with synthetic amino acids, problems such as reduced egg production, poor egg size or reduced growth rate occur with pigs and broilers. The poor utilisation of synthetic amino acids was attributed to different rates of delivery of the free amino acids and the amino acids from intact protein to sites of synthesis. Possible upper limits to the use of synthetic amino acids to replace protein have been discussed and an optimum utilisation of free synthetic amino

acids has been shown when meals were offered at least twice-daily. If free amino acids are absorbed and excreted ahead of the intact dietary protein, this could explain why broiler breeders fed once per day and eating their meal sometimes in as little as 10-20 minutes are likely to show reduced protein utilisation. The possibility of eliminating synthetic amino acids from feeds for broiler breeder hens needs to be investigated.

The optimum energy intake for a flock of broiler breeders cannot be calculated in the same way as the optimum amino acid supply. Gous *et al*. (1992) showed that fattened broilers can make use of excess body lipid reserves providing that their protein intake is sufficiently high to allow this. Considering the excessive amounts of carcass fat present in a broiler breeder hen at all stages during the laying period, if these birds are able of drawing on lipid reserves to supply the body with energy, it is unlikely that energy is a limiting factor in egg production, and instead, likely that they are being supplied with energy in excess of their needs. Alternatively, the lipid stores may not be labile reserves of energy from which the bird can obtain energy when required, in which case this energy source can not be utilised, nor can we make assumptions about the adequacy of dietary energy supply by observing the carcass fat content of broiler breeders. The possibility of broiler breeder hens being made to utilise their excess body lipid reserves as an energy source and the effect on laying performance needs to be investigated because this may help to solve some of the difficulties in meeting the changing energy requirements of broiler breeder hens.

The daily energy allotments are also difficult to prescribe because the energy requirements of broiler breeders change according to their egg production and with fluctuations in environmental temperature. Temperature is the major environmental factor that influences heat production, measured mainly as energy required for maintenance. Because the food intake of broiler breeders is restricted, they cannot increase their food intake if the environmental temperature falls so the food allowance needs to be adjusted accordingly. Whether heat production is a linear or non-linear function of temperature remains unsettled and determining the energy requirement for maintenance as influenced by temperature for broiler breeder hens during the laying period still needs to be investigated

The question of whether non-laying birds consume as much food as do laying birds was investigated by Bowmaker (1991), who found that all birds, irrespective of output,

consumed all the feed that was allocated to them, except if that feed was severely limiting in some nutrient. Goddard (1997) found that lysine concentration had a significant effect on food intake, below a concentration of 3g lysine/kg food, decreasing linearly with decreasing dietary lysine concentration. It appears that if a restricted amount of food is available, the hens will consume as much of this as possible, irrespective of whether or not they are producing an egg that day. However, access to the food trough, when a limited amount of food is supplied, is a function of the pecking order or position in the hierarchy of each hen. Whether or not the non-laying hens are less aggressive than those in lay, and would hence consume less food as a result, is a question that has not been resolved, but which is vital when simulating the performance of a population of breeders.

When predicting nutrient requirements of a broiler breeder hen the composition of the products being formed must be known or predicted. The protein-containing components of the egg differ in energy and amino acid content, and the weights of these components and the ratio between them changes as the hen's age. By predicting egg weight as the sum of the weights of the three components; yolk, albumen and shell, and using yolk weight as the driving variable and the allometric relationships that exist between these components it would be possible to predict the weights of these components even under conditions where the hen is being undersupplied with nutrients.

The estimates of energy and amino acid requirements of broiler breeder hens are commonly based on single predictions, which can be adjusted empirically to specific genetic stocks, environments and management strategies. However, the number of internal and external factors and interactions, which have to be considered for optimum feeding strategies, is very large. The most appropriate means of determining the optimum nutrient intakes for flocks of broiler breeders would therefore not be by means of further experiments with different levels of nutrients, but rather by means of simulation modelling. Because the principles of *ad libitum* feed intake applied to commercial laying hens cannot be used for broiler breeders, and no consistent method of determining the requirements of broiler breeders exists, it was decided to investigate the modelling of energy and amino acid requirements by use of simulation in order to optimise a feeding strategy for broiler breeder hens after sexual maturity.

The following chapter deals with the determination of the pattern of change in the feathers and the feather-free body (water, lipid and protein) of the mature broiler breeder hen.

CHAPTER 3

BODY COMPOSITION OF BROILER BREEDER HENS: BODY PROTEIN CONTENT AFTER SEXUAL MATURITY

3.1 INTRODUCTION

When modelling the nutrient requirements of broiler breeder hens during the laying period a large proportion of these requirements are to maintain the bird. Emmans and Fisher (1986) and Fisher (1998) indicated that maintenance requirements are more accurately estimated when based on the protein content of the body than on body weight, so it is important to know how the body composition of broiler breeders changes during the laying period. Feed restriction is used to control the body weight of both immature and mature broiler breeders. While the effect of feed restriction on body weight is well documented, much less is known about its effect on body composition. This has been measured during the rearing period (Bennett and Leeson, 1990), at the end of the rearing period (Blair *et al.*, 1976; Pearson and Herron, 1980, 1981, 1982; Spratt and Leeson, 1987; Renema *et al.*, 1999) and at the end of the laying period (Blair *et al.*, 1976; Pearson and Herron, 1980, 1981, 1982; Spratt and Leeson, 1987; Attia *et al.*, 1995; Wilson *et al.*, 1995). However, the pattern of changes in body composition over time in the mature broiler breeder hen has not been rigorously investigated. The methodology used in analysing the chemical composition of breeders during rearing and lay has been inconsistent, making it even more difficult to make use of previously published information to predict changes in composition over time. In some cases, for example, feathers were included in the birds being analysed, whilst in other cases they were not.

The present study was undertaken to determine the pattern of change in the feathers and the feather-free body (water, lipid and protein) of the mature broiler breeder hen.

3.2 MATERIALS AND METHODS

1500 Cobb broiler breeder females were reared on two growth curves, the first as recommended by the primary breeder (Cobb 500 breeder guide, 2001) designed to achieve 2100g at 20 weeks, while the other was a fast growth curve to achieve the same weight, but

at 15 weeks. At 20 weeks, 880 pullets were transferred to 16 floor pens in an open-sided house. The lighting program was 8L: 16D to 20 weeks, and 16L: 8D (04:00-20:00) during the laying period.

All birds were fed a 210g CP/kg, 12.4MJ AME/kg crumbled diet *ad libitum* to three weeks of age and a 175g CP/kg, 11.9MJ AME/kg pelleted diet scattered on the litter to six weeks, at which stage the feed was again changed to a 140g CP/kg, 11.5MJ AME/kg and finally to a 145g CP/kg, 11.5MJ AME/kg layer diet from 5 eggs/100 bird d. egg production onwards. Daily feed allocation was progressively increased to a peak of 165g/bird d at 30 weeks before being reduced by 5g/bird for each subsequent 5% fall in rate of lay.

Six birds from each growth curve were sampled at 15, 20, 30, 40, 50 and 60 weeks for carcass analysis. The birds were killed by cervical dislocation prior to feeding so as to reduce the variation associated with feed in the digestive tract. The carcasses were defeathered and, after freezing, were sectioned and passed twice through an electric meat grinder in order to ensure thorough mixing and grinding. Samples (300 g) were freeze-dried to determine moisture content. The dried material was analysed for nitrogen using the LECO nitrogen analyser (LECO Africa (Pty) Limited, P.O. Box 1439, Kempton Park, South Africa) and for gross energy (GE) using an adiabatic bomb calorimeter. All results were converted to g/100g on a wet basis. Protein content was calculated as 6.25 times nitrogen content. Lipid content (LC) was calculated from GE using the equation: LC = -0.8756 + 0.004754 GE, g/g (University of KwaZulu-Natal, unpublished).

The means for all ages and the two growth curves were calculated using the general analysis of variance in Genstat (1997).

3.3 RESULTS

Mean feather-free body weights and composition from 15 to 60 weeks of age are presented in Table 3.1. The rearing treatments were designed to produce differences in body weight at 20 weeks, thus the faster-growing birds were 720g heavier ($P<0.001$) at 20 weeks because of a greater proportion of body lipid (71 vs. 121g/kg) and feather weight (28 vs. 43g/kg) for the control and fast birds, respectively). There was no difference in body protein content between growth curves at 20 weeks when this was expressed as a

proportion of feather-free body weight (186 vs. 178g/kg for the control and the fast birds, respectively).

Table 3.1 Mean feather-free body weight and composition of broiler breeder females reared on two growth curves (control = C and fast = F) from 15 to 60 weeks of age

Age (week)	Feather-free body weight (g)			Feather weight (g)		
	C	F	Mean	C	F	Mean
15	1813	2130	1972	59	77	68
20	1709	2371	2040	50	107	79
30	3142	3727	3435	283	308	295
40	3775	3847	3811	234	274	254
50	3757	4170	3964	95	122	108
60	4079	4008	4043	127	168	147
Mean	3046	3376		141	176	
s.e.d			145.9			22.5

Age (week)	Water weight (g/100g)			Protein weight (g/100g)			Lipid weight (g/100g)		
	C	F	Mean	C	F	Mean	C	F	Mean
15	72.5	72.1	72.3	17.5	18.3	17.9	7.8	9.3	8.5
20	72.2	68.3	70.2	18.6	17.8	18.2	7.1	12.1	9.6
30	66.3	63.8	65.0	17.3	16.9	17.1	14.4	15.8	15.1
40	64.1	62.6	63.4	17.1	16.9	17.0	17.0	18.1	17.5
50	63.8	62.9	63.3	16.2	17.2	16.7	16.7	18.0	17.3
60	59.7	61.9	60.8	16.2	17.5	16.8	20.5	18.6	19.6
Mean	66.4	65.3		17.2	17.4		13.9	15.3	
s.e.d			1.218			0.412			1.535

There were no interactions in protein, lipid or feather growth between age and shape of growth curve, indicating that the pattern of component growth was the same for birds reared on the control and the fast growth curves. Consequently, data from the two growth curves were pooled to increase the number of replications at each age. The patterns of change for body protein and lipid contents and the pattern of change for feather weight of broiler breeder hens from 15 to 60 weeks of age are shown in Figure 3.1.

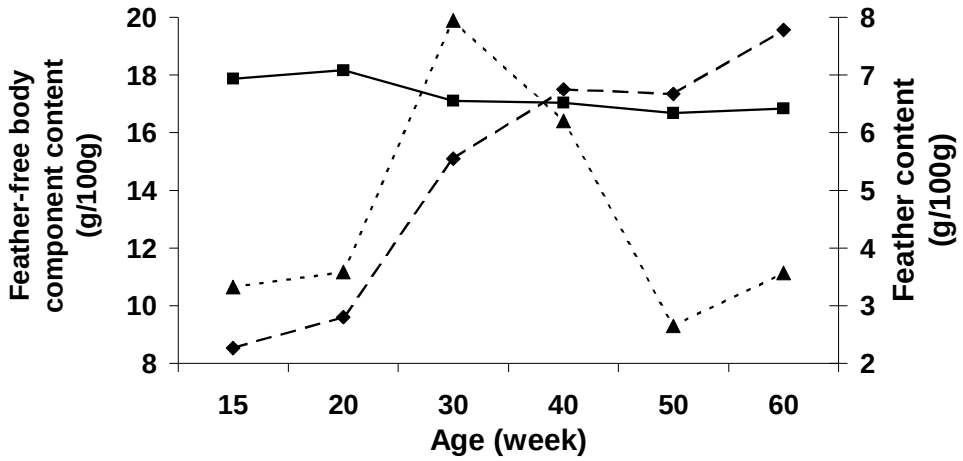


Figure 3.1. The patterns of change in body protein (solid line) and lipid (dashed line) contents and in feather (dotted line) weight of broiler breeder hen from 15 to 60 weeks of age

Initially, the weight of protein was between 354 and 368g at 15-20 weeks increasing ($P<0.001$) to 648g at 40 weeks and then remaining constant for the rest of the laying period. The body lipid content increased ($P<0.001$) from 175g (85g/kg) at 15 weeks to 805g (196g/kg) at 60 weeks. The proportion of body lipid was inversely proportional to that of water, the latter decreasing ($P<0.001$) from 723g/kg at 15 weeks to 608g/kg at 60 weeks. Feather weight increased from 33 at 15 weeks to 80g/kg body weight at 30 weeks. The three components of the body (g/kg) were regressed against age, and the resultant regression coefficients are shown in Table 3.2.

Table 3.2 Linear regression equations relating feather-free body weight and composition from 15 to 60 weeks of age

	Constant term	s.e	Linear coefficient	s.e	R^2
Water (g/kg d)	741.1^{***}	9.7	-0.324^{***}	0.033	54.3
Fat (g/kg d)	61.7^{***}	11.7	0.330^{***}	0.040	45.9
Protein (g/kg d)	181.7^{***}	3.2	-0.032^{**}	0.011	9.0

3.4 DISCUSSION

Knowledge of the changes that take place in body composition during the laying period, particularly those in protein content, may be used as the basis for calculating the maintenance requirements of these birds. Birds reared on the fast growth curve were

heavier, with greater amounts of feather, protein, lipid and water than birds reared on the control growth curve. However, there was no significant difference in body protein content expressed as a proportion of feather-free body weight due to growth curve at 20 weeks, indicating that pullets on the different growth curves deposited muscle tissue at a similar rate. This latter observation has been reported previously. Blair *et al.* (1976) fed broiler breeder pullets 0.9, 1.0 or 1.1 of the feed intake recommended by the breeder and observed that birds on all three treatments had body protein contents between 200 and 209g/kg at 22 weeks of age. Bennet and Leeson (1990) assigned pullets from 10 to 24 weeks of age to one of three diets formulated to contain 150g crude protein/kg and 10.67 (low-energy), 11.72 (standard) or 12.89 (high-energy) MJ ME/kg. They revealed a relatively constant carcass protein content of 200 to 210g/kg from 14 to 24 weeks of age. Renema *et al*. (2001) grew pullets on one of three growth curves: STD (Standard), LOW (150g lighter than STD) and HIGH (150g heavier than STD) and found no difference in carcass protein content as a proportion of body weight due to growth curve at 20 weeks (209, 207, and 208g/kg for the LOW, STD and HIGH birds, respectively). These researchers found a higher proportion of body protein content around photostimulation age because they were using a different methodology than the one used in the present study. In the experiment by Blair *et al*. (1976), carcasses were plucked and eviscerated, while Bennet and Leeson (1990) used unplucked carcasses, and Renema *et al*. (2001) analysed unplucked carcasses with the exception of liver, making difficult a comparison of results.

The increase in body protein content between 20 and 40 weeks suggests that birds continue to deposit body protein during the early part of the laying period. This result is in agreement with Pearson and Herron (1980) who also found that feather-free body protein content continued to increase between 22 and 34 weeks of age. Part of this increase will be in the growth of the ovary and oviduct (Bowmaker and Gous, 1989). Differences in age at sexual maturity between birds in the flock will also contribute to the variation in the apparent increase in body weight during this period, with early maturing birds no longer growing, and perhaps even losing weight, whilst those not yet sexually mature would continue to grow until the first egg was laid. Feather weight continued to increase during this period also, reaching 0.08 of the body weight by 30 weeks. Thereafter the increase in body weight was due to an increase in lipid weight at the expense of water with protein content remaining a relatively constant proportion of the feather-free body weight from 30 weeks onward. The equal and opposite regression coefficients and the highest R^2 values for

changes in water and lipid content over time (Table 3.2) suggest that most of the variation that occurs in the body of the adult broiler breeder is in these two components.

The predominant requirement, when determining the nutrient requirements of broiler breeders during lay, is for maintenance followed by that for egg output. It is questionable whether provision should be made for the growth of body tissue. Clearly, the change in body weight observed during the laying period is not independent of nutrient intake but it could be argued that body protein and lipid deposition or utilisation, leading to a change in body weight, should be regarded as being a consequence of the nutrients consumed and not as an obligatory process. This being the case, the balance of ME intake remaining after accounting for maintenance and egg production would be converted into body lipid with varying efficiencies depending on whether the dietary lipid was deposited directly as body lipid or first converted to CO_2 and H_2O (Emmans, 1994). Importantly, provision should not be made for an obligatory gain in body protein during lay.

Between 30 and 40 weeks of age the mature birds lost feathers, indicating either a moulting process or a progressive wearing away of feathers that ended by 50 weeks of age.

The results of this experiment indicate that body protein content and feather weight continue to increase during the early part of the laying period, so for purposes of modelling the nutrient requirements of broiler breeders during the latter part of the growing period (>20 weeks of age) and through sexual maturity, the growth of these two components should be considered when calculating the daily nutrient requirement, together with those for maintenance and egg production. Most of this growth can be accounted for by considering the growth of ovary and oviduct, and by differences in the age at which sexual maturity is attained. Considering that feathers have a protein content of around 0.84 (Chandler, 2005) and that the feather-free body protein content was 180g/kg at 20 weeks with a feather weight of 80g, a body protein content of 200-210g/kg may be used as the basis for calculating the maintenance requirements of broiler breeder hens at sexual maturity, which is in agreement with most of the previous reports on this subject. The weight of body protein remains relatively stable throughout the laying period, so it should not be necessary to assume that protein growth is obligatory when determining nutrient requirements of broiler breeder hens. The change in feather weight, however, is of such a

magnitude that this should be considered when calculating amino acid requirements of these birds during the laying period.

The following chapter deals with the measurement of the maintenance requirements for threonine and lysine in poultry.

CHAPTER 4

THREONINE AND LYSINE REQUIREMENTS FOR MAINTENANCE IN ADULT BROILER BREEDERS

4.1 INTRODUCTION

In order to develop an effective model for the precise feeding of broilers during growth and of broiler breeder hens after sexual maturity, the maintenance requirement for each essential amino acid must be known, particularly as the maintenance requirement becomes the major proportion of the total requirement as birds age. One method of determining these requirements is to use a factorial approach, such as that applied in the Reading Model (Fisher *et al*., 1973). Where this has been used for broiler breeders, the maintenance coefficients for lysine and methionine calculated by Bowmaker and Gous (1991) were 11.2W and 1.52W respectively, where W is body weight, kg. These values are considerably lower than those derived for laying hens (73W and 31W for lysine and methionine, respectively) (McDonald and Morris, 1985). Such differences are unacceptably high, so a more satisfactory method of determining these requirements is needed.

Maintenance amino acid requirements are normally defined at nitrogen equilibrium, the state in which nitrogen intake exactly equals the sum of nitrogen losses so that the nitrogen content of the body remains constant (Sakomura and Coon, 2003). Ideally such studies should be conducted on adult male fowl, as these birds are most likely to be in a steady state thereby avoiding the confounding effect, when interpreting the results of trials conducted on growing birds, of partitioning the amino acids consumed between growth and maintenance. Nevertheless, most authors have approached the problem of estimating the amounts of an amino acid required for maintenance using response trials with populations of laying hens or growing birds. Fisher *et al.* (1973) developed the so-called Reading Model to estimate the coefficients of response (mg amino acid required per g egg output and per kg body weight) to amino acid intake in laying hens, and this technique was subsequently used relatively successfully with growing birds (Clark *et al*., 1982; Boorman and Burgess, 1986) even though the Reading Model applies only to populations that are in a steady state, which is not the case with growing animals. No attempt was made in these

latter trials to reduce growth rate to zero when attempting to determine the maintenance requirements of the birds. Instead, the growth rate was extrapolated to zero and the intercept on the X-axis (amino acid intake/bird or /kg) produced the required coefficient. The technique used by Edwards *et al*. (1997; 1999) and Sakomura and Coon (2003), who used growing broilers and broiler breeder pullets respectively, differed considerably from the above technique. They used feeds that contained increasing amounts of the test amino acid as the only protein source and measured accretion of that amino acid by whole body analysis. This begs the question of whether growing birds would use a single amino acid for maintenance in the absence of any others, and whether this technique adequately addresses the problem of some birds losing weight whilst others gain weight during the balance period of three weeks.

An alternative approach to estimating the maintenance coefficient is to measure this in the absence of growth using adult roosters (Leveille and Fisher, 1958; Gous *et al*., 1984; Gous, 1986). The maintenance requirement for a number of amino acids including threonine and lysine by adult roosters has been determined by Leveille and Fisher (1959, 1960) in which the nitrogen source used was a whole egg diet and a free amino acid mixture containing 13 amino acids, supplied at the same level as found in whole egg protein. The resultant curvilinear response for isoleucine in that trial suggested that an amino acid other than the one under test was probably first-limiting, and the observed food refusal of birds eating pelleted food first-limiting in threonine cast doubts as to the validity of the results obtained. A method of measuring maintenance requirements using adult male cockerels was suggested by Gous *et al*. (1984) and was applied successfully by Burnham and Gous (1992) for measuring the isoleucine required for maintenance of broilers.

The present two studies were designed to eliminate the problems that have been identified in earlier attempts to measure the maintenance requirements for threonine and lysine in poultry, by measuring the nitrogen balance of mature cockerels subjected to a range of intakes of a feed known to be first limiting in threonine or lysine. A technique similar to that suggested by Gous *et al*. (1984) was applied in these trials to measure the maintenance requirements for threonine and lysine.

4.2 MATERIALS AND METHODS

24 adult cockerels of a laying strain were housed in individual cages in both studies. Each cage was supplied with one nipple drinker and drip cup, and one feeder. The house was cross-ventilated using up to six fans. The lighting program used throughout the experimental period was 16L: 8D (04:00-20:00).

For the threonine study only, the birds were subjected to a surgical procedure two days before the beginning of the trial where a plastic ring was sutured around the vent in order to attach a colostomy bag for collecting excreta. Feathers around the cloaca were removed the day before the surgical procedure, to allow better adhesion of the ring to that area and also for sanitary reasons. In the lysine study, a tray covered with foil was suspended beneath each cage to catch the excreta, and feathers around the cloaca were also removed.
In both studies, a protein-free basal diet was made available to the birds *ad libitum* to allow each bird to meet its daily energy, vitamin and mineral needs. A summit diet was formulated to contain all the essential amino acids in the balance assumed to meet the maintenance requirement of a bird, but with threonine or lysine at a lower concentration than required, thereby making one of these the limiting amino acid in each feed. The composition of the protein-free and summit diets used in the threonine (PFD_T and SD_T) and lysine (PFD_L and SD_L) studies are presented in Table 4.1. Quantities of the summit diet were weighed out (0, 10, 20, 30, 40 and 50g, for the threonine study and 0, 2, 4, 6, 8 and 10g for the lysine study) giving a series of intakes of threonine and lysine (unbalanced series) ranging from 0 to 239mg/kg and 0 to 40mg/kg body weight day, respectively. The range of intakes was chosen to ensure that the intake resulting in zero N balance would lie somewhere between the two extremes. N-free diet was then added to the summit diet to make the amount of food allocated to the bird each day by intubations up to 50g. To confirm that threonine or lysine was the limiting amino acid in the summit feed, and that the response obtained was to threonine or lysine and not to protein, a second series (balanced series) was prepared by adding to the summit feed either 2g threonine /kg or 4g lysine /kg diet, respectively. The same allocations of feeds in the balanced series were weighed out, and N-free diet was also added to these feeds to make the daily allocation by intubations up to 50g per day. Each feeding treatment was replicated twice. The threonine trial ran for three periods of 6d, the treatments being randomly allocated to the roosters in each period, i.e. each feeding treatment was replicated 6 times. The lysine trial ran for 6d.

All food was removed from feed troughs the day before starting the 6d experimental period in order to clear the digestive tract of protein-containing material. This feed was replaced, on the first day of the 6d trial period (24-hour after the start of the fasting period), with the N-free diet, which was made available *ad libitum* throughout the trial. On the second day (48-hour after the start of the fasting period), the test feeds were given by intubations, and this was repeated at the same time each day for 4d. On the morning of the third day (first day of the 3d balance period) the body weight of each bird was measured, and after being force fed, for the threonine study only, each bird was fitted with a colostomy bag, which was attached over its cloaca, after which the bird was returned to its cage. On each subsequent day the bag or the tray from the previous day was removed before the bird was fed, and another bag was attached and tray (covered with a new piece of foil) replaced before the bird was returned to the cage. Three bags or three pieces of foil of excreta, each representing the daily output from the previous day, were thus collected for each bird. Each bag was cleaned with water, and the excreta were transferred into pre-weighed aluminium dishes and placed in an oven kept at 60C to dry for 48h. Each piece of foil was directly placed in the oven. Subsequently, each aluminium dish or piece of foil plus contents was weighed, to determine the weight of dry excreta by difference, and the dry faeces were milled. The nitrogen content of the dry sample was determined using a Leco N analyser and thus the nitrogen output of each bird was calculated.

A linear regression of nitrogen retention on threonine and lysine intakes was fitted to the data from each replication, and a test of significance (linear regression with groups) was performed on the regression equations to establish whether they differed significantly from one another, using Genstat (1997).

Table 4.1 Composition (g/kg) of the protein-free diet and the summit diet used in the threonine (PFD_T and SD_T) and lysine (PFD_L and SD_L) experiments. Amino acid contents are given as digestible

Ingredients	SD_T	SD_L	PFD_T	PFD_L
Maize gluten 60		998.8		
Maize	231.0			
Soybean 48	376.0			
Soybean full fat	53.0			
Sunflower 37	173.0			
Fishmeal	20.0			
L-lysine HCL	7.0			
DL-methionine	3.4			
DL-tryptophan		1.2		
Starch			280.0	282.0
Sucrose			300.0	281.0
Cellulose			313.7	156.9
Sand				156.9
Limestone	14.3		10.7	10.7
Monocalcium phosphate	14.3		23.5	23.5
Sodium chloride			5.6	5.6
Salt	0.1			
Sodium bicarbonate	6.0			
Oil sunflower	99.4		60.0	80.0
Choline chloride			1.2	1.2
Vitamin/mineral premix	2.5		2.5	2.5
Nutrient				
AME (MJ/kg)	13.0	15.4	11.6	10.8
Crude protein	314.0	657.8	7.8	1.8
Lysine	18.9	10.4		
Threonine	9.5	20.6		
Arginine	19.9	19.4		
Histidine	5.6	-		
Isoleucine	11.6	25.1		
Phenylalanine	12.8	41.2		
Valine	13.6	33.0		
Calcium	9.9	0.2	9.9	9.0
Available phosphorus	4.5	4.9	4.5	5.4

4.3 RESULTS

For the threonine study only, four of the 24 birds died on the first day of force-feeding. Four of the 20 remaining birds lost their colostomy ring one day after the surgical procedure and were consequently removed from the trial. The remaining 16 birds were used in the first 6d trial period. Three birds lost their colostomy ring during the second 6d trial period and 1 bird lost its ring during the third period, resulting in 13 birds and 12 birds being used during the second and the third trial periods, respectively.

It became clear from the threonine study results that the nitrogen balance of birds receiving more than 180mg/kg body weight varied considerably thereby increasing the standard error of the regression equation. Given that the requirement of threonine for maintenance was in the region of 60mg/kg, it was decided to use in the analysis only data from birds fed up to 180mg threonine/kg body weight day.

The body weights of the cockerels at the start of the balance periods, the intakes of threonine or lysine and the nitrogen retention for each of the remaining replications are presented in Table 4.2 and 4.3.

Table 4.2 Results of the nitrogen balance from the threonine study

Threonine intake (mg/kg d)	Number of replications	Initial body weight (g)	Nitrogen Intake (mg/kg d)	Nitrogen Excretion (mg/kg d)	Nitrogen Retention (mg/kg d)
First trial period					
Unbalanced series					
0	1	2304	12	354	-342
39	2	2555	214	330	-116
126	2	2389	663	427	236
171	1	2340	895	385	510
Balanced series					
0	1	2512	11	249	-238
51	1	2347	227	179	49
100	2	2396	434	288	147
Second trial period					
Unbalanced series					
0	2	2333	12	112	-101
47	1	2109	258	324	-66
87	1	2289	464	214	249
128	2	2345	673	383	290
160	2	2511	838	402	436
Balanced series					
94	1	2543	409	251	158
147	1	2443	633	339	294
Third trial period					
Unbalanced series					
42	1	2400	182	214	-32
85	1	2420	367	156	211
166	1	2480	721	175	546
Balanced series					
0	1	2800	12	288	-288
47	1	2510	177	184	-7
107	1	2240	403	281	122
143	1	2430	535	231	305

Table 4.3 Results of the nitrogen balance for the lysine study

Lysine intake (mg/kg d)	Number of replications	Initial body weight (g)	Nitrogen Intake (mg/kg d)	Excretion (mg/kg d)	Retention (mg/kg d)
Unbalanced series					
0	2	2542	6	204	-198
7	2	3124	73	225	-152
14	2	3040	145	252	-107
25	2	2496	264	312	-47
33	2	2499	343	391	-47
43	2	2394	447	396	51
Balanced series					
0	2	2605	6	328	-323
12	2	2501	91	258	-167
22	2	2567	170	421	-251
34	2	2493	259	330	-71
41	2	2754	310	308	2
52	2	2781	387	322	66

The resultant regression equations for the balanced and the unbalanced series are given in Table 4.4 for the threonine study and Table 4.5 for the lysine study.

Table 4.4 Responses in nitrogen retention (mg/kg body weight d) to threonine intake (mg/kg body weight d), as determined by regression analysis

	Constant term	s.e	Linear coefficient	s.e	R^2
Unbalanced series	-227.3^{***}	40.3	4.3^{***}	0.4	92.1
Balanced series	-222.9^{***}	29.7	3.7^{***}	0.3	94.3

*** P<0.001

Table 4.5 Responses in nitrogen retention (mg/kg body weight d) to lysine intake (mg/kg body weight d), as determined by regression analysis

	Constant term	s.e	Linear coefficient	s.e	R^2
Unbalanced series	-190.7^{***}	24.2	5.3^{***}	1.0	72.9
Balanced series	-234.9^{**}	62.6	5.5^{*}	1.7	59.4

*** P<0.001 ** P<0.01

The slopes and intercepts of the two series did not differ significantly one from the other in either study. Consequently, data from both series were pooled to increase the number of replications of each feeding treatment. The resultant regression equation for the threonine and lysine studies were: N retention = -230.4 (27.6) + 4.134 (0.274) I (R^2=91.9) and N retention = -198.3 (± 15.3) + 5.03(± 0.50) I (R^2=91.8), respectively, where I is the intake of threonine or lysine in mg/kg body weight day (Figure 4.1 and 4.2).

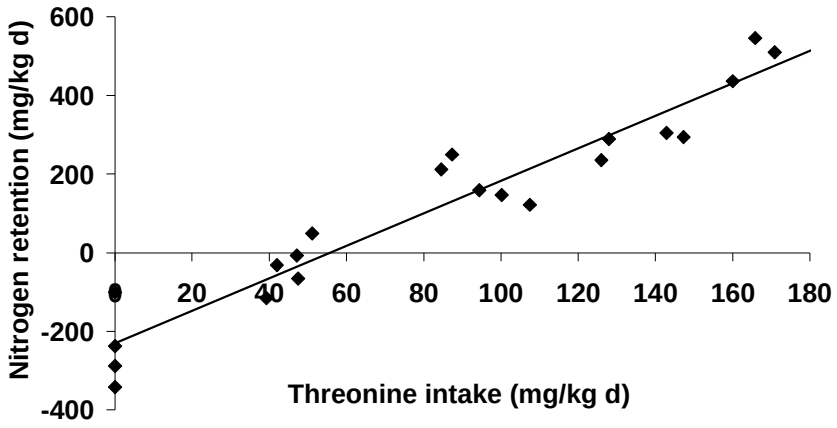


Figure 4.1 Response in nitrogen retention to threonine intake

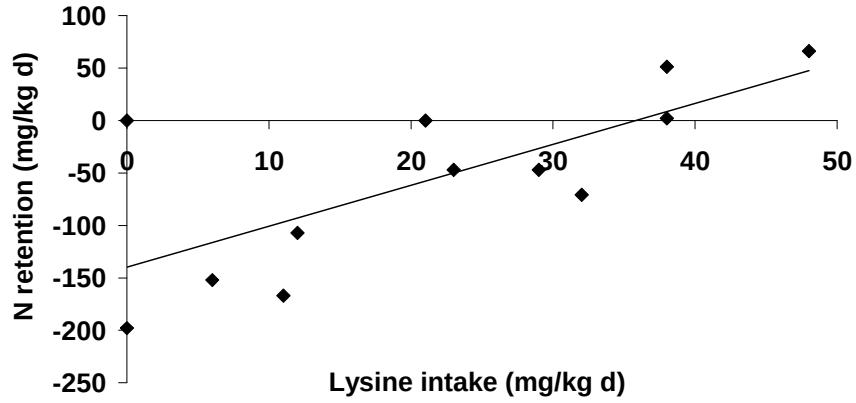


Figure 4.2 Response in nitrogen retention to lysine intake

The maintenance requirement for threonine and lysine, calculated as the threonine and lysine intake required to maintain the body of an adult cockerel at zero nitrogen retention, was estimated to be 56mg threonine and 39mg lysine per kg body weight day.

4.4 DISCUSSION

When modelling amino acid requirements for maintenance of broiler breeders after sexual maturity, an important concern is to determine the amount of each amino acid required to maintain a hen in a functioning state at zero egg production. The maintenance requirements for threonine have been estimated for cockerels by Leveille and Fisher (1960) as 74 and

55mg/kg for what they termed the maintenance and the minimum maintenance requirements, respectively. The maintenance requirement was defined as the lowest amount of dietary amino acid that maintained the same nitrogen balance as observed on a whole egg protein diet or an amino acid mixture containing all the essential amino acids in the same composition as whole egg protein. The minimum maintenance requirement was defined as the lowest dietary inclusion rate of an amino acid which maintained zero nitrogen balance and was equivalent to the definition used in the present study. The requirement for lysine was found not to exceed 29mg/kg d and no minimal maintenance level could be demonstrated (Leveille and Fisher, 1959). Bowmaker and Gous (1991), using a factorial approach, estimated that the lysine requirement for maintenance in broiler breeders was 11.2mg/kg body weight, these values being considerably lower than 73mg/kg estimated using laying hens (McDonald and Morris, 1985). The result obtained here for the threonine requirement is the same as the minimum maintenance requirement suggested by Leveille and Fisher (1960). Indeed, as suggested by Burnham and Gous (1992), there are a number of points in favour of the technique used here, which are likely to provide good estimates of the maintenance requirements of these birds. For example, the technique ensures that a known daily amount of the first-limiting amino acid is consumed, that the birds do not need to mobilise body protein reserves to meet their maintenance energy requirements, and the collection of excreta directly into colostomy bags prevents contamination of faeces by feathers, skin, feed and other debris, rich in nitrogen, which would otherwise increase the apparent nitrogen output, resulting in a lower estimate of the maintenance requirement for that amino acid. We believe that the experimental procedure employed in the threonine study is the most sensible approach for determining the daily requirement of each amino acid for maintenance of poultry: the results between the three trial periods were uniform, the slopes of the responses to the unbalanced and balanced series of diets were the same, and so the response obtained was to threonine and not to protein.

The lysine requirement for maintenance obtained in this study (39mg/kg body weight) is higher than that estimated for broiler breeders by Bowmaker and Gous (1991) (11mg/kg) but considerably lower than the estimate for laying hens by McDonald and Morris (1985) (73mg/kg). It is unlikely that the result would have been much different from this if the excreta had not been collected directly into trays as all visible debris was removed prior to N analysis.

A question regarding the amino acid nutrition of hens that requires closer scrutiny is the extent to which the maintenance requirements are related to body weight as opposed to body protein content. Because adult birds generally have considerable lipid reserves (the lipid content of carcasses of broiler breeders can vary from 151 to 196g/kg from 30 to 60 weeks of age, respectively) (Chapter 3) and because it can be argued that there is no energy cost in maintaining such lipid reserves (Emmans and Oldham, 1988), it is unlikely that the amino acids required for maintenance would be related directly to the body weight of the bird. A more accurate estimate of the amount required for maintenance, when comparing adults of different size and body composition, would be that related to the protein content of the body. To this end, Emmans and Fisher (1986) scaled the maintenance requirement according to the feather-free body protein content and its degree of maturity by in their adaptation of Taylor's (1980) size scaling rule. The equation suggested by Emmans and Fisher (1986) is: $MP = m_p P_m^{0.73} u$, where MP = maintenance protein requirement (g/day), m_p = 0.008kg ideal protein/unit day, P_m = mature protein weight (kg) and u = degree of protein maturity (P/P_M), equal to 1 in this study. Assuming a mean feather-free body protein content of 160g/kg body weight and a body weight of 2.5kg for the birds used in this trial, the body protein weight would be 0.40kg. From the result of both studies, the maintenance requirement can be expressed as (56*2.5) = 140mg threonine and (39*2.5) = 98mg lysine /bird day and because the birds were mature, as ($140/0.40^{0.73}$) = 273 mg threonine and ($98/0.40^{0.73}$) = 191mg lysine /unit $P_m^{0.73}$ day. Using the above equation of Emmans and Fisher (1986), the threonine and lysine contents are thus 273/8 = 34g/kg and 191/8 = 24g/kg protein respectively, which is lower than the coefficient of 42g/kg and 75g/kg protein suggested by Emmans (1989). However, Emmans and Fisher (1986) used the amino acid composition of the body to predict the amino acid requirements for maintenance, and this may not be accurate.

The maintenance requirement for amino acids is an area of nutrition presenting many problems because the concept is not well defined. However, the improved method suggested by Gous *et al*. (1984) has proved to be of value in determining the maintenance requirements for amino acids in mature birds (Burnham and Gous, 1992; the present study) and thus further experiments of this nature are warranted, in which the requirements of all of the essential amino acids for maintenance are measured, as these values will improve the accuracy of models of amino acid requirements for broiler breeders.

The following chapter deals with the evaluation of the efficiency of use of two synthetic amino acids in broiler breeder hens during the peak production period.

CHAPTER 5

UTILISATION OF SYNTHETIC AMINO ACIDS BY BROILER BREEDER HENS

5.1 INTRODUCTION

Crystalline amino acids are used increasingly to meet the lysine, methionine and threonine requirements of poultry. Initially this was on economic grounds but increasingly their use is being encouraged by concerns over N-pollution (Fisher, 2000). When modelling the amino acid requirements of broiler breeder hens, a question that requires closer scrutiny is the efficiency with which synthetic amino acids are used for egg production. In spite of the benefits brought about by the use of synthetic amino acids in poultry feeds, there are still some unresolved issues about their utilisation. Two issues, considered here, are whether egg production would be affected when these ingredients are included at high levels, and whether their use could affect egg production when feed is provided for only a short period each day, such as in feed-restricted broiler breeder hens. Previous experiments conducted with pigs and broilers fed one meal a day have indicated a significantly lower utilisation of free synthetic amino acids than of those bound to protein (Batterham, 1974; Batterham and O'Neill, 1978; Batterham and Murison, 1981; Baker and Izquierdo, 1985) this being overcome when meals were offered at least twice daily (Batterham and Murison, 1981). Because broiler breeders throughout the world are feed-restricted, fed once a day and may eat their meal in as little as 10-20 minutes, the possibility arises that supplemental crystalline amino acids may be used less efficiently by these birds under such circumstances.

The objective of this experiment was to evaluate the efficiency of use of DL-Methionine and L-Lysine HCl in broiler breeder hens during the peak production period. In order to balance the arrival of the protein-bound amino acids and free amino acids at the site of absorption by delaying the rate of absorption of free amino acids, the effect of frequency of feeding on the utilisation of synthetic methionine and lysine was also studied.

5.2 MATERIALS AND METHODS

240 Cobb broiler breeder hens aged 27 weeks were housed in individual cages. The birds had been reared on two different growth curves, the first as recommended by the primary breeder (Cobb 500 breeding guide, 2001) designed to achieve 2100g at 20 weeks, while the other was a fast growth curve to achieve the same weight, but at 15 weeks. 120 broiler breeder females from each growth curve were randomly allocated to individual cages arranged in six rows, back to back, each row having two levels of 48 cages. Each cage was supplied with one nipple drinker and drip cup, and one feeder. The house was cross-ventilated using six fans. The lighting program was 16L: 8D (04:00-20:00) throughout the experimental period.

Throughout the ten-week experiment, each hen was fed one of five dietary treatments obtained by blending two basal feeds (B0 and B100) appropriately (Table 5.1). These feeds were formulated to contain no synthetic amino acids (B0) or with the maximum amount of synthetic lysine and methionine whilst maintaining a minimum of 150g protein/kg in the feed. In formulating these basal feeds, minimum contents of all essential amino acids for broiler breeders laying at their maximum output (Fisher, 1998) were specified, thereby ensuring that no amino acids were more limiting than lysine or methionine in either of the basal feeds. Treatments involved feeding five levels of crude protein (183, 175, 167, 158 and 150g/kg feed), supplemented with synthetic lysine (0, 0.43, 0.85, 1.28 and 1.70g/kg) and methionine (0, 0.15, 0.30, 0.45 and 0.60g/kg) in order to maintain constant lysine and TSAA levels, respectively. Diets were isoenergetic and all birds received 160g daily. The feeds were given in mash form either once or twice daily. The once-daily feeding was at 07h00 and the twice-daily feeds (80g per feeding) were given at 07h00 and 13h00.

Table 5.1 Composition (g/kg) of the two basal feeds. Amino acid contents are given as digestible

Ingredient	B0	B100	
Maize	491.0	509.4	
Wheat bran	118.7	197.5	
Soybean full fat	177.7	128.5	
Sunflower 37	129.0	70.7	
L-lysine HCL[1]		1.7	
DL-methionine		0.6	
Vit + min premix	1.5	1.5	
Limestone	71.1	72.2	
Salt	3.1	3.2	
Monocalcium phosphate	7.9	6.6	
Oil-sunflower		7.9	
Nutrient			Requirement[2]
AME (MJ/kg)	11.3	11.4	
Crude protein	183.0	150.0	
Lysine	6.9	7.0	7.0
Methionine	2.8	2.9	2.9
Methionine + Cystine	5.4	5.3	5.0
Threonine	5.5	5.1	4.4
Arginine	10.5	9.7	6.2
Tryptophan	1.7	1.5	1.5
Isoleucine	6.4	5.5	4.8
Phenylalanine + tyrosine	11.9	10.0	8.2
Valine	7.6	6.5	5.5

[1] Activity of L-lysine HCl = 78.4g lys/100g.
[2] Fisher (1998), for a bird consuming 160g feed/d

Bodyweight was recorded at the beginning of the trial, after six weeks and finally at the end of the trial (after 10 weeks). Weekly food intake was calculated by subtracting the amount remaining at the end of each week from the amount fed. Egg weight was recorded on three days of each week and egg production for the remaining four days.

The means for all treatments were calculated, using the general analysis of variance in Genstat (1997), for the final four weeks of the experiment, on the assumption that by this time the responses of birds would have stabilised on each treatment. A linear regression analysis was performed, to determine the effect of dietary synthetic amino acid content on rate of lay, egg output, egg weight, bodyweight change, feed intake and efficiency of utilisation of protein, lysine and methionine. The efficiency of utilisation of protein was calculated for each individual bird in the experiment as follows: efficiency = protein content in eggs / protein available for egg production. The value for the protein content of egg was obtained from unpublished data (University of KwaZulu-Natal, 2004) assuming that the proportions of yolk, albumen and shell in an egg were 27.3, 63.6, and 9.1g/100g

weight respectively at 35 weeks of age and, from Fisher (1994), that the N content of these components was 27, 17 and 5.3g/kg, respectively. The protein available for egg production was calculated as protein intake – protein required for maintenance. The maintenance protein requirement is related to feather-free body protein weight as suggested by Emmans and Fisher (1986). The expression used was MPr = Mp BPm^0.73 u where MPr = maintenance protein requirement, kg/day, BPm = feather-free body protein weight at maturity, kg, u = BP/BPm and BP = body protein weight, kg. In this case u = 1, as the birds were mature. The constant, Mp, has been estimated as 8g/unit day (Emmans and Fisher, 1986). For the calculation of body protein weight, the bodyweight was assumed to contain 180g protein/kg (Wilson *et al*, 1995; Fisher, 1998). The efficiency of utilisation of lysine and methionine was calculated for each bird in the experiment in the same way as was the efficiency of utilisation of protein. The values for the lysine and methionine contents of whole egg (Table 5.2) were based on the amino acid composition of egg components (Lunven *et al.*, 1973). The lysine and methionine required for maintenance was given by the same maintenance scaling rule used for protein: Mlys or Mmet = Mp BPm^0.73 u. The amino acid composition of ideal protein for maintenance was assumed to be the same as that of body protein. So, the lysine and methionine content of the body were estimated as 75 and 25g/kg of body protein (Emmans, 1989; Fisher, 1998).

Table 5.2 Lysine and methionine content of whole egg (Lunven *et al*., 1973)

	Lysine	Methionine
mg/g N	439	195
mg/g egg	8.209	3.646

Those hens that laid for not more than one week during the final four weeks of the trial were excluded from the analysis because their efficiencies of utilisation of protein and amino acids would be extremely low (Fisher, 1980), leading to discontinuous protein synthesis and hence large differences in protein and amino acid utilisations between birds.

5.3 RESULTS

The mean responses in laying performance, food intake, body weight, gain in weight, and efficiencies of utilisation of protein, methionine and lysine, to the five dietary treatments and two feeding frequencies, over the final four weeks of the trial, are presented in Table 5.3. The interactions between the dietary synthetic amino acid content and the shape of the growth curve were not significant for the responses in performance and also in efficiency of utilisation of protein, lysine and methionine indicating that the response to the dietary synthetic amino acid content was the same for birds reared on the control and the fast growth curves. Consequently, data from the two growth curves were pooled to increase the number of replications of each dietary treatment. The resultant regression equations for each dependent variable that were obtained by linear regression are presented in Table 5.4.

A number of hens did not lay for more than a week during the final four weeks of the trial, the numbers being 1, 3, 1, 4 and 3 on feed treatments 1 to 5 respectively. A Chi Square test revealed that the treatments imposed did not influence these numbers, the Chi Square value for such observations being 2.867, which was not statistically significant.

Table 5.3 Mean responses, in performance and efficiency of nutrient utilisation, to dietary treatments over the final four weeks of the trial

	Rate of lay (%)			Egg weight (g)			Egg output (g/d)		
Frequency of feeding (/d)	1	2	Mean	1	2	Mean	1	2	Mean
Synthetic amino acid (g/d)									
0.0	74.9	76.2	75.6	66.0	67.7	66.8	48.8	51.1	50.0
0.6	71.5	76.4	74.0	64.0	65.4	64.7	44.8	49.5	47.2
1.2	74.0	75.6	75.0	64.3	66.9	65.6	47.3	50.2	48.8
1.7	72.0	75.2	73.6	66.5	65.9	66.2	46.2	49.3	47.8
2.3	67.1	71.1	67.1	65.5	64.9	65.2	39.9	45.1	42.5
Mean	72.0	74.9	73.1	65.2	66.2	65.7	45.4	49.0	47.2
s.e.d			5.2			1.7			3.9

	Body weight (g)			Body weight change (g/d)			Feed intake (g/d)		
Frequency of feeding (/d)	1	2	Mean	1	2	Mean	1	2	Mean
Synthetic amino acid (g/d)									
0.0	3533	3722	3628	-0.3	-3.6	-1.9	159.9	159.8	159.8
0.6	3617	3694	3655	-1.2	-4.6	-2.9	159.9	159.9	159.9
1.2	3504	3607	3555	-2.4	-1.7	-2.0	159.7	159.4	159.5
1.7	3515	3541	3528	-3.3	-2.8	-3.0	160.0	160.0	160.0
2.3	3434	3521	3478	-0.6	-0.4	-0.5	158.9	160.0	159.4
Mean	3521	3617	3569	-1.5	-2.6	-2.1	159.7	159.8	159.7
s.e.d			100.4			2.0			0.8

	Efficiency of utilisation of protein			Efficiency of utilisation of lysine			Efficiency of utilisation of methionine		
Frequency of feeding (/d)	1	2	Mean	1	2	Mean	1	2	Mean
Synthetic amino acid (g/d)									
0.0	0.245	0.264	0.254	0.527	0.574	0.551	0.591	0.641	0.616
0.6	0.242	0.251	0.246	0.496	0.517	0.507	0.525	0.546	0.535
1.2	0.280	0.281	0.280	0.539	0.545	0.542	0.569	0.574	0.571
1.7	0.294	0.288	0.291	0.535	0.523	0.529	0.561	0.549	0.555
2.3	0.298	0.301	0.299	0.506	0.513	0.510	0.527	0.536	0.532
Mean	0.272	0.277	0.274	0.521	0.534	0.528	0.555	0.569	0.562
s.e.d			0.039			0.038			0.030

Table 5.4 Responses in feed intake, average daily gain (ADG), laying performance (rate of lay, egg weight and egg output) and efficiency of utilisation of protein (ep), lysine (elys) and methionine (emet) to synthetic amino acid content (g/kg), as determined by linear regression analysis

	Linear coefficient	s.e
Feed intake (g/d)	-0.152	0.161
ADG (g/d)	0.453	0.437
Rate of lay (%)	- 2.950**	1.100
Egg weight (g)	- 0.318	0.360
Egg output (g/ d)	- 2.507**	0.820
ep	0.024***	0.004
elys	- 0.010	0.008
emet	- 0.026***	0.009

*** P < 0.001 **P < 0.01 *P < 0.05

The replacement of lysine and methionine in intact protein with the synthetic form, up to 2.3g/kg feed, had no effect on feed intake, bodyweight gain, egg weight or efficiency of lysine utilisation. The regression analysis of ep on dietary synthetic amino acid content showed that a significant linear relationship existed between the two: ep increased with increasing concentrations of synthetic amino acid, an extra gram of synthetic amino acid /kg diet resulting in an increase of 2.4% in ep. Moreover, increasing levels of synthetic amino acids reduced nitrogen excretion by 24.4% (Table 5.5). Supplements of 2.3g/kg synthetic amino acids showed protein-sparing effect of 3.3 percentage units with a better utilisation of protein and a reduction in N excretion.

Table 5.5 Effect of reducing dietary crude protein and supplementing with synthetic amino acids on nitrogen excretion

	Diets	
	183 g CP kg^{-1}	150 g CP kg^{-1} + 1.7 g Lys kg^{-1} + 0.6 g Met kg^{-1}
N intake (g/d)	29.3	24.0
Efficiency of utilisation of protein (%)	24.7	30.2
N retained (g/d)	7.2	7.3
N excreted (g/d)	22.1	16.7
Reduction in N excretion (%)	-	24.4

However, the relationships between rate of lay, egg output, emet and dietary synthetic amino acid content were linear (P<0.01, P<0.01 and P<0.001, respectively), with rate of

lay, egg output and emet decreasing by 3.0%, 2.5g/d (Figure 5.1) and 2.6% (Figure 5.2) with each additional gram of free amino acid content /kg diet.

Feeding twice-daily vs. daily resulted in increases in rate of lay and egg output ($P<0.05$ and $P<0.01$, respectively) over all feeds used, but no differences in egg weight, or in the slopes of the three responses when regressed against synthetic amino acid inclusion. Although the efficiencies of utilisation of protein, lysine and methionine were all numerically higher when birds were fed twice-daily these differences were not significant, nor was there an interaction between frequency of feeding and amino acid supplementation for any of these variables.

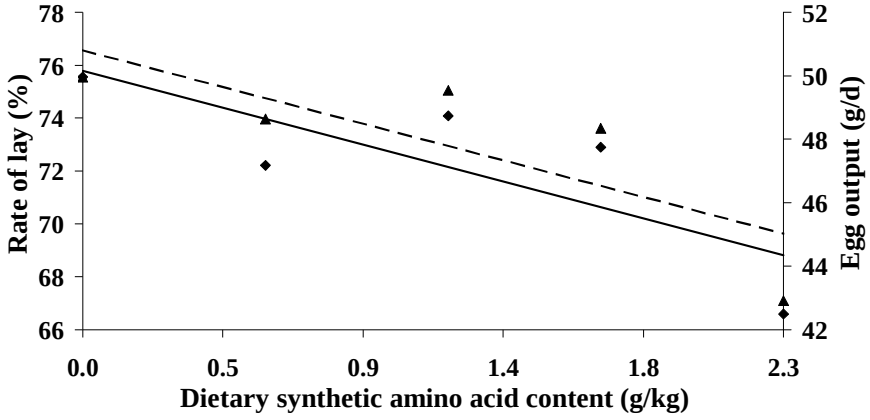


Figure 5.1 Observed and fitted relationships between rate of lay (%), egg output (g/d) and dietary synthetic amino acid content (g/kg feed). Observed mean rate of lay (▲), egg output (■) and the fitted equations (— — rate of lay, — egg output)

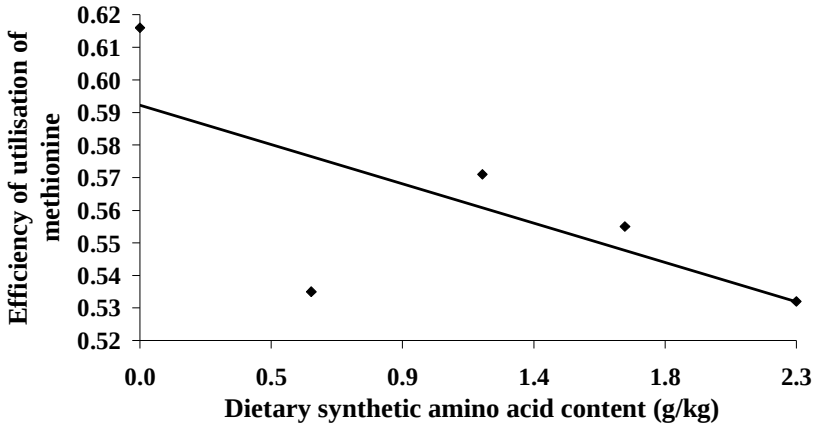


Figure 5.2 Observed and fitted relationship between efficiency of utilisation of methionine and dietary synthetic amino acid content (g/kg feed).

5.4 DISCUSSION

Supplementing animal feeds with synthetic amino acids is of importance not only on nutritional and economic grounds, but also because of environmental considerations (Han and Lee, 2000). This study showed a protein sparing effect of 3.3 percentage units with a better utilisation of protein and a reduction in N excretion when synthetic amino acids were used. A reduction in nitrogen excretion of 24.4% was obtained with an "ideal amino acid balance", which is of considerable consequence in countries where N pollution is a problem. However, it appeared not possible to obtain the same performance with lower protein diets supplemented with synthetic lysine and methionine. For each extra gram of dietary free amino acid content per kg diet, the rate of lay and egg output decreased by 3.0% and 2.5g per day, respectively. This means, in agreement with Batterham and Murison (1981) in pigs, that synthetic amino acids are not utilised as well as the protein-bound amino acids when birds were fed a restricted amount of food once a day. The ɛlys had no relationship with the dietary synthetic amino acid content, probably because lysine was not the first-limiting amino acid in the feed offered. Because the methionine efficiency ratio declined in a linear ($P<0.01$) fashion as supplemental synthetic amino acids increased from 0 to 2.3g/kg diet, it is likely that methionine was first-limiting in the feed. It is likely that under restricted feeding conditions, optimal performance cannot be achieved when

extensive amino acid supplementation is used to replace essential amino acid from intact protein.

There have been many reports of a depression in growth or performance when low protein feeds, supplemented with amino acids to the same level as those in intact protein, are fed to poultry (e.g. Ferguson et al., 1998; Kerr and Kidd, 1999a and b; Waibel et al., 2000). One reason given for this is that one of the amino acids not normally considered in a feed formulation program may inadvertently be first-limiting in such a feed. To ensure that this was not the case here, all essential amino acids were considered when formulating feed B100, making use of the requirements specified by Fisher (1998), thus taking care that the amino acid balance in the two basal feeds was relatively constant. Of the non-test amino acids only tryptophan was not in excess of requirement. However, the small difference in tryptophan content between the two basal feeds suggests that it is unlikely that the large differences in response measured here could have been a response to tryptophan or indeed to any of the other non-test amino acids, especially as the same ingredients were used to supply these amino acids in both basal feeds.

It is more likely that the observed response was due to the more rapid absorption of the synthetic amino acids once digested compared with the amino acids from intact protein. This phenomenon, which has been measured in growing pigs (Yen et al., 2004), would result in an unbalanced amino acid mixture being available for incorporation into protein once the intact proteins had been digested and absorbed. It is for this reason that frequent feeding of low-protein feeds has been successful with growing pigs (Cook et al., 1983).

With frequent meals, one would assume an equilibrium would be established between gut, blood and tissues with regard to amino acid utilisation for protein synthesis (Baker and Izquierdo, 1985). However, our results with twice-daily feeding showed that there was no interaction between frequency of feeding and amino acid supplementation. This finding is not in general agreement with Batterham's more recent work with pigs (1974, 1978 and 1981) where he showed that growing pigs meal-fed once daily utilised crystalline lysine no better than 50 to 67% of that achieved by pigs meal-fed six times daily. Although differences in efficiency of utilisation of protein and the test amino acids were not significant when comparing once- and twice-daily feeding, they were numerically greater where intact protein was fed than at the other end of the scale. This is contrary to the

theory that more frequent feeding would result in greater efficiency of utilisation of free amino acids. But given that the synthetic amino acids were utilised less efficiently by the hens (see below) one could expect less variation in performance between birds fed lower amounts of the limiting amino acid, as performance would be equally constrained in all birds. It is possible that feeding more frequently than twice-daily may overcome the poorer efficiency of utilisation of synthetic amino acids, but this was not tested in the present experiment.

In practical applications of the Reading Model (Fisher *et al.*, 1973) and in subsequent publications pertaining to this model (Pilbrow and Morris, 1974; Morris and Blackburn, 1982 and McDonald and Morris, 1985) the assumption has been, for the sake of simplicity, that all amino acids are utilised by laying hens with an efficiency of between 0.80 and 0.85. However, this applies to laying hens fed *ad libitum*. The efficiency of utilising methionine from bound protein in this trial was 0.62 (Table 3) but only 0.532 with maximum inclusion of synthetic methionine. With 0.21 of the methionine in feed 5 (B100) being in the synthetic form and the remainder (0.79) being bound, the utilisation of free methionine in this feed was 0.276 (calculated as [0.532-(0.79*0.6)]/0.21), effectively reducing the methionine content to only (0.79*2.9) = 2.3g/kg, which would adequately explain the decrease in performance on this feed. This has important consequences both in designing feeds for broiler breeders and when modelling their responses to amino acids during the laying period. It would appear that free amino acids should not be used in feeds for broiler breeders.

When modelling the utilisation of synthetic amino acids in broiler breeder feeds, three situations need to be considered: 1) if none are fed, the first-limiting amino acids in the feed may be utilised at a maximum rate of 0.60–0.80, 2) if all amino acids are (theoretically) supplied in the synthetic form, the efficiency will also be maximal because all free amino acids will be available for protein synthesis at the same time, 3) if a portion of the amino acid requirement is supplied in the synthetic form, the efficiency will decrease in relation to the ratio of synthetic to protein-bound amino acids. This decrease may be calculated by assuming that the free amino acid is utilised less efficiently: thus in this study the efficiency of methionine utilisation decreased by 3g/kg for each 1g of free methionine added per kg feed.

When laying in closed cycles, broiler breeders should be as efficient as laying hens in converting dietary amino acids to egg output (Fisher, 1980): an efficiency of between 0.75 and 0.85 has been suggested by McDonald and Morris (1985) and by Emmans and Fisher (1986). Broiler breeders fed intact protein here utilised lysine and methionine for egg production with mean efficiencies of 0.55 and 0.62, respectively, these being lower than the equivalent values estimated for laying hens, but similar to those reported by Bowmaker and Gous (1991) (0.47 for lysine and 0.50 for methionine) and Goddard (1997) (between 0.58 and 0.68 for lysine) in their studies with broiler breeders. It is likely that lysine was not first-limiting in the present trial, given its lower efficiency compared with that for methionine. The range in efficiencies of utilisation of lysine fell between 0.11 and 0.73 and between 0.12 and 0.82 for methionine, with only three birds having an efficiency of utilisation of methionine greater than 0.75. This low efficiency could be accounted for in some birds as being the result of making use of an average protein content in the carcass of 180g/kg when calculating maintenance requirement, or of hens being inefficient egg producers. A subsequent analysis was performed in which the carcass protein contents were assumed to be either 160 or 200g/kg. This wide range of protein contents had little effect on the resultant efficiencies, being 0.50 and 0.55 for lysine, and 0.53 and 0.57 for methionine, for the two body protein contents respectively. Not all the birds were laying at a rate greater than 0.5. Their rate of lay varied between 20 and 100%. A subsequent analysis was performed in which data from birds laying at not more than 50% were excluded from the analysis. The resultant efficiency of utilisation of lysine for egg production was 0.54 and of methionine 0.56; values that are no different from the efficiencies calculated using data from those birds that laid not more than one week during the final four weeks of the trial. Two possibilities exist that might explain the lower efficiency of utilisation of the limiting amino acids by broiler breeder hens, although neither is very convincing: one possibility is that these birds have higher maintenance requirements per kg of body protein than laying hens, and the other is that amino acids may be wasted in the processes of yolk formation and subsequent reabsorption or through internal laying, both of which occur to a greater extent in broiler breeders than in laying hens. The question of lower efficiency in converting dietary amino acid in egg output in broiler breeders compared with laying hens needs further investigation.

Whereas crystalline amino acids may enable nutritionists to comply better with constraints in linear programming (least cost formulation) when formulating feeds for broiler breeders,

by lowering the cost of the feed and contributing to a reduced nitrogen excretion, the results of the trial reported here suggest that these synthetic amino acids should not be used in such feeds. It is evident that these free amino acids are utilised less efficiently by broiler breeders, resulting in a reduced rate of lay compared with birds fed intact protein. It is likely that these amino acids are rapidly absorbed and metabolised before the intact protein has been digested and absorbed, resulting in an unbalanced mixture being available for incorporation into egg protein.

The following chapter deals with the extent to which broiler breeder hens could make use of excess body lipid reserves as a means of maintaining laying performance.

CHAPTER 6

UTILISATION OF BODY LIPID AS AN ENERGY SOURCE IN BROILER BREEDERS

6.1 INTRODUCTION

Regulation of food intake of broiler breeders during the laying period is a potential means of reducing costs and improving the efficiency of broiler chick production. Food allowances for breeder hens are manipulated according to the pattern of egg production. Thus, birds are fed a generous allowance early in lay followed by a period of mild regulation over peak production and a subsequent reduction in allowance as egg production declines in the latter part of lay. It is accepted that if broiler breeders are overfed they deposit the excess energy as carcass fat and this may lead to a marked reduction in egg production, fertility and hatchability (Pearson and Herron, 1981; McDaniel *et al.*, 1981b). However, it has been shown that fattened broilers utilise lipid reserves as an energy source provided the dietary protein intake is sufficient to allow this (Gous *et al.*, 1992). Thus, contrary to the way in which amino acid requirements are calculated, when the optimum energy intake of a broiler breeder is calculated, account should be taken of the possibility that excess energy may be stored and later utilised by the hen. If broiler breeder hens are able to draw on lipid reserves to supply the body with energy, it is less likely that energy will be the limiting factor in egg production, unless food intake is severely restricted, as lipid reserves would be built up on non-egg forming days, to be available when required. However, if the lipid stores are not labile reserves of energy, or if the hen can utilise only a fraction of these stores, no assumptions could be made about the adequacy of dietary energy supply by observing the carcass fat content of broiler breeders. In the unlikely event that broiler breeder hens were unable to make full use of lipid reserves, there would be no advantage in allowing the accumulation of such reserves, and the way in which the energy requirements are calculated would become more complex and critical.

The present study was designed to determine the extent to which broiler breeder hens could make use of excess body lipid reserves as a means of maintaining laying performance.

6.2 MATERIALS AND METHODS

352 Cobb broiler breeder hens aged 37 weeks were housed in individual cages. The birds had been reared on two different growth curves, the first as recommended by the primary breeder (Cobb 500 breeding guide, 2001) designed to achieve 2100g at 20 weeks, while the other was a fast growth curve to achieve the same weight, but at 15 weeks. 176 broiler breeder females from each growth curve were randomly allocated to individual cages arranged in 6 rows, back to back, each row having two levels of 48 cages. Each cage was supplied with one nipple drinker and drip cup, and one feeder. The house was cross-ventilated using six fans. The lighting program was 16L: 8D (04:00-20:00) throughout the experimental period.

The experiment was divided into two phases. In the first phase, the birds were allocated one of four daily allowances: 160, 175, 190 or 205g of a commercial broiler breeder feed (11.9 MJ ME/kg, 159g protein/kg, and 24g calcium/kg) for a period of four weeks in order to achieve four levels of fatness in the hens. During the second phase, also lasting four weeks, the birds were given a high protein, low energy feed (Table 6.1) at three rates of allocation (120, 100 or 80g/hen.d). A high dietary protein content was used to ensure that the amino acid supply was adequate at these low food intakes, i.e. dietary energy, and not other nutrients, was likely to be limiting. The 24 treatments (2 initial growth curves, 4 initial levels of fatness, 3 final feed allocations) were replicated using seven hens per treatment (Table 6.2). The basal diet was analysed for AME, protein, digestible amino acids, calcium and phosphorus content. AME was measured using the method of Fisher (1982) in which 50g of the diet is given by tube (Sibbald, 1976) following a 48 h fasting period, and excreta are collected over the following 48 h. The AME value was corrected to zero N retention and to reflect an intake of 80g/d (AME_{n80}). Protein was measured as nitrogen x 6.25 using a LECON analyser; amino acids by the method described by Dennison and Gous (1980); and calcium and phosphorus using the AOAC (1975) methods of analysis.

Table 6.1 Composition (g/kg) of the feed used in Phase 2 of the trial. Amino acid contents are given as digestible

Ingredient	Basal feed
Maize	472.0
Soybean 48	317.6
Sunflower 37	31.3
Wheat bran	86.5
DL methionine	1.7
Vit + min premix	1.5
Limestone	76.1
Salt	4.5
Monocalcium phosphate	8.8
Nutrient	
AME (MJ/kg)	10.1
Crude protein	211.0
Lysine	9.5
Methionine	-
Threonine	5.1
Arginine	8.4
Histidine	5.1
Isoleucine	7.7
Phe + Tyr	13.4
Valine	9.2
Calcium	36.9
Available phosphorus	-

Table 6.2 A description of the dietary treatments used in the trial

Treatment	Food allocation Phase1 (g/bird d)	Food allocation Phase 2 (g/bird d)	Protein intake Phase 2 (g/d)	Energy intake Phase 2 (kJ AME/d)
1	160	80	16.8	805
2	160	100	21.1	1006
3	160	120	25.3	1208
4	175	80	16.8	805
5	175	100	21.1	1006
6	175	120	25.3	1208
7	190	80	16.8	805
8	190	100	21.1	1006
9	190	120	25.3	1208
10	205	80	16.8	805
11	205	100	21.1	1006
12	205	120	25.3	1208

Bodyweight was recorded at the beginning of the trial, after four weeks and then weekly until the end of the trial (after eight weeks). Weekly food intake was calculated by subtracting the amount remaining at the end of each week from the amount fed. Egg weight was recorded on three days of each week and egg production for the remaining four. At the end of the first phase of the experiment, two birds from each daily allowance

and from each growth curve (a total of 16 birds) were sacrificed and their carcasses, excluding feathers were minced and then analysed for GE, protein, moisture and ash. Then, two of the seven birds in each treatment were sacrificed at weeks 5, another two at week 6 and the remaining three at the end of the trial. The abdominal fat pad was removed from each bird and weighed and ten birds were chosen for carcass analysis on the basis of the distribution of the weights of their abdominal fat pads. All results were converted to percentages on a wet basis. The lipid content (LC) of the body was calculated from the gross energy using the following equation (University of KwaZulu-Natal, unpublished data): LC = -0.8756 + 0.004754 GE

The mean response over the final two weeks of Phase 2 was used to calculate rate of lay, egg weight, egg output, body weight and change in body weight, using the general analysis of variance in Genstat (1997). It was assumed that after two weeks of restriction in energy all birds would have reached a "steady state". The changes in body weight, rate of lay, egg weight and egg output over time were analysed by fitting a polynomial regression model to the data, using Genstat. For the sixteen birds that were sacrificed at the end of the first phase of the trial, a regression of carcass fat on body weight was performed. The body lipid content (g/kg body weight) was calculated for each treatment and used to calculate the body lipid content of all the remaining birds at the end of the first phase. A regression analysis was performed of carcass fat content (g/kg bodyweight) on abdominal fat content (g/kg bodyweight) for the ten birds sacrificed at week 5, 6 and 8. These regression equations were used to calculate the carcass content from the abdominal fat contents of the remaining 86 birds at week 5 and 6 and 134 birds at week 8. The body lipid content for each treatment was then used to calculate the body lipid content of all the remaining birds over the four-week period of the Phase 2. An analysis of variance was then performed on these body lipid contents.

6.3 RESULTS

The individual results were grouped according to treatment. Three birds, which stopped laying during the trial and looked sick, were excluded from the analysis. No significant differences between birds on the two growth curves across treatments and within phase were observed; hence these data were pooled to increase the number of replications. The effect of feeding four daily allowances (160, 175, 190 and 205g/bird d) on body weight

gain over the four weeks and performance in the last week of phase 1 of the trial is shown in Table 6.3. There were no significant differences in rate of lay, egg weight or egg output between birds fed these allocations during phase 1. However, the body weights at the end of the period were significantly different. As was intended, birds fed the highest allocation were heavier and birds fed the lowest allocation were lighter at the end of the first phase of the trial. The chemical composition of the slaughtered hens at the end of Phase 1 is shown in Table 6.4. There was no significant difference in carcass composition of the birds that were sacrificed and analysed at the end of the first phase. The relationship between carcass fat and body weight was not statistically significant: carcass fat = 101.4 + 0.017 body weight (R^2=3.5%).

The responses in rate of lay, egg output and change in body weight over the last four weeks (Phase 2) of the trial, whether linear or quadratic, are presented in Table 6.5. The mean responses in laying performance, body weight and gain in weight to the daily feed allowance allocated in Phase 1 and Phase 2 over the final two weeks of the trial are presented in Table 6.6. The body weight of the breeders increased significantly with feed allocation in both periods. However, body weight loss during the final four weeks of the trial increased with FA1 (the heaviest birds at the start of Phase 2 lost the greatest amount of body weight), but decreased with increasing FA2. There was a significant interaction between FA1 and FA2 during the last two weeks of the trial. The body weight of birds fed 100 and 120g/d in Phase 2, following 160, 175 and 190g/d in Phase 1, decreased linearly over time. On 160 and 175g/d in Phase 1, the body weight between birds fed 100 and 120g/d in Phase 2 decreased over time and the mean body weight over the final two weeks was not significantly different. Birds fed 190g/d in Phase 1 and 100g/d in Phase 2 had body weights that decreased more rapidly (-280.8 vs. –140.7g/week) and were lighter (3468 vs. 3715g) over the last two weeks than birds fed 120g/d. The mean body weight over the final two weeks was the same between birds fed 100g/d in Phase 2 and 160, 175 and 190g/d in Phase 1. Birds fed 120g/d in Phase 2 and 190g/d in Phase 1 were significantly heavier than those fed 120g/d in Phase 2 and either 160 or 175g/d in Phase 1 (3715 vs. 3463 vs. 3499g, respectively). Body weight decreased quadratically with age (rapidly at first, and slowing down thereafter) in all birds fed 80g/d and in those fed either 100 or 120g/d in Phase 2 following 205g/d in Phase 1.

Table 6.3 Mean body weight and performance of broiler breeders in the last week of phase 1

Food allocation (g/d)	Body weight (g)		Rate of lay (%)		Egg weight (g)		Egg output (g/bird d)	
Phase 1	Mean	SEM[1]	Mean	SEM[1]	Mean	SEM[1]	Mean	SEM[1]
160	3770[a]	29	69.0	2.0	70.1	0.5	49.4	1.4
175	3884[b]	26	69.8	2.3	69.0	0.6	50.7	1.4
190	3946[c]	29	70.6	2.2	70.0	0.5	52.4	1.2
205	4046[d]	27	68.3	2.2	69.5	0.5	49.4	1.4

[a-d] Means with different superscripts are significantly different.
[1] Standard error of mean

Table 6.4 Mean carcass composition (g/kg) of the broiler breeders sampled at the end of phase 1

Food allocation (g/d)	Carcass weight (g)		Water (g/kg)		Fat (g/kg)		Protein (g/kg)		Ash (g/kg)	
Phase 1	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
160	3784	85	650.9	14.9	151.0	18.9	147.7	6.2	23.3	1.4
175	3876	168	621.0	7.4	185.6	5.7	196.3	16.5	21.0	1.6
190	3553	254	632.6	17.3	168.9	20.8	206.1	21.6	23.6	3.7
205	3877	182	637.3	14.5	167.5	15.1	170.5	3.9	20.3	1.1

[1] Standard error of mean

Table 6.5 Rate of change in performance (rate of lay and egg output) and in body weight over the last four weeks of the trial as influenced by the feed allocated in Phase 1 and Phase 2, as determined by regression analyses

Food allocation (g/d)		Rate of lay (%/d)		Egg output (g/bird d/d)	
Phase 1	Phase 2	Linear coefficient	s.e.	Linear coefficient	s.e.
160	80	-1.5***	1.4	-1.3***	0.2
160	100	-0.5**	1.1	-0.3**	0.1
160	120	0.2		0.1	
175	80	-1.5***	1.7	-1.1***	0.2
175	100	-0.7***	1.3	-0.5***	0.1
175	120	-0.4*	1.4	-0.2	
190	80	-1.4***	1.3	-1.0***	0.1
190	100	-0.5**	1.2	-0.4***	0.1
190	120	-0.1		-0.1	
205	80	-1.0***	1.5	-0.6**	0.1
205	100	-0.9***	1.4	-0.6***	0.1
205	120	0.2		0.01	

Food allocation (g/d)		Body weight loss (g/bird/d)			
Phase 1	Phase 2	Linear coefficient	s.e.	Quadratic effect	s.e.
160	80	-34.7***	7.1	0.584*	0.259
160	100	-14.8***	3.26		
160	120	-8.4***	2.4		
175	80	-40.0***	7.9	0.741*	0.286
175	100	-17.1***	2.2		
175	120	-15.5***	2.5		
190	80	-40.1***	8.5	0.700*	0.306
190	100	-20.1***	2.3		
190	120	-10.3**	3.4		
205	80	-44.9***	10.0	0.863*	0.363
205	100	-41.8***	7.8	0.710*	0.282
205	120	-35.1***	7.1	0.918***	0.259

*** P<0.001 ** P<0.01 * P<0.05

There were no significant differences in rate of lay or egg output at the end of the first phase of the trial, i.e. food intakes ranging from 160 to 205g/d produced the same egg output. However, the amount of food allocated during phase 1 significantly influenced both rate of lay and egg output of some birds in phase 2: these measures of performance both increased with FA1 at a rate of 3.5% and 4.0g/d, respectively, for every additional 10g of food given in period 1, in hens fed only 80g/d in phase 2. However, rate of lay and egg output remained the same over the last two weeks when birds were fed either 100 or 120g/d, irrespective of FA1. The result is presented graphically in Figure 6.1. Rate of lay and egg output both increased significantly ($P<0.05$) with increasing FA2. There was also a significant ($P<0.001$) linear decline in rate of lay and egg output over time. Mean rate of lay and egg output over the last two weeks of Phase 2, of all hens fed 80g/d in Phase 2 other than those fed 205g/d in Phase 1, were significantly ($P<0.001$) lower, and declined more rapidly, than those fed 100g/d in phase 2. Where hens were fed 120g/d in Phase 2, rate of lay and egg output remained the same throughout the four-week period.

The relationship between carcass fat and abdominal fat content of the ten carcasses analysed at week 5, 6 and 8 was found to be highly significant ($P<0.001$) (Table 6.7) which enabled the carcass fat content of the remaining birds to be estimated. The mean responses at weeks 5, 6 and 8 for abdominal fat and carcass fat content of the body are presented in Table 6.8 together with their standard errors. The nature of the responses in abdominal fat pad and body lipid content over time are presented in Table 6.9. Treatments had no effect on abdominal fat and carcass fat content of the birds at week 5. At week 6 and 8, abdominal fat pad and carcass fat increased with increasing FA2. Numerically, the mean abdominal fat pad and body lipid content of birds fed 80g/d in Phase 2 decreased linearly more rapidly followed by those fed 100g/d and then 120g/d on 160, 175 and 190g/d in Phase 1. Birds fed 205g/d in Phase 1 showed a same rate of decline in abdominal fat and body lipid content.

Table 6.6 The response in rate of lay (ROL), egg weight (EW), egg output (EO), body weight (BW) and change in body weight (ADG) of broiler breeders to feed allowances in Phase 1 and Phase 2 over the last two weeks of the experimental period

Food allocation (g/d)		EP (%)	EW (g)	EO (g/d)	BW (g)	ADG (g/d)
Phase 1	Phase 2					
160	80	39.6	68.6	19.6	3281	-9.3
160	100	58.9	69.7	41.0	3470	-11.5
160	120	69.6	69.5	48.2	3463	-4.0
175	80	33.4	67.8	21.9	3368	-8.6
175	100	55.4	70.2	39.0	3411	-11.2
175	120	64.3	68.2	45.8	3499	-6.6
190	80	41.2	68.0	27.8	3343	-11.8
190	100	61.3	69.9	42.8	3468	-14.6
190	120	63.7	70.7	47.0	3715	-6.7
205	80	49.4	68.4	37.1	3452	-14.6
205	100	51.2	68.5	36.2	3461	-9.4
205	120	66.1	69.4	45.9	3780	-6.0

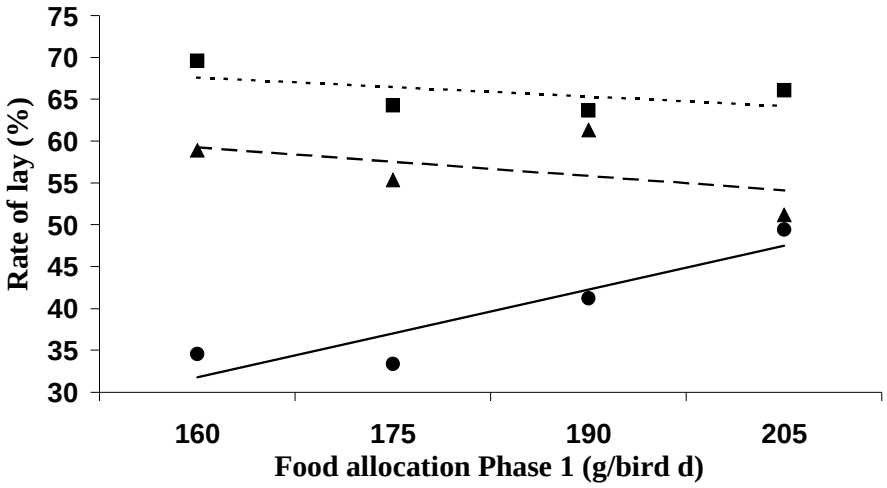


Figure 6.1 Rate of lay of broiler breeder hens over the final two-week period of the trial according to their daily feed allowances in phases 1 and 2. Solid line and ● represents 80g/d in phase 2, dashed line and ▲represents 100g/d, and dotted line and ■ represent 120g/d

Table 6.7 The relationship between carcass fat (g/kg) and abdominal fat content (g/kg) of the ten carcasses analysed at 42, 43 and 45 weeks of age

Age (week)	Constant term	s.e.	Linear coefficient	s.e.	R^2 (%)
42	103.3^{***}	11.8	3.3^{***}	0.417	87.3
43	76.5^{***}	8.1	4.9^{***}	0.383	94.8
45	63.3^{***}	7.5	4.6^{***}	0.325	95.6

Table 6.8 Abdominal fat pad weight (g/kg body weight) and body lipid content (g/kg body weight) of broiler breeders at week 5, 6 and 8, according to the feed allowances in Phase 1 (FA1) and Phase 2 (FA2)

FA1 (g/d)	Week 5				Week 6				Week 8			
	Fat Pad		Body lipid		Fat Pad		Body lipid		Fat Pad		Body lipid	
	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.
160	18.0	1.6	158.6	5.2	16.1[ab]	1.4	151.8[ab]	7.0	14.5	1.0	126.3	4.6
175	20.0	1.9	165.4	6.4	19.0[b]	1.5	166.5[b]	7.2	15.3	1.3	130.5	5.9
190	19.0	1.6	162.3	5.4	14.3[a]	1.2	143.3[a]	5.6	17.1	1.7	138.3	7.9
205	22.2	1.8	172.6	6.0	19.1[b]	1.4	166.9[b]	6.9	14.8	1.2	127.9	5.7
FA2 (g/d)	Week 5				Week 6				Week 8			
	Fat Pad		Body lipid		Fat Pad		Body lipid		Fat Pad		Body lipid	
	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.
80	19.3	1.7	162.9	5.7	15.0[a]	1.3	146.6[a]	6.2	12.8[a]	0.9	118.6[a]	4.1
100	19.7	1.5	164.3	5.0	16.7[b]	1.0	155.2[b]	5.1	14.6[b]	0.9	127.0[b]	4.2
120	20.5	1.3	166.7	4.4	19.7[c]	1.3	169.7[c]	6.2	19.0[c]	1.4	146.6[c]	6.5

[a-c] Means with different superscripts are significantly different ($P<0.05$).

Table 6.9 Rate of change in body lipid content (g/kg body weight) of broiler breeders over the last four weeks of the experiment according to the feed allowance allocated in Phase 1 and Phase 2, as determined by regression analyses

Food allocation (g/d)		Body lipid (g/kg body weight d)	
Phase 1	Phase 2	Linear coefficient	s.e.
160	80	-2.1***	0.57
160	100	-1.7**	0.57
160	120	-1.0	
175	80	-2.2**	0.73
175	100	-2.0***	0.54
175	120	-1.3	
190	80	-1.9*	0.69
190	100	-0.8	
190	120	-0.3	
205	80	-2.1**	0.66
205	100	-2.9***	0.60
205	120	-1.8*	0.79

*** P<0.001 ** P<0.01 * P<0.05

6.4 DISCUSSION

Meeting the energy requirement of broiler breeder hens throughout their various stages of production is difficult because their food intake is restricted. The problem of overfeeding broiler breeders is a real concern to any broiler breeder manager, because it leads to the deposition of body lipid which has a negative effect on reproductive performance (Pearson and Herron, 1981; McDaniel *et al*, 1981). Underfeeding these birds is also a concern, especially with day-to-day fluctuations in temperature. If broiler breeder hens were found to utilise their body lipid reserves as an energy source, it would certainly go a long way in alleviating these difficulties. It appears from the results of this trial that they are capable of doing so.

The intention of allocating a range of feed intakes to the breeder hens during phase 1 of the trial was to create four groups of birds with varying levels of body lipid. However, whereas body weight at the end of this period was directly related to food allocation and to energy intake, there appeared to be no relationship between body weight and carcass fat content among the birds sampled. The heaviest birds sampled were no fatter than the lightest birds, implying that the excess food consumed was not deposited only as carcass fat. Because of the large variation in weight and carcass composition between birds it is possible that the sample size was too small to make meaningful deductions about the relationship between

body weight and lipid content. Because weight gain of breeders during lay has been reported to be primarily related to excessive energy intake (Pearson and Herron, 1980, 1982; Wilson and Harms, 1986) it is likely that the lipid reserves in the heaviest birds were greater than in the lighter birds at the end of phase 1. This is borne out by the subsequent laying performance of hens in the second phase, which essentially followed expectations based on feed allocations in phases 1 and 2.

All birds lost weight during phase 2 reflecting the low nutrient intake in relation to requirement during this period. The amount of weight lost appeared to be unrelated to the food allocation in phase 1, but was least with the highest allocation in phase 2. It can be assumed that the loss in weight was predominantly lipid, for the reasons given above.

Hens fed either 100 or 120g/d in phase 2 were able to maintain their performance over the four weeks of this phase, with mean rates of lay of 57 and 66 eggs/100 birds per d, respectively, over the final two weeks of the trial. Birds from the same flock were kept on the floor and restricted according to the Cobb Manual using a commercial broiler breeder feed (11.9MJ ME/kg, 159g protein/kg), and their rate of lay over this period was 63 eggs/100 birds per d, thus confirming that the performance of birds on these two feed allocations was acceptable. Rate of lay of birds fed 80g/d was directly related to daily energy intake in Phase 1, and clearly demonstrated that egg production could be sustained for a short period of time if lipid reserves were available, and the daily food allocation provided sufficient nutrients (other than energy).

Egg weight was not affected by any of the feed allocations until the third week of phase 2. At this stage, eggs laid by hens given 80g/d (805kJ AME/d, 16.8g CP/d) reduced in size. Protein intake would have been marginally limiting for reproductive performance at this daily feed allowance, but this would also have been due to a shortage of energy *per se.* As suggested by Miller and Payne (1961) and Pearson and Herron (1980), energy requirements might be satisfied preferentially to protein requirements, reflecting an increase in the utilisation of protein as an energy source. This would result in a decrease in protein available for egg formation.

This trial was not designed to determine the energy requirements of broiler breeder hens, but rather to ascertain whether, for a short period of time, these hens could maintain their

egg production at an energy intake that is lower than recommended. Energy intake on each of the three treatments in phase 2 of this trial was only 805, 1006 and 1208kJ/bird d, respectively, whereas recommended energy intakes range from 1730 (Pearson and Herron, 1981) through 1840 and 1955 (Cobb, 2005) to 2000kJ ME/bird d (Bowmaker and Gous, 1991). The birds in this study clearly obtained the balance of energy required for egg production from body lipid reserves, the birds receiving 80, 100 and 120g/d in Phase 2 lost body weight at a rate of 2.3, 1.9 and 1.1g/d respectively.

As was expected, the use of body lipid reserves increased with decreasing feed allocations in Phase 2. Assuming that 8.4kJ ME is required per g egg output (Emmans, 1974), an output of 48g/d would require 403kJ ME/d. The difference in intake between birds given 80g and those given 100g/d is 201kJ ME, half the amount required for 48g egg output/d, and the difference between the intakes of 80 and 120g is 403kJ, the equivalent of one egg. Consequently, the additional energy provided to birds on 120g/d was sufficient to enable them to lay at the given rate throughout the second phase of the trial compared with the birds given 80g/d. It is assumed that the energy required for maintenance was essentially the same for hens on all treatments, as this is related to the body protein content and not the energy content of the body, and it was assumed that body protein content remained constant in all treatments.

Broiler breeder hens would be unable to make use of all their lipid reserves to enable them to continue to lay when food intake is severely restricted because a minimum amount of body lipid is needed to maintain the birds (Wellock *et al*., 2003). This trial suggests that the minimum lipid content would be around 110g/kg body weight, given that the amount in the hens fed 80g/d was close to this concentration. This concentration of lipid in the body could be used as the minimum lipid content when modelling energy utilisation of broiler breeders after sexual maturity. The results of this experiment may be used as a reference to test the broiler breeder model being developed.

The following chapter deals with an investigation of how broiler breeders partition their dietary ME at low temperatures.

CHAPTER 7

ENERGY PARTITIONING AT LOW TEMPERATURES IN BROILER BREEDERS

7.1 INTRODUCTION

The amount of energy to be allocated daily to broiler breeders is difficult to prescribe because their daily energy requirements change with egg production and with fluctuations in environmental temperature. The effect of temperature on apparent metabolisable energy (AME) intake has been widely investigated in laying hens but not in broiler breeder hens. Emmans (1974) reviewed the effect of temperature on energy intake of laying hens and partitioned energy between maintenance, egg production and growth: MEin = aW(T) + cΔW + dE, where MEin is daily intake of ME, W is body weight, ΔW is body weight change, E is egg output (g/bird d), T is environmental temperature, and a, c and d are the coefficients for maintenance, growth and production, respectively. He found that weight gain and egg output in birds fed equal amounts of nutrients were virtually unaffected by temperature over a wide range, as were the composition of the eggs produced and weight gained.

Temperature is the major environmental factor that influences the maintenance energy requirement of birds, which has been reported to decrease both linearly (Emmans, 1974; NRC, 1994) and quadratically (Peguri and Coon, 1988, as cited by Sakomura, 2004) with increasing temperature. Broiler breeders, being control-fed, do not have the option of increasing feed intake as temperature decreases, as a means of meeting their increased energy requirements, so meeting the energy requirement of these birds is partly under control of the poultry nutritionist who allocates a fixed daily amount of food to the flock. When the environmental temperature falls the amount of food or energy provided must therefore be adjusted, so full-fed laying hen models are not appropriate for broiler breeders.

Very few studies have been conducted to model energy requirements of broiler breeders. Energy required for maintenance was found to decrease linearly in broiler breeder pullets 4 weeks of age (Sakomura *et al.*, 2003) and quadratically in broiler breeder hens aged 31

weeks (Rabello, 2001; Rabello, in press, as cited by Sakomura, 2004), as temperature increased, using the comparative slaughter technique of Farrell (1974). Such studies are relatively unhelpful as it is not clear how the breeder hen will partition dietary energy when feed intake is restricted and the temperature falls. The present experiment was designed to study the simultaneous effects of temperature and dietary energy intake on the performance of broiler breeder hens fed fixed daily quantities of nutrients (other than energy), and to investigate how these hens partitioned their dietary ME as the environmental temperature decreased.

7.2 MATERIALS AND METHODS

288 Cobb broiler breeder females were housed in six environmentally controlled chambers at 44 weeks of age for a twelve-week period. Each chamber housed 48 hens in individual cages arranged in four rows, two on either side of a central passageway, and with each row consisting of 12 cages. Each cage was supplied with one nipple drinker and drip cup, and one feed container. Temperatures in the chambers were kept constant at 10, 12, 15 (two chambers), 17.5 and 20 °C for two six-week periods. Data were collected throughout each period but only those from the final three weeks of each period were used in the analysis. The lighting programme was 16L: 8D (04:00-20:00) throughout the experimental period.

Each hen was allocated 160g daily of one of four feeds containing 12.9, 11.9, 10.5 or 9.7MJ AME_n/kg. The amino acid contents were formulated to provide the same daily intakes for each of the four experimental feeds according to the breeder's recommendations (Cobb Production Manual, 2005). Feeds were analysed for AME, protein, digestible amino acids and calcium content (Table 7.1). AME was measured using the method of Fisher (1982) in which 50g of the diet is given by tube (Sibbald, 1976) following a 48 h fasting period, and excreta are collected over the following 48 h. The AME value was corrected to zero N retention and to reflect an intake of 80g/d (AME_n^{80}). Protein was measured as nitrogen x 6.25 using a LECO N analyser; amino acids by the method described by Dennison and Gous (1980); and calcium and phosphorus were analysed using the AOAC (1975) methods of analysis.

Table 7.1 Composition (g/kg) of the feeds used in he trial. Amino acid contents are given as digestible

Ingredient	F1	F2	F3	F4
Maize	263.9	263.9	263.9	263.9
Soybean full fat	213.3	213.3	213.3	213.3
Wheat bran	163.3	163.3	163.3	163.3
Maize gluten 60	28.8	28.8	28.8	28.8
Sunflower 37	13.3	13.3	13.3	13.3
DL-methionine	1.0	1.0	1.0	1.0
Vit + min premix	1.5	1.5	1.5	1.5
Limestone	76.3	76.3	76.3	76.3
Salt	3.4	3.4	3.4	3.4
Monocalcium phosphate	0.5	0.5	0.5	0.5
Starch	97.4	65.3	32.1	0.0
Filler	79.2	131.1	184.7	236.6
Oil-sunflower	60.0	40.2	19.8	0.0
Nutrient (analysed)				
AME (MJ/kg)	12.9	11.9	10.5	9.7
Crude protein	157.0	158.6	158.9	160.5
Lysine	7.7	8.1	8.2	7.6
Threonine	4.9	4.6	4.5	5.4
Arginine	8.9	8.3	8.3	8.5
Histidine	3.8	3.5	3.6	3.6
Isoleucine	6.5	6.2	6.1	6.0
Valine	7.5	7.1	6.9	6.9
Calcium	29.3	26.3	25.5	32.0
Phosphorus	3.8	3.9	3.8	3.9

Body weight was recorded bi-weekly. Food remaining in the trough was discarded at the end of each week, after being weighed, from which daily food intake was calculated. Egg production was recorded daily, and egg weight on three days each week. Temperature was recorded every five minutes throughout the trial, using Hobo data loggers (Onset Computer, 470 MacArthur Blvd., Bourne, MA 02532), from which a weighted mean temperature over the final three weeks of each period was calculated. Twelve birds were sacrificed at the beginning of the trial, and at the end of each six-week period three birds from each feed and temperature (a total of 36 birds per period) were sacrificed for carcass analyses. At the end of the first six-week period, the sampled birds were replaced with birds from the same flock. Defeathered carcasses were analysed for gross energy (GE), protein, moisture and ash. All results were converted to percentages on a wet basis. The lipid content (LC) of the body was estimated from the GE concentration using the equation: LC = -0.8756 + 0.004754 GE (University of KwaZulu-Natal, unpublished).

As a means of predicting the chemical composition of all birds in the trial a regression analysis was first performed of carcass weight on body weight using the carcass analysis

data collected at the end of each six-week period. The carcass water, protein, lipid and ash contents of birds on each treatment were then predicted from the relevant regression equations relating these components to carcass weight, from which daily gains in these components were calculated.

Treatment means were calculated, using the general analysis of variance in Genstat (1997), from the results collected during the final three weeks of each period, on the assumption that by this time the responses would have stabilised on each treatment. A multiple linear regression analysis was performed using Genstat 8th Edition (2005) to determine the effect of dietary energy intake and temperature on food (energy) intake, rate of lay, egg output, egg weight, change in bodyweight and all chemical components of the body. Linear and quadratic terms for energy intake were fitted, the quadratic term then being dropped if this proved not to be significant.

7.3 RESULTS

Mean environmental temperatures in the rooms were close to those set, being 9.9 (±1.9), 12.2 (±1.0), 14.8 (±2.0), 17.0 (±2.0) and 19.5 (±1.1) ºC respectively during the final three weeks of each test period.

The effects of temperature and dietary energy allocation on mean rate of lay, egg weight and egg output are given in Table 7.2. Multiple linear regression analyses (Table 7.3) identified an interaction between energy intake and temperature, in both rate of lay ($P<0.005$) and egg output ($P<0.01$), with these variables being unaffected by the range of temperatures used when hens were given the highest energy allocation, but with laying performance decreasing increasingly as the temperature and energy intakes were reduced. Rate of lay decreased at the rate of 2.05 eggs/100 bird d for each 1ºC drop in temperature on the lowest AME feed, at 1.59 and 1.24 for the next highest AME feeds, and at -0.05 on the highest energy feed. Egg weight increased, as temperature declined, on all but the 10.5 MJ/kg feed, the rates being 0.205, -0.194, 0.699 and 0.288g/ºC. The interaction between temperature and energy allocation proved not to be significant for egg weight (Table 7.3). The responses in egg output on the four feeds, to environmental temperature, are illustrated in Figure 7.1.

Table 7.2 Mean responses in rate of lay, egg weight and egg output to temperature (T) and dietary energy allocation (ME) over the final three weeks of the two six-week periods

	Rate of lay (eggs/100 bird d)					Egg weight (g)					Egg output (g/ bird d)				
ME (MJ/kg)	9.7	10.5	11.9	12.9	Mean	9.7	10.5	11.9	12.9	Mean	9.7	10.5	11.9	12.9	Mean
T (ºC)															
9.9	31.6	47.0	44.3	52.2	43.8	71.3	69.4	73.4	73.4	71.9	19.6	32.3	32.1	37.7	30.4
12.2	42.9	55.5	51.3	53.4	50.8	72.7	70.0	72.2	72.0	71.7	29.4	38.2	40.4	38.3	36.6
14.8	46.6	50.2	61.3	59.4	54.4	69.4	69.9	68.9	71.6	69.9	32.0	34.0	42.2	43.5	37.9
17.0	49.2	58.1	49.8	47.2	51.1	70.7	71.1	63.5	71.9	69.3	35.8	41.5	38.6	34.9	37.7
19.5	53.1	65.0	59.6	54.4	58.0	69.9	71.2	69.3	70.0	70.1	38.5	47.8	41.9	38.6	41.7
Mean	44.7	55.2	53.3	53.3		70.8	70.3	69.5	71.8		31.1	38.7	39.0	38.6	
r.m.s.		496.0 (398 d.f.)					41.31 (357 d.f.)					269.2 (480 d.f.)			

Table 7.3 Multiple linear regression coefficients[1] (± standard errors) describing the responses in rate of lay, egg weight, egg output, weight and carcass component gains to AME intake (MJ/d), environmental temperature (^{O}C) and their interaction

Variate	Constant term	AME in	AME in^2	T	AME x T	R^2 (%)
Rate of lay	-249.9	236.2	-0.0418	8.3	-4.06	11.3
(/100 bird d)	±61.4	±57.0	±0.0143	±2.49	±1.4	
Egg output	-308	309.0	0.0675	5.86	-2.84	15.3
(g/bird d)	±64.9	±69.0	±0.0193	±1.99	±1.11	
Egg weight	74.15			-0.247		1.3
(g)	±1.59			±0.103		
Weight gain	-99.3	108.3	-0.02634	-0.3287		29.1
(g/d)	±12.2	±13.9	±0.00397	±0.0787		
Protein gain	-12.11	15.07	-0.00414	-0.284	0.1306	27.7
(g/d)	±2.86	±2.66	±0.000665	±0.116	±0.0654	
Lipid gain	-13.31	13.98	-0.003088	-0.0596		28.2
(g/d)	±2.28	±2.60	±0.000741	±0.0147		
Water gain	-43.1	53.69	-0.01476	-1.041	0.48	27.6
(g/d)	±10.4	±9.66	±0.00242	±0.423	±0.238	
Ash gain	0.5031			-0.1248	0.05948	22.0
(g/d)	±0.0729			±0.01	±0.00496	

[1] Only coefficients with P<0.05 are included in this table

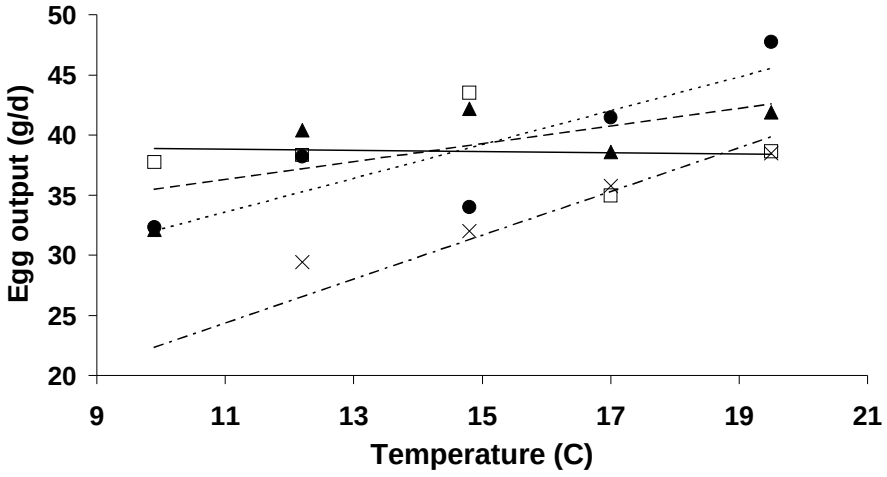


Figure 7.1 Observed and fitted relationship between egg output (g/d) and temperature (°C) at four daily energy allocations (□ = 12.9; ▲ = 11.9; ● = 10.5; x = 9.7) with fitted equations (solid line = 12.9; dotted line = 11.9; dashed line =10.5; dotted and dashed line = 9.7). The slopes of the four regressions were -0.05, 0.75, 1.42 and 1.84 respectively

Mean energy intakes and body weight gains, as influenced by dietary energy allocation and environmental temperature, are given in Table 7.4. Not all the energy allocated to the birds was consumed each day, the difference being 19, 13, 42 and 64kJ/d for hens on the lowest to

the highest AME allocations respectively. Weight gains increased curvilinearly with increasing AME allocation (means over all temperatures being -0.6, 3.2, 5.6 and 7.2g/d for the four energy allocations) but decreased with increasing temperature (Table 7.3), the decrease being proportional to the ME intake. Each additional 100kJ of energy intake resulted, overall, in an increase of 0.1g in body weight.

Table 7.4 Mean responses in energy intake and body weight gain to temperature (T) and dietary energy allocation (ME) over the final three weeks of the two six-week periods

	Energy intake (MJ/d)					Body weight gain (g/bird d)				
ME (MJ/kg) T (ºC)	9.7	10.5	11.9	12.9	Mean	9.7	10.5	11.9	12.9	Mean
9.9	1551	1668	1832	1963	1754	2.1	5.6	7.2	9.3	6.1
12.2	1533	1671	1875	2044	1781	-0.7	3.6	5.9	5.5	3.6
14.8	1550	1655	1861	2018	1771	0.2	2.3	5.4	7.0	3.7
17.0	1483	1662	1859	1952	1739	-2.8	3.7	7.1	10.3	4.6
19.5	1547	1677	1883	2022	1782	-1.9	0.8	2.2	3.6	1.2
Mean	1533	1667	1862	2000		-0.6	3.2	5.6	7.2	
r.m.s		10382 (401 d.f.)					42.69 (400 d.f.)			

Defeathered carcasses at 44 and 50 weeks contained 622 ± 24 and 605 ± 37g/kg moisture, 167 ± 8 and 169 ± 10g/kg protein, 178 ± 29 and 193 ± 38g/kg lipid and 59 ± 7 and 59 ± 8g/kg ash, respectively (mean ± standard deviation). Changes in carcass composition during the experimental periods are given in Table 7.5. In all cases other than ash gain, carcass gains increased curvilinearly with energy consumption but decreased with environmental temperature (Table 7.3). Ash gain also decreased with temperature ($P<0.01$), but energy intake influenced this only through its interaction with temperature ($P<0.01$). Significant interactions ($P<0.05$) between energy intake and temperature occurred in the case of both body protein gain and body water gain, but not for body lipid gain.

Table 7.5 Mean water, protein, lipid and ash gains in response to temperature (T) and dietary energy allocation (ME) over the final three weeks of the two six-week periods

	Water gain (g/d)					Protein gain (g/d)				
ME (MJ/kg)	9.7	10.5	11.9	12.9	Mean	9.7	10.5	11.9	12.9	Mean
T (ºC)										
9.9	1.2	3.2	4.0	5.0	3.4	0.3	0.9	1.1	1.4	0.9
12.2	-0.5	2.2	3.8	3.3	2.2	-0.1	0.6	1.1	0.9	0.6
14.8	0.1	1.5	3.1	4.0	2.2	0.0	0.4	0.9	1.1	0.6
17.0	-1.6	2.1	3.9	5.6	2.5	-0.5	0.6	1.1	1.5	0.7
19.5	-1.3	0.4	1.3	2.2	0.7	-0.4	0.1	0.4	0.6	0.2
Mean	-0.4	1.9	3.2	4.0		-0.1	0.5	0.9	1.1	
r.m.s		15.64 (401 d.f.)					1.18 (401 d.f.)			

	Lipid gain (g/d)					Ash gain (g/d)				
ME (MJ/kg)	9.7	10.5	11.9	12.9	Mean	9.7	10.5	11.9	12.9	Mean
T (ºC)										
9.9	0.3	0.9	1.4	1.9	1.1	0.1	0.3	0.4	0.5	0.3
12.2	-0.1	0.6	1.2	1.1	0.7	-0.1	0.2	0.4	0.3	0.2
14.8	0.0	0.4	1.0	1.5	0.7	0.0	0.2	0.3	0.4	0.2
17.0	-0.4	0.6	1.3	2.1	0.9	-0.2	0.2	0.4	0.5	0.2
19.5	-0.4	0.1	0.4	0.8	0.2	-0.1	0.0	0.1	0.2	0.1
Mean	-0.1	0.5	1.1	1.5		0.0	0.2	0.3	0.4	
r.m.s		1.407 (401 d.f.)					0.149 (401 d.f.)			

The initial regression equation that was fitted, for predicting ME intake (kJ/d) as a function of body weight (W, kg), egg output (EO, g/d), average daily gain (ΔW, g/d) and temperature (T, ºC), predicted the ME requirements for egg output and weight gain to be 6.4 and 9.9kJ/g d, respectively, but suggested that temperature had no effect on maintenance requirements of the birds. Consequently a different approach was used to determine this effect, in which the calculated requirements for egg production and growth were first subtracted from the ME consumed, using the above coefficients, and the remainder was then regressed against W and W.T. The resultant equation, where ΔW was used, was:

$ME = W [379(\pm 8.71) - T] + 6.4(\pm 0.38)\ EO + 9.9(\pm 1.05)\ \Delta W$ ($P<0.001$, $R^2=50.4\%$)

and where ΔL (g lipid gain/d) was used in place of ΔW the equation was:

$ME = W [379(\pm 8.59) - T] + 6.4(\pm 0.374)\ EO + 53.5(\pm 5.42)\ \Delta L$ ($P<0.001$, $R^2 = 51.3\%$).

Temperature had a linear (P<0.001) effect on energy required for maintenance, increasing by 1.0kJ AME/d. kg W. ^{o}C from 19.5ºC to 9.9ºC. The ME requirements for egg output and weight gain were 6.4 and 9.9kJ/g d, respectively.

7.4 DISCUSSION

The objective of this trial was to determine how broiler breeder females partitioned a fixed daily allocation of dietary energy between maintenance, egg production and body growth as the environmental temperature was decreased below 20^{o}C.

Egg production declined linearly throughout the range of temperatures used when hens were fed 11.9, 10.5 and 9.7MJ /kg indicating that the birds were using increasing amounts of dietary energy for maintenance as the temperature declined, leaving less available for production, while birds fed 12.9MJ/kg (2000kJ/d) maintained their performance at all temperatures. Low temperatures have no effect on egg production in hens fed *ad libitum (*Emmans, 1974*)*, but where energy intake is restricted, as was the case with hens on the lower energy allocations, energy would need to be partitioned differently, the most likely scenario being that rate of laying would be reduced to accommodate the higher maintenance requirement. When fitting a multiple linear regression to the data the maintenance requirement appeared unaffected by temperature (the term WT was not significant), this being the reason for utilising an alternative approach to finding the effect of temperature on maintenance. Once the requirements for egg production and growth had been subtracted from the energy consumed, the remainder was regressed against W and WT, and both terms then yielded regression coefficients that were highly significant. The decrease in temperature from 19.5ºC to 9.9ºC increased the daily maintenance requirement by 1.0kJ AME / kg W. ^{o}C. Consequences of the reduced rate of laying were increases in lipid reserves and egg weight, the latter possibly being due to the additional time that the yolk spent in the ovary resulting in concomitant increases in yolk, albumen and shell. Dietary protein consumed in excess of requirement, resulting from the lower production, would have had to be deaminated and converted to body lipid, which would explain the observed increase in lipid reserves at the lower temperatures. It is anomalous that when dietary protein intake is adequate but energy is limiting, egg production ceases, which then results in an overabundance of energy that must be stored in the body. We have evidence that the energy stored in this way is available to the

bird for later use (Chapter 6) thus egg production may continue on low energy intakes, but in an erratic manner.

The ME requirement for maintenance obtained in this study was 364kJ/kg W, or 505kJ/kg $W^{0.75}$ (mean body weight of 3.7kg) at 19.5ºC, which was essentially similar to the value of 534kJ/kg $W^{0.75}$ reported by Balnave (1978b) using caged broiler breeder hens in respiration chambers held at 22˚C and aged 45 weeks. However, values lower than this have been reported by Johnson and Farrell (1983) (367kJ/kg $W^{0.75}$ or 292kJ/kg d) and Spratt *et al.* (1990) (365kJ/kg $W^{0.75}$ d or 266kJ/kg d) for broiler breeder hens in respiration calorimeters at 21ºC. Equivalent values published by Rabello (2001), as cited by Sakumora (2004), were 380kJ/kg $W^{0.75}$ for broiler breeder hens in cage, and 472kJ/kg $W^{0.75}$ (Rabello *et al.* in press) with breeders raised on the floor at 21ºC. The ME requirement for maintenance of two strains of laying hen was estimated to be 518kJ/kg W for white strains and 410kJ/kg W for brown strain at 21ºC (Emmans, 1974). The higher maintenance requirement found in our study could be explained by the difference in body composition of the birds used. According to Blaxter (1989), the increment in lipid deposition in mature birds provided a decrease in ME for maintenance because the metabolic ratio in lipid tends to be lower than in other tissues. The hens used in this experiment had a lower proportion of less metabolically active adipose tissue relative to metabolically active lean tissue, which could explain the higher value of maintenance ME requirement than in laying hens. Because of the lack of information about the body composition of birds used in previous studies this could not be tested with previous data. Another explanation is that birds temporarily out of lay will continue to synthesize egg yolk in ovarian follicles and this will result in an elevated maintenance energy requirement (Balnave, 1978b). Because broiler breeder hens are poorer layers than egg-type hens, having shorter prime sequence lengths and therefore more pause intervals (Robinson *et al.*, 1993), the maintenance ME requirement of broiler breeders is likely to appear higher than in good layers. A corollary is that the ME apparently needed for egg production in broiler breeders may appear to be lower per g of egg output than in laying hens because part of the energy incorporated into yolk material may be seen to be part of the maintenance requirement.

The ME required for egg output in the current study was 6.4kJ/g, which is lower than values of 8.0 to 13.2kJ/g quoted in the literature, this difference possibly being due to differences in apparent efficiency of energy utilisation for egg production (see above): the energy content of eggs ranges from 5.6kJ/g (Sibbald, 1979) to 7.5kJ/g (Chwalibog, 1992), while energy

efficiencies quoted in the literature range from 60 to 85% (Luiting *et al.*, 1990; Chwalibog, 1995) depending upon genotype, bird age, lighting pattern, egg size and egg composition (Chwalibog, 1992). Maximum egg output in this trial was about 45g/bird d, which is on target for breeder flocks of 45 weeks, whereas at peak some broiler breeders may achieve a mean of 50g egg output/d. The additional ME required for the 5g higher egg output (32.5kJ) would increase the requirement for egg production to 325kJ/bird d, so for a 3.5kg broiler breeder laying at this rate and kept at a temperature of about 20ºC, her ME requirement would be 1275 + 325 = 1600kJ/d.

The results of this research show that at temperatures between 15 and 20ºC broiler breeders are capable of maintaining egg production on an energy intake as low as 1667kJ ME/d, which is considerably lower than that recommended by Cobb (2005) **(**1840 to 1955kJ ME/bird d). At energy intakes higher than this, breeders gained weight implying that they were being fed in excess of requirement, whereas an ME intake of 1533kJ ME/d depressed performance significantly, with a concomitant loss in body weight. The housing conditions in this trial make comparisons of maintenance requirements difficult as birds kept in cages are not as active as those housed in groups on the floor, but those on the floor are able to keep warm by huddling together with others. However, the linear increase in maintenance requirement with a decrease in environmental temperature is likely to be sufficiently accurate for purposes of modelling the requirements of broiler breeders for cold thermogenesis.

It could be argued that body protein and lipid deposition, or utilisation, leading to a change in body weight, should be regarded as being a consequence of the nutrients consumed and not as an obligatory daily process. This being the case, the balance of ME intake remaining after accounting for maintenance and egg production would be converted into body lipid with varying efficiencies depending on whether the dietary lipid was deposited directly as body lipid or first converted to CO_2 and H_2O (Emmans, 1994). Changes in the body weight of hens in this trial were measurable, the ME used for weight gain (9.9kJ/g) being less than that quoted for laying hens of 18.5, (Davis *et al.* 1972), 20.9, Emmans (1974) and 23.0kJ/g (NRC, 1994) or for broiler breeders of 31.9kJ/g (Rabello, 2001). These values differ presumably with the tissue being formed and because of differences in the efficiency of ME utilisation for their growth. The efficiency of energy deposition has been reported to be 47% for broiler breeders and 65% for laying hens (Sakomura *et al.*, in press, cited by Sakomura, 2004) whereas Emmans (1974) assumed an efficiency of 80% in converting dietary ME to egg and carcass

energy. It is unlikely that any body protein is deposited in productive hens; hence gain in weight in this trial was assumed to be lipid only. The ME used in depositing lipid was 53.6kJ/g, which was higher than the value of 40.0kJ/g reported by Spratt *et al.* (1990) for broiler breeders and 37.8kJ/g reported by Sakomura *et al.* (2003) for breeder pullets, but similar to the value of 56.6kJ/g found by Sakomura *et al.* (2005) for broilers. Tess *et al.* (1984) reported a wide range of values for the energy cost of lipid synthesis (40 to 68kJ/g) in pigs. The energy cost of lipid deposition depends on the composition (protein, carbohydrate and lipid) of the experimental feed and is not a constant value; also, lipid from body reserves may have influenced the energetic cost of lipid deposition (Spratt *et al.*, 1990).

It appears from this study that broiler breeders, on a fixed daily allocation of dietary energy, will reduce egg output when faced with an energy deficiency, which has the result of increasing lipid reserves when the feed is adequate in protein content due to the deamination of the protein not used for egg production. This enables the hen to build up a reserve of energy so that egg production can be sustained, albeit erratically. The additional energy required for cold thermogenesis amounts to 1.0kJ AME/kg W. ^{o}C, which should be added to the maintenance requirement of broiler breeders for environmental temperatures below about 18^{o}C.

The following chapter deals with the modelling of the changes in the proportions of the breeder egg components during the laying period.

CHAPTER 8

MODELLING CHANGES IN EGG COMPONENT PROPORTIONS IN BROILER BREEDERS OVER TIME

8.1 INTRODUCTION

Knowledge of the chemical composition of eggs and physiological processes involved in yolk and albumen production has mostly been obtained from research conducted on commercial layers. Much of the relevant research conducted over the past 50 years has confirmed the findings of Romanoff and Romanoff (1949) in terms of chemical composition and proportional changes in the components with increasing egg weight and hen age. At a fixed hen age and over a range of egg weights, the weights of all three components (yolk, albumen and shell) increase with egg weight, but albumen increases at the expense of yolk and shell. As the laying period progresses the component weights also increase, but in this case the yolk increases at the expense of albumen and shell (Anderson *et al.*, 1978; Fletcher *et al.*, 1981; Fletcher *et al.*, 1983; Ahn *et al.*, 1997). Because the nutrient requirements of the hen for egg production are based on the amount and chemical composition of the products being formed, and as the chemical composition of yolk, albumen and shell differs substantially one from the other, it is essential, when modelling the response to nutrient intake in the broiler breeder hen, to know how the relative proportions of the components of the egg change with egg size and breeder age. Such measurements need to be specific to the strain of laying hen being modelled, as significant strain variation exists with respect to egg composition (Johnston, 2004). As a result of the changes that take place in the relative proportions of the three egg components with time, it is preferable to predict egg weight as the sum of the weights of these three components rather than predicting egg weight as an entity. This may be accomplished by predicting both rate of yolk production and mean yolk weight with time, and then relating the weights of the other components allometrically to yolk weight as suggested by Emmans and Fisher (1986).

Johnston (2004) measured the allometric coefficients a and b for three strains of laying hen, and then predicted changes in the proportions of egg components during the laying cycle, using the above theory. Because large differences were apparent in these coefficients

between laying strains it is likely that even greater differences might occur between laying hens and broiler breeders. Consequently, the objective of the present study was to predict yolk weight, to derive suitable values for the coefficients *a* and *b* in the allometric functions relating albumen weight to yolk weight, and yolk plus albumen weight to shell weight, and to examine the relationships between yolk, albumen and shell weights at different egg weights and hen ages in broiler breeders with the use of a population model.

8.2 MATERIALS AND METHODS

363 and 404 fresh eggs were collected from a flock of 1200 Cobb and Ross broiler breeder hens, respectively, housed in floor pens in an open house. Collections were made on two occasions before 30 weeks, and then every five weeks thereafter to 60 weeks of age. All the eggs were chosen at random from those laid, except for obviously dirty or cracked eggs, to avoid possible sampling bias, and stored overnight at 16°C before the components were measured.

The method used to determine the weights of the egg components was that described by Cotterill *et al.* (1962), which was reported by Fletcher *et al.* (1981) to reflect low coefficients of variation and high R^2 values, as well as being easier and faster to perform in the laboratory. The eggs were weighed prior to being broken open. The yolk was separated from the albumen using a domestic egg separator; the albumen was discarded and the yolk rolled on damp paper towel. Any adhering chalazae were removed from the yolk with the aid of tweezers. Some yolk membranes ruptured during the procedure and these eggs were discarded. Only intact yolks were weighed. The two halves of the shell were carefully washed to remove the albumen then were left to dry at 21 ºC for 48 hr prior to being weighed. The albumen weight was determined by subtracting the yolk and dry shell weights from the initial whole egg weight. Genstat (1997) was used for statistical analysis.

8.3 RESULTS

The number of eggs sampled on each occasion over the 30-week period, together with the mean and standard deviation of each component weight, are in Table 8.1. The proportions of each component in the whole egg, and the yolk:albumen ratio, are given in Table 8.2.

Table 8.1. Mean weights of components of eggs from Cobb and Ross broiler breeder hens over a period of 35 weeks (n=sample size)

Age		Egg weight (g)		Yolk weight (g)		Albumen weight (g)		Shell weight (g)	
(week)		Cobb	Ross	Cobb	Ross	Cobb	Ross	Cobb	Ross
25	Mean	50.5	51.5	12.9	12.6	32.9	33.8	4.8	5.0
	SD	2.1	4.2	0.9	1.2	1.8	3.2	0.4	0.6
	n	30	54						
27	Mean		54.6		14.3		35.5		4.9
	SD		3.1		0.9		2.5		0.4
	n		49						
28	Mean	55.1		14.6		35.4		5.0	
	SD	2.6		0.8		2.4		0.5	
	n	30							
30	Mean	61.2	57.7	16.5	15.5	39.2	37.5	5.6	4.7
	SD	4.7	4.2	1.1	1.2	3.8	3.4	0.6	0.6
	n	13	37						
35	Mean	67.8	60.6	18.5	18.8	43.1	36.1	6.2	5.6
	SD	3.2	3.7	1.1	1.8	2.5	2.7	0.4	0.6
	n	47	55						
40	Mean	71.4	64.7	19.7	19.3	45.2	39.4	6.5	6.0
	SD	4.6	3.0	1.6	1.7	3.4	2.2	0.5	0.5
	n	50	56						
45	Mean	71.5	67.1	21.6	20.7	43.5	40.5	6.5	6.0
	SD	5.6	4.7	2.0	1.9	3.9	3.1	0.5	0.7
	n	43	52						
50	Mean	73.2	70.4	21.9	21.7	44.7	42.2	6.6	6.5
	SD	4.4	6.0	1.5	1.7	3.8	4.6	0.6	0.7
	n	51	58	51					
55	Mean	73.6	70.0	22.3	22.8	44.6	41.0	6.7	6.3
	SD	3.6	4.8	1.6	2.1	2.9	3.9	0.5	0.5
	n	57	43						
60	Mean	74.5		22.7		45.1		6.7	
	SD	5.0		1.6		4.0		0.5	
	n	42							

Table 8.2. Proportions of components of eggs from Cobb and Ross broiler breeder hens over a period of 35 weeks (n=sample size)

Age		Yolk (%)		Albumen (%)		Shell (%)		Y:A ratio	
(week)		Cobb	Ross	Cobb	Ross	Cobb	Ross	Cobb	Ross
25	Mean	25.5	24.5	65.0	65.7	9.5	9.8	0.393	0.374
	n	30	54						
27	Mean		26.1		64.9		8.9		0.403
	n		49						
28	Mean	26.6		64.3		9.1		0.414	
	n	30							
30	Mean	27.0	26.9	63.9	64.9	9.2	8.1	0.423	0.416
	n	13	37						
35	Mean	27.3	31.1	63.6	59.7	9.1	9.2	0.430	0.523
	n	47	55						
40	Mean	27.6	29.8	63.2	61.0	9.1	9.2	0.438	0.490
	n	50	56						
45	Mean	30.2	30.8	60.7	60.3	9.1	8.9	0.499	0.512
	n	43	52						
50	Mean	30.0	30.9	61.0	59.9	9.0	9.2	0.494	0.518
	n	51	58	51					
55	Mean	30.3	32.5	60.6	58.5	9.1	9.0	0.502	0.560
	n	57	43						
60	Mean	30.5		60.5		9.0		0.505	
	n	42							

Predicting yolk weight

Logistic functions were used to predict yolk weight (YW, g) from hen age (HA, d) for Cobb ($P<0.001$; $R^2=81.8\%$) and Ross ($P<0.001$; $R^2=79.1\%$) strains, respectively:

$$YW = -6.227 + 29.3 / (1 + \exp(-0.01479(HA - 132.8))) \quad \text{(Equation 8.1)}$$

$$YW = -193.1 + 216.6 / (1 + \exp(-0.01121 (HA + 89.88))) \quad \text{(Equation 8.2)}$$

These two equations did not differ significantly one from the other. Consequently, data were pooled to increase the number of replications. However, once pooled, the logistic equation gave a poorer fit (74.9%) than a linear-by-linear equation ($P<0.001$, $R^2=82.2\%$) so the latter was used to describe this relationship (Equation 8.3), which can thus be used to predict yolk weight from hen age for the full laying cycle for broiler breeder hens.

$$YW = 28.083 + 34.2 / (1-0.01836 * HA) \quad \text{(Equation 8.3)}$$

Figure 8.1 illustrates the actual and predicted relationships between yolk weight and hen age for the two strains.

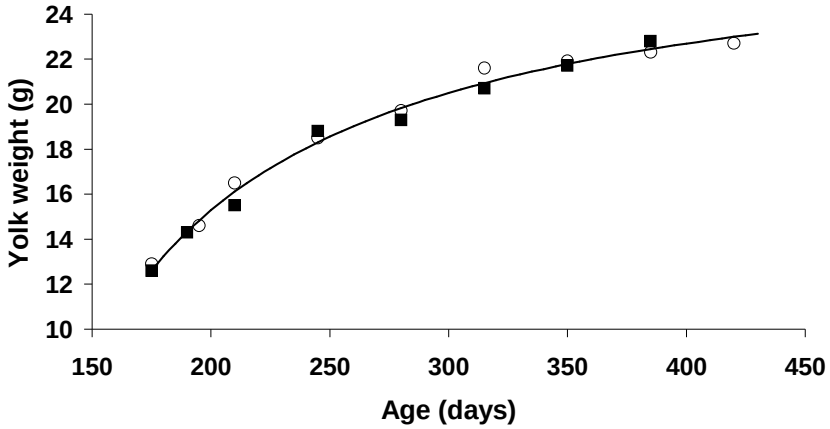


Figure 8.1 Mean yolk weights for Cobb (O) and Ross (■) hens over a period of 36 weeks, together with the predicted weight (solid line)

Predicting albumen weight from yolk weight

Using individual egg data, linear regression analyses were performed on *ln* albumen weight *vs. ln* yolk weight. The resultant allometric coefficients are shown in Table 8.3 for Cobb and Ross strains, respectively.

Table 8.3. Allometric coefficients describing ln albumen weight (g) in terms of ln yolk weight (g) (± S.E.) at different ages for eggs produced by Cobb and Ross breeders

Age (weeks)	a coefficient		b coefficient	
	Cobb	Ross	Cobb	Ross
25	3.5*** ±0.346	2.6*** ±0.321	-0.009	0.381** ±0.127
27		2.8*** ±0.421		0.303
28	4.1*** ±0.622		-0.190	
30	2.5	3.0*** ±0.526	0.417	0.236
35	2.9*** ±0.399	3.2*** ±0.324	0.281* ±0.137	0.137
40	2.7*** ±0.365	3.7*** ±0.271	0.388** ±0.123	-0.021
45	2.1*** ±0.412	2.7*** ±0.339	0.538*** ±0.134	0.339** ±0.112
50	3.6*** ±0.524	1.9*** ±0.532	0.057	0.588*** ±0.173
55	3.6*** ±0.383	2.9*** ±0.493	0.074	0.254
60	2.1*** ±0.574		0.564** ±0.184	

*** P<0.001 **P<0.01 *P<0.05

The correlation coefficients ranged from 0 to 26.9% and 0 to 17.5% for Cobb and Ross strains, respectively, indicating weak to moderate relationships between the variables. At a fixed age, there appears to be no consistent relationship between albumen weight and yolk weight, nor was there a significant difference in the response in albumen weight to yolk weight between the various ages. Consequently, the yolk and albumen weights for all eggs measured were pooled per strain and, over the range of ages from 25 to 60 weeks, highly significant allometric functions for Cobb ($P<0.001$, $R^2=58.0\%$) (Equation 8.4) and Ross ($P<0.001$, $R^2=38.7\%$) (Equation 8.5) birds, respectively resulted when regressing *ln* albumen weight on *ln* yolk weight:

$$ln\ AW = 2.2584 + 0.5002\ ln\ YW \qquad \text{(Equation 8.4)}$$

$$ln\ AW = 2.6998 + 0.3250\ ln\ YW \qquad \text{(Equation 8.5)}$$

The slopes and the intercepts of these regressions differed significantly between the two strains, justifying the use of a different equation for each strain when predicting albumen weight from yolk weight.

Substituting the exponential of constant *a* (2.2584 and 2.6998) and the value of slope *b* (0.5002 and 0.3250) in the following allometric function $y = a.x^{b}$, the relationship becomes

$$AW = 9.5257\ YW^{0.5002} \qquad \text{(Equation 8.6)}$$

$$AW = 14.8768\ YW^{0.3250} \qquad \text{(Equation 8.7)}$$

Albumen weight may thus be predicted from yolk weight for the full laying cycle for Cobb and Ross hens using Equations 8.6 and 8.7 respectively.

As yolk weight increased the albumen content in eggs laid by Ross breeders increased at a slower rate, and the range in albumen weights was lower, compared with Cobb eggs (Figure 8.2).

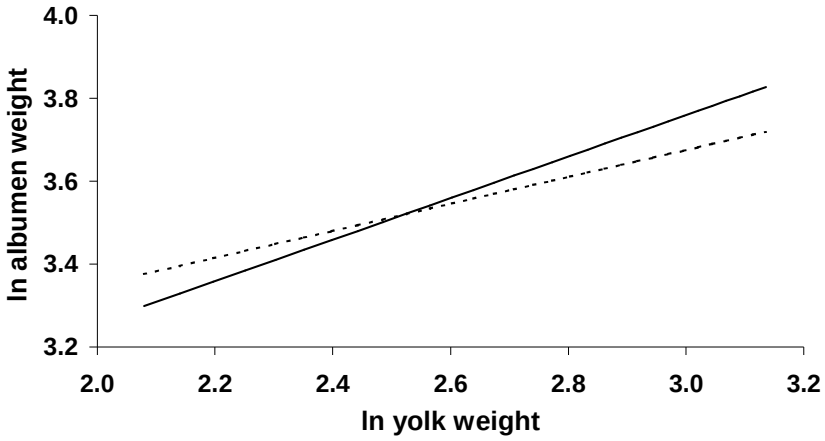


Figure 8.2 Allometric relationship between ln albumen weight and ln yolk weight for Cobb (solid line) and Ross (dotted line) strains of broiler breeder

Predicting shell weight from egg components weight

Linear regression analyses were performed of ln shell weight *vs.* ln egg content weight for the different ages within strains. The resultant regressions equations are given in Table 8.4 for the two strains.

Table 8.4 Allometric coefficients (± standard error) describing ln shell weight (g) in terms of ln egg content weight (g) at different ages for Cobb and Ross breeders

Age (weeks)	a coefficient		b coefficient	
	Cobb	Ross	Cobb	Ross
25	-1.0	-1.4* ±0.660	0.663	0.779*** ±0.172
27		-0.6		0.558* ±0.213
28	-1.0		0.669	
30	-0.7	-3.0** ±1.07	0.607* ±0.256	1.141*** ±0.270
35	0.1	-0.5	0.408* ±0.198	0.542* ±0.220
40	-0.1	-0.8	0.482*** ±0.137	0.627* ±0.258
45	-0.6	-2.8*** ±0.683	0.587*** ±0.126	1.111*** ±0.166
50	-1.2	-1.1	0.730*** ±0.179	0.723*** ±0.137
55	-0.7	-0.02	0.619** ±0.186	0.446** ±0.163
60	0.5		0.339* ±0.156	

*** P<0.001 **P<0.01 *P<0.05

Correlation coefficients ranged from 7.7 to 32.3% and from 9.4 to 43.7% for Cobb and Ross strains, respectively, indicating weak to moderate relationships between the variables. As there were no consistent relationship between shell and egg content weights either within or between ages, the values were pooled and, over the range of ages from 25 to 60 weeks, highly significant allometric functions for Cobb ($P<0.001$, $R^2=70.4\%$) (Equation 8.8) and Ross ($P<0.001$, $R^2=52.4\%$) (Equation 8.9) birds, respectively, were obtained:

$$ln\ SW = -1.610 + 0.8324\ ln\ ECW \qquad \text{(Equation 8.8)}$$

$$ln\ SW = -1.690 + 0.8481\ ln\ ECW \qquad \text{(Equation 8.9)}$$

The slopes and the intercepts of the two strains did not differ significantly one from the other. Consequently, data from both strains were pooled, the resultant linear function ($P<0.001$, $R^2=70.4\%$) being

$$ln\ SW = -1.7681 + 0.8686\ ln\ ECW \qquad \text{(Equation 8.10)}$$

Substituting the exponential of the constant *a* (-1.7681) and the value of the slope *b* (0.8686) in the allometric function $y = a. x^{b}$, the relationship becomes

$$SW = 0.1707\ ECW^{0.8686} \qquad \text{(Equation 8.11)}$$

Equation 8.11 may therefore be used to predict shell weight from the weight of the egg contents for broiler breeder hens over the full laying cycle.

Predicting egg weight

Mean potential egg weight (EW, g) may be estimated for each genotype by adding together the predicted yolk, albumen and shell weights (Equation 8.12).

$$EW = YW + AW + SW \qquad \text{(Equation 8.12)}$$

Cobb eggs were larger and contained more albumen and less yolk than Ross eggs (see Figure 8.3), but eggs of the same size from each strain had similar amounts of shell deposited around the eggs. The proportion of yolk in the egg increased by 0.20 and 0.33 over the 35-week laying period whereas the albumen and shell contents decreased by 0.07 and 0.11 and 0.05 and 0.08 for the Cobb and Ross strains, respectively.

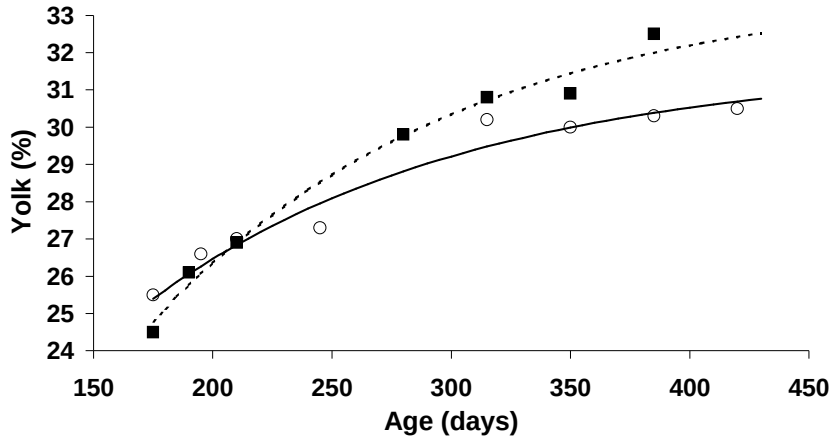


Figure 8.3 Mean observed and predicted yolk proportions in eggs of Cobb (○, solid line) and Ross (■, dotted line) hens over a period of 36 weeks. Predicted values obtained from exponential functions for Cobb (31.709 – 23.22 (0.99259 ^ HA), R^2 = 50.0) and Ross (33.8 – 34.44 (0.99237 ^ HA), R^2=64.0), respectively

Using the predicted egg weight and component proportions in a population model

The mechanistic, stochastic population model of egg production designed by Johnston (2004) for laying hens was adapted for broiler breeder hens (unpublished data, 2006). This model may be utilised to predict, stochastically, yolk, albumen and shell weights, and hence egg weights for hens of different strains and ages.

Using the parameter estimates and CV's in Table 8.5, normally distributed values of yolk, albumen and shell for 100 broiler breeder hens of each strain over a period of 35 weeks of lay were simulated.

Table 8.5 Parameter estimates and CV's used in the population model

Parameters	Value	CV
Age at photostimulation (APS, d)	140	-
Length of final photoperiod (P, h)	16	-
BW at photostimulation (BWPS, g)	2200	-
BW at 20 weeks (BW20, g)	2200	-
Time the lights are turn off (h)	22	-
Age at first egg (d) after Lewis and Morris (2006b)	$440.5 - 1.256\ APS + 2.159^{-9}\ APS^5 - 9.229^{-12}\ APS^6 - 0.0402\ BWPS + 1.208^{-5}\ BWPS^2 - 0.035\ BW20 - 1.616\ P$	0.04
Double yolk		-
Less than 2% to 30 weeks	$-0.00291 + 75438\ (0.940345^{Hen\ Age})$	-
More than 2% to 30 weeks	$0.576 + 3734\ (0.962421^{Hen\ Age})$	-
Soft shell		-
Less than 3% to 30 weeks	-6.36 - 4.509 /(1- 0.009463 Hen Age) + 0.01607 Hen Age	-
More than 3% to 30 weeks	-10.55 – 8.45 / (1- 0.010099 Hen Age) + 0.02544 Hen Age	-
Yolk weight (YW, g)	28.083 + 34.2 / (1-0.01836 * Hen Age)	0.05
Albumen weight (AW, g)		
Cobb	$9.5257\ YW^{0.5002}$	0.05
Ross	$14.8768\ YW^{0.3250}$	0.05
Shell weight	$0.1707\ ECW^{0.8686}$	0.02

Values obtained for the proportions of yolk, albumen and shell in eggs at 40 weeks of age are illustrated in Figures 8.4 to 8.6.

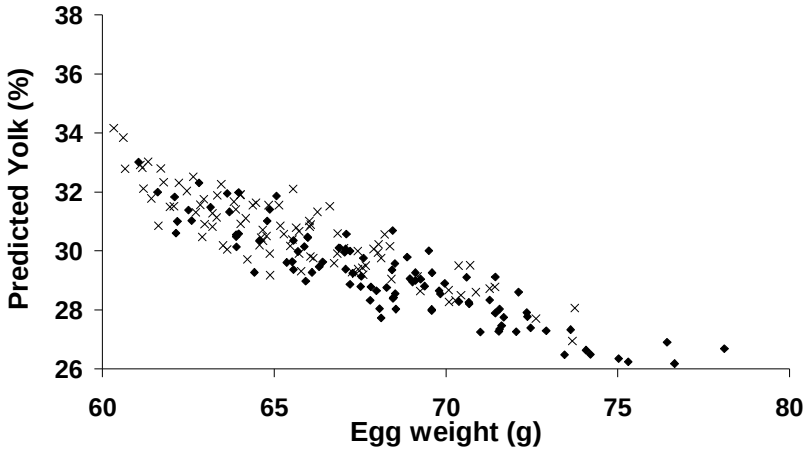


Figure 8.4 Relationship between proportion of yolk and egg weight from a simulated flock of 100 Cobb (■) and Ross (x) hens at 40 weeks

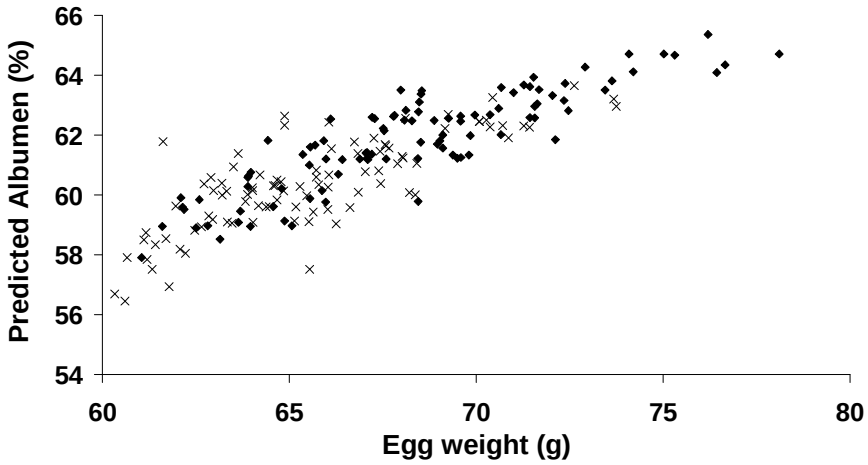


Figure 8.5 The positive relationship between proportion of albumen and egg weight for a simulated flock of 100 Cobb (■) and Ross (x) hens at 40 weeks

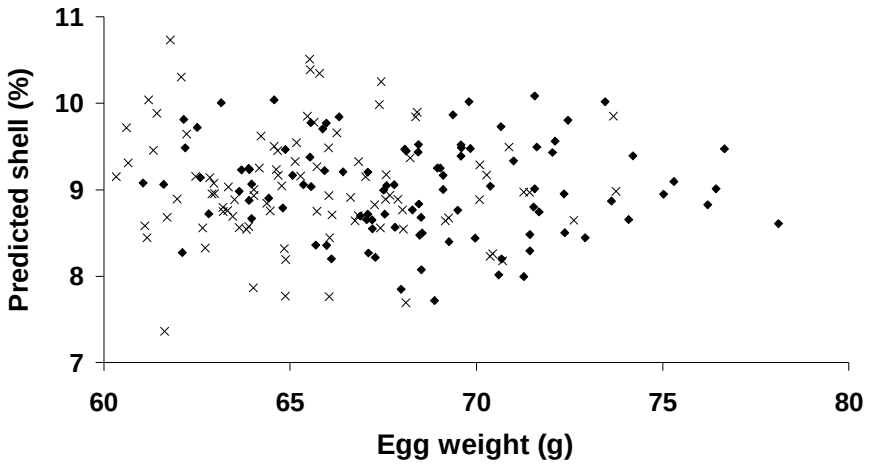


Figure 8.6 The relationship between the proportion of shell in the egg and egg weight for a simulated flock of 100 Cobb (■) and Ross (x) hens at 40 weeks

Using hen age as the basis, the yolk, albumen and shell weights for both strains were predicted over the entire laying period and then summed to obtain a predicted egg weight for age for both the Cobb and Ross strains. These predicted weights are illustrated in Figure 8.7 together with the mean weights measured.

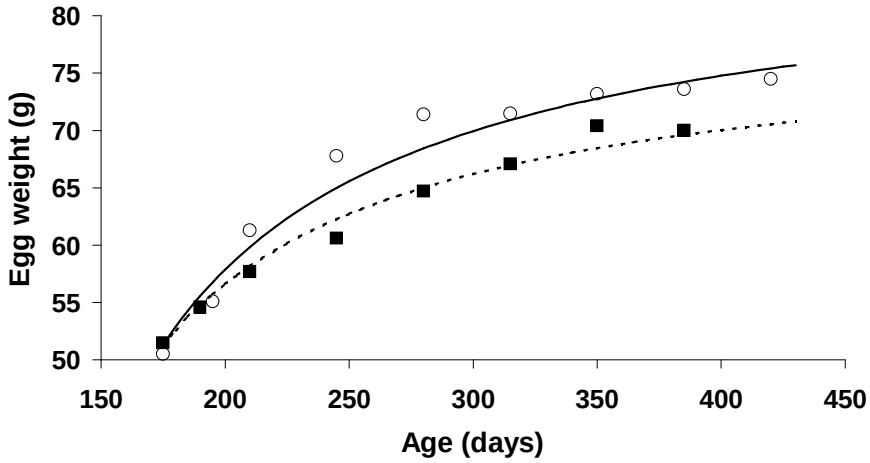


Figure 8.7 Mean observed and predicted egg weights for Cobb (■, solid line) and Ross (○, dotted line) hens over the laying period

8.4 DISCUSSION

This exercise forms part of a project to model the effect of nutrient intake on egg production of broiler breeders. Because the components of the egg differ in nutrient content, and because the proportion of these components change over time, the daily intake of nutrients required to produce an egg will also change with time. Such information is essential when attempting to determine the nutrient requirements of a broiler breeder hen at different stages of lay, and in predicting performance when the hen is supplied with a given amount of feed of a given nutrient composition. The main objective of this exercise was thus to produce some means of predicting the changes that occur in the weights of the egg components in broiler breeders over the laying period.

The curvilinear relationship between albumen weight and yolk weight for Cobb and Ross strains means that as hens age and yolk weight increases, albumen weight also increases but at a decreasing rate. Similarly the curvilinear relationship between shell weight and the weight of the egg contents means that with advancing age and increasing yolk plus albumen weight, shells gradually become thinner because shell weight also increases at a decreasing rate.

Whereas the relationship between yolk and albumen is reasonably strong when data from the entire laying period are pooled, at a fixed age there appears to be no consistent relationship between these two components. Yolk weight is known to vary according to the position of the egg in a sequence; the first or second eggs usually containing the largest yolks (Gilbert, 1972). The amount of albumen secreted around the yolk during egg formation presumably varies between individuals and from egg to egg. It is not surprising, therefore, that the proportions of the two components are inconsistent at a given age. Similar results have been found for laying hens (Johnston, 2004). Both albumen weight and shell weight may be predicted using allometric functions (such as those given by Equations 8.6 and 8.8 for Cobb hens, and 8.7 and 8.9 for the Ross strain). Equation 8.3 may be used to predict yolk weight from broiler breeder hen age so that yolk weight increases with age, and some degree of variation may be introduced when modelling a population of hens, the result of which is well illustrated in Figures 8.4 to 8.6. These results present convincing evidence that the proportions of yolk, albumen and shell of the egg change with egg weight and hen age.

The population model appears to be capable of predicting both the weights of the three components and their relative proportions at each age as well as changes in the weights, when the allometric functions are used to predict albumen weight from yolk weight and shell weight from the weight of the egg contents. At a fixed age, the absolute weights of all three components, yolk, albumen and shell increase as egg weight increase and the proportion of albumen increases (Figure 8.5) at the expense of yolk (Figure 8.4) and shell (Figure 8.6); i.e. amongst the eggs collected from broiler breeder flocks on a given day the larger eggs are likely to have proportionally more albumen. However, as the hens proceeded further into the laying period, the yolk:albumen ratio increased steadily, indicating the greater proportion of yolk contained in the eggs from older hens.

When yolk weight is low, Cobb eggs contain less albumen than do Ross eggs, but as yolk weight increases, eggs from Cobb breeders contain a higher proportion of albumen. This may have implications for the growth of embryos in the egg. From the large differences apparent between the two strains it would appear to be essential that the parameters *a* and *b* are established for each strain in order to improve the accuracy of model prediction between strains.

An egg component analysis similar to that conducted here was performed by Johnston (2004) using three commercial laying strains, namely, Amber-Link, Hy-Line Silver and Hy-Line Brown. Eggs from broiler breeder hens are considerably larger, with heavier yolk weights than those from these laying strains (19.8g for broiler breeders *vs*. 16.9, 15.5 and 14.6g for Amber-Link, Hy-Line Sylver and Hy-Line Brown, respectively, at 40 weeks) but allometric functions with appropriate parameter values are as effective in estimating egg component weights in the laying strains as in the broiler breeder strains used in this exercise. It is interesting to note the similarity in shell weight between broiler breeder hens and laying hens over the laying period.

The simulation model reflects realistic egg and component weights for breeders of a given age and over the laying period, which may thus be used with confidence to predict the nutrient requirements of hens of a given strain. The challenge that remains is to predict the consequences of an inadequate nutrient intake on egg weight and rate of lay.

The following chapter deals with the development of the Breeder Model.

CHAPTER 9

MODELLING THE NUTRIENT REQUIREMENTS AND PERFORMANCE OF BROILER BREEDERS AFTER SEXUAL MATURITY: A DESCRIPTION

9.1 INTRODUCTION

The requirement of a broiler breeder during the laying period for energy and each of the essential nutrients is a function of the potential reproductive performance of the bird, of its state, and of the environment in which the bird is kept. These requirements will differ among the birds in a flock, as will their daily food intakes, and consequently the task of designing feeds, feed allocations and feeding schedules that will maximise profit on the varied broiler breeder farms on which the feeds are to be used, is extremely difficult. The Breeder Model described in this chapter is a computerised, mechanistic, stochastic and dynamic approach to the evaluation of the effects of genotype, environment and feed on both the requirements and performance of broiler breeders during lay, designed to assist in achieving more efficient feeding of these birds.

Simulation modelling is used here to support the understanding of the nutrient requirements and performance of broiler breeders during the laying period. The factors of consequence in determining nutrient requirements are body protein weight, for maintenance, and egg output. The obligatory growth in body protein weight of hens after laying their first egg is assumed to be negligible, and, in relation to the resources needed for maintenance and egg production, can probably be ignored (Emmans and Fisher, 1986). Daily requirements for maintenance and egg production are simulated using information about the environment (mean daily temperature), the age at sexual maturity, body protein and lipid weights at the start of lay, the pattern of laying including mean clutch length, prime sequence length and the rate of decay in ovulation rate, and the relationship between yolk weight and age. Daily nutrient intake is defined in terms of dietary protein and digestible amino acid content, dietary effective energy and daily food allocation. Outputs provide information on potential and actual egg output (rate of laying and egg weight), both daily and weekly, for individuals and for flocks of breeders, with respect to yolk, albumen and shell weights, body lipid deposition and the current state of body protein and

lipid. Outputs also include daily body weight, the limiting amino acid in the feed, actual food consumption, heat production, income, expenditure and margin.

This chapter describes how the Breeder Model functions and the processes and algorithms employed. The model was initially developed in Microsoft Excel 2000 for one bird over a seven day period, and later it was rewritten in DELPHI C++ to simulate any number of birds over a defined period of up to 30 weeks in lay. The programming language DELPHI was used to facilitate model operation, especially speed, through a user-friendly interface. The Breeder Model is available on the CD at the back of the thesis, together with a description of how to load the programme. This version will be available to you for a one-year period. For any further information, please contact the programmers through the EFG Software web site (www.efgsoftware.net).

9.2 DESCRIPTION OF THE GENOTYPE - POTENTIAL EGG OUTPUT

A laying bird may be characterised genetically by five parameters, namely, mature size and mature body lipid content, potential age at sexual maturity, potential rate of laying and egg weight over a given laying period. Potential egg output (rate of lay x egg weight), which is expected to change over time, is defined as the maximum egg output that the hen can achieve when given perfect nutritional and husbandry conditions. An egg is described as a mixture of yolk, albumen and shell, the composition of which will change with time and genotype, but which may be predicted from allometric relationships with yolk weight. Hens lay an egg daily for a number of consecutive days before pausing for one or more days, *i.e.* hens lay in sequences or clutches. A number of double-yolk and soft-shell eggs may be laid during the laying period, reducing the total number of settable eggs. Internal ovulations take place randomly, disrupting oviposition.

9.2.1 Mature size

The mature size of a broiler breeder should be described in terms of body protein weight. Model inputs required to determine the state of the bird at the start of the simulation period (body protein weight, BP_0, g) are initial body weight (BW_i, g) and initial body protein

content (BPC_i, %). Similarly, initial body lipid weight (BL_i, g) is calculated from BW_i and the initial body lipid content (BLC_i, %) (model input), (Equations 9.1 and 9.2).

$$BP_i = (BPC_i * BW_i) / 100 \quad \text{(Equation 9.1)}$$

$$BL_i = (BLC_i * BW_i) / 100 \quad \text{(Equation 9.2)}$$

There is a need to ensure that, during the laying period, body lipid weight is not depleted below some realistic value. The Breeder Model assumes that birds need a minimum body lipid weight (MBL, g) equivalent to a certain proportion of body weight (C_{MBL}, %), (Equation 9.3). The default C_{MBL} value is 11% (see Chapter 6) and may be changed by the user.

$$MBL = (C_{MBL} * BW) / 100 \quad \text{(Equation 9.3)}$$

It is assumed in the Model that lipid in excess of MBL may be used as an energy source, and that the bird will attempt to use this excess in preference to dietary energy as a means of returning to the genetically determined lipid to protein ratio in the body. The body lipid in excess of MBL is termed a lipid reserve (BLR, MJ) and is calculated using MBL, BLR and the gross energy content of lipid (GE_l, MJ/kg), (Equation 9.4).

$$BLR = (BL – MBL) * GE_l \quad \text{(Equation 9.4)}$$

where GE_l = 39.6 MJ/kg (Emmans, 1994).

If body lipid weight is equal to, or less than, the minimum body lipid weight then the lipid reserve is zero (Equation 9.5).

$$\text{If } (BL – MBL) * GE_l \leq 0$$
$$\text{then } BLR = 0 \quad \text{(Equation 9.5)}$$

It is assumed that there is no obligatory increase in body protein weight once the broiler breeder pullet has reached sexual maturity, even if the bird has not yet reached somatic

maturity, and that any increase in body weight that occurs thereafter is due to an increase in body lipid content. Changes in body lipid content are assumed to occur almost continuously, due to the need to deal with excesses and shortages of dietary energy brought about by differences in energy intake and energy requirements for egg production.

9.2.2 Predicting age at sexual maturity

The starting point when modelling egg production should be the prediction of mean age at first egg, based on the treatment applied during rearing (Johnston and Gous, in press). A model for the prediction of age at sexual maturity (AFE, days) following a constant photoperiod or a single change in photoperiod from 8 to 16h for broiler breeders has been proposed by Lewis and Gous (personal communication, in press), and this model is used here to predict AFE.

AFE for birds maintained on a constant photoperiod from hatching may be calculated from the following equations (Lewis and Gous, in press):

$P \leq 10h$	$y = (202.5 - 1.15\ P) - ((BW - 2100) * 0.02)$	(Equation 9.6)
$10h < P < 13h$	$y = (191 + 23.7\ P) - ((BW - 2100) * 0.02)$	(Equation 9.7)
$P \geq 13h$	$y = (214.7 - 0.76\ P) - ((BW - 2100) * 0.02)$	(Equation 9.8)

where P = photoperiod (h) and BW = body weight at 20 weeks.

When broiler breeders are exposed to a constant photoperiod from hatching they reach sexual maturity about 1d earlier for each 1-h longer photoperiod up to 10h (Figure 9.1), and this rate is similar to that observed in early genotypes of egg-type hybrids (Lewis *et al*., 1998), but only a quarter of that reported for modern egg-type stock, where selection for egg numbers has accelerated sexual maturity in pullets reared on 8 to 10-h days but not in those reared on very short days (Lewis and Morris, 2005).

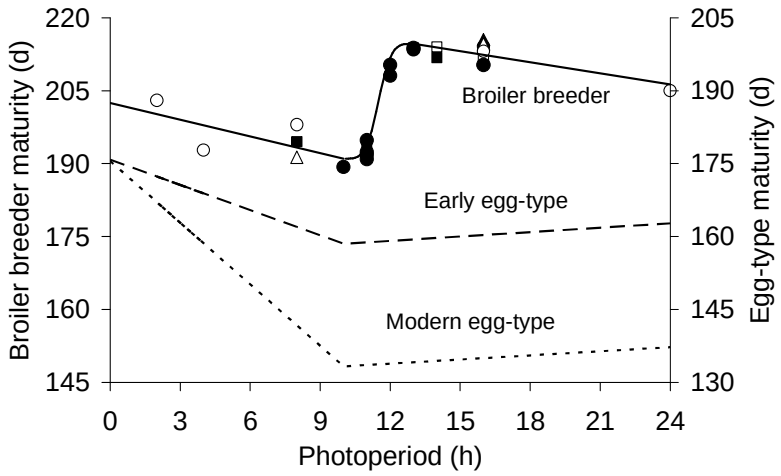


Figure 9.1. Mean age at first egg for broiler breeders weighing between 1.9 and 2.4 kg body weight at 20 weeks of age and maintained on constant photoperiods from 2d of age (●, ▲, Δ Lewis et al., 2003; □, ■ Lewis et al., 2004a) and mean age at initial semen production for broiler breeder males weighing 2.9 kg at 24 weeks of age (○ Renden et al., 1991). Differences among trials were removed by least squares analysis. The broken line shows the response of early egg-type hybrids (Lewis et al., 1998a) and the dotted line the response of modern egg-type hybrids to constant photoperiods (Lewis & Morris, 2005) (Lewis, 2006a).

When broiler breeders are given photoperiods between 10 and 13 h, age at sexual maturity (ASM) is markedly delayed, with birds maintained on 13 h maturing between three and four weeks later than birds held on 10 h. Thereafter, maturity is advanced by about 0.8 d per 1-h of photoperiod (Lewis *el al.*, 2004). The responses to photoperiods longer than 10h are in complete contrast to those of egg-type hybrid, and show that broiler breeders exhibit photorefractoriness, which is a natural phenomenon that prevents animals becoming sexually acive when the ensuing environmental conditions are inopportune for successfully raising offspring.

AFE for birds transferred from 8 to 16h may be calculated by Equation 9.9.

$$y = (177.87 – 0.0152\ BW) + 0.360\ t \qquad \text{(Equation 9.9)}$$

where BW = body weight at 20 (g) weeks and t = age at transfert (days).

The model in Figure 9.2, created using data from Robinson *et al*. (1996), Joseph *et al*. (2002), Lewis *et al*. (2003), Ciacciariello and Gous (2005), and unpublished data from the University of KwaZulu-Natal that had been adjusted for differences among trials by least squares analysis, shows that broiler breeders transferred from 8 to 16 h before nine weeks of age respond as if they have been reared on constant 16-h days and so mature three weeks later than birds maintained on 8 h. The model also predicts that a flock will be about 19 weeks of age before all individuals are responsive to an increase in daylength, though the earliest mean ASM following photostimulation will occur at about 18 weeks. Thereafter, the stimulatory effect of a transfert to 16 h decreases by 0.36 d for each 1 d delay in photostimulation until, about 10 d before the latest maturing birds of a flock spontaneously starts egg production (≈ 30 weeks), none of the birds is responsive. It is asumed that the age at which individuals dissipate photorefractoriness and become responsive to an increment in photoperiod forms a normal distribution, and that the proportion of sensitive birds may be calculated using a mean of 98 d and a standard deviation of 13.2 d. The proportion of birds maturing spontaneously in response to an 8-h photoperiod forms a normal distribution with a mean of 221 d and a SD of 9 d, and constant 16-h birds mature 19 d later than constant 8-h birds.

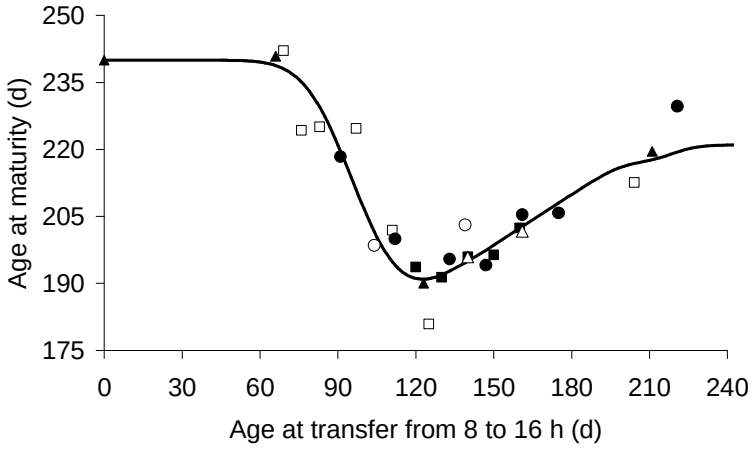


Figure 9.2 A model for mean age at 50% egg production for broiler breeders weighing about 2.1-kg body weight at 20 weeks of age and transferred at various ages from 8- to 16-h photoperiods (■ [Shaver Starbro] Robinson et al., 1996; Δ [Ross] Joseph et al., 2002a; ▲ [Cobb 500] Lewis et al., 2003; ○, □ [Ross] Ciacciariello & Gous, 2005; ● [Cobb 500] unpublished data, University of KwaZulu-Natal)(Lewis, 2006a)

9.2.3 Potential rate of laying

Compared with laying hens, broiler breeders lay approximately half as many eggs and have a higher instance of defective eggs (Yu *et al.*, 1992). As the demand for growth potential increases, it becomes more difficult for parent stock to reproduce effectively. A critical time in the life of a broiler breeder hen is the period from photostimulation to its peak of production. During this time the number of large yellow follicles may be affected by age at photostimulation, feeding levels and body weight (Hocking, 1996; Renema *et al.*, 1999). Hens that lay earlier than desired or are overfed, causing excessive follicular development, would show reproductive anomalies that include the production of defective eggs (double-yolked and poor shell quality) and internal ovulations.

The mechanistic, stochastic population model of egg production designed by Johnston (2004) for laying hens was adapted here for broiler breeder hens to predict the rate of egg production of an individual or a theoretical flock of broiler breeders during the laying period, including occurences of double-yolked and soft-shelled eggs and internal ovulations. The rate of egg production in a hen is determined by the length of her oviposition sequences and by the number and duration of the pauses.

9.2.3.1 *Internal cycle length*

Internal cycle length is described as the lag between successive ovulations and is predicted from the function given by Emmans and Fisher (1986), (Equation 9.10).

$$ICL = ICL_0 - Lag + 1 / ((1/Lag) - kt) \quad \text{(Equation 9.10)}$$

where ICL_0 = internal cycle length at first egg, k = a decay factor,and t = time from first egg, in days.

Hens that lay very long sequences usually have very short follicular maturation rates of 24 hours or less, while hens that have slow rates of follicular maturation, between 26-28 hours, lay short sequences of 2 to 3 days in duration (Etches, 1990).

If the bird's internal cycle length is less than the external cycle length (EXCL) (usually 24 hr), rate of lay (R) is given by Equation 9.11.

$$R = 24 / EXCL \qquad \text{(Equation 9.11)}$$

If the internal cycle length is greater than external cycle length, rate of lay is given by Equation 9.12.

$$R = Lag / ((ICL - EXCL)(1 + (Lag / (ICL - EXCL)))) \qquad \text{(Equation 9.12)}$$

Johnston (2004) pointed out that these functions suggested by Emmans and Fisher (1986) allow a decrease in egg production with advancing hen age, but they do not permit the simulation of shorter egg sequences produced by many hens at onset of lay. In order to reproduce these, the internal cycle length needs to be longer than 24 hours initially, before decreasing with advancing time from first egg to below the daylength and subsequently increasing above 24 hours. The required curvilinear shape may be adequately simulated for broiler breeders with the use of the following line-plus-exponential equation:

$$ICL = 23.05 + 2.485 (0.98082 \wedge t) + 0.0222 t \qquad \text{(Equation 9.13)}$$

where t = time from first egg, in days.

The trend given by these functions is shown in Figure 9.3.

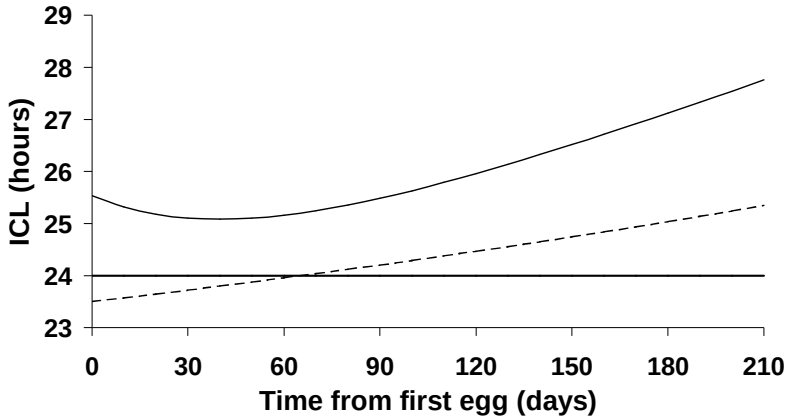


Figure 9.3 The change in internal cycle length over time, predicted from Equation 9.10 (dashed line, ICL_0 = 23.5 h, lag = 8.5 h, k = 0.0001) and Equation 9.13 (solid line). The bold line represents the 24-hour daylength.

To introduce variation in the rate of change in internal cycle length within a population, coefficients of variation of 0.5% and 1% are used to generate normal distributions for each parameter in Equations 9.10 and 9.13, respectively. The rate of ovulation of individual hens within a population will then differ. The rate of ovulation for breeder hens using the internal cycle length illustrated in Figure 9.3 are shown in Figure 9.4.

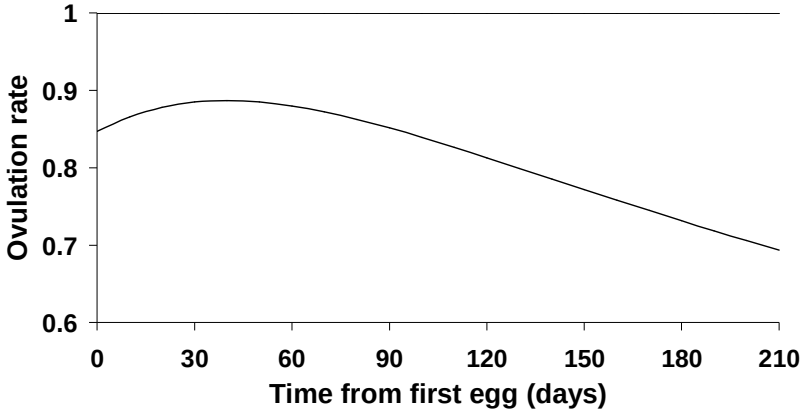


Figure 9.4 Predicted ovulation rate for breeder hens using the internal cycle length illustrated in Figure 9.3. The bold line represents a rate of lay of 100%. Because the internal cycle length in each case is longer than 24 hours, the ovulation rate is less than 100%.

9.2.3.2 *Predicting time of lay*

Time of lay, oviposition time, is predicted as for layers (Johnston, 2004). It is assumed that oviposition occurs roughly half an hour before the next ovulation, with a range of seven to 75 min (Fraps, 1955). A normal distribution of oviposition-to-ovulation intervals is produced, for example with a mean of 30 minutes and a coefficient of variation of 30%, which would result in a range of intervals from three to 57 minutes. A different method is used for predicting the time of lay for the last egg of a sequence, since there is no associated ovulation. A lag value is added to the oviposition time of the penultimate egg. The lag is influenced by the sequence length: the shorter the sequence, the greater the lag value, and is calculated from a linear-by linear function (Equation 9.14).

$$y = 1.75 - 0.9 / (1 - 1.969\ x) \qquad \text{(Equation 9.14)}$$

where y = lag between the last two ovipositions of a sequence, in hours, and x = ovulation rate.

9.2.3.3 *Double-yolked eggs*

Double-yolked eggs, as simulated here, are the result of the simultaneaous ovulation of two follicles in the hierarchy. The proportion of a flock expected to lay double-yolked eggs is assumed to be 36% for all strains, being the value found by Johnston (2004) for laying hens. The user may select one of three rates of production of double-yolked eggs: zero, low (less than 2% to 30 weeks of age) or medium (more than 2% to 30 weeks of age), the latter two being represented by exponential functions (Equations 9.15 and 9.16, respectively). It is assumed in the model that broiler breeders produce a maximum of 2.3% double-yolked from 19 to 29 weeks of age (Yu *et al.*, 1992)

DY = -0.00291 + 75438 (0.940345 ^ HA) (Equation 9.15)

DY = 0.576 + 3734 (0.962421 ^ HA) (Equation 9.16)

where DY = % double-yolked eggs and HA = hen age, in days.

The trends given by these functions are illustrated in Figure 9.5.

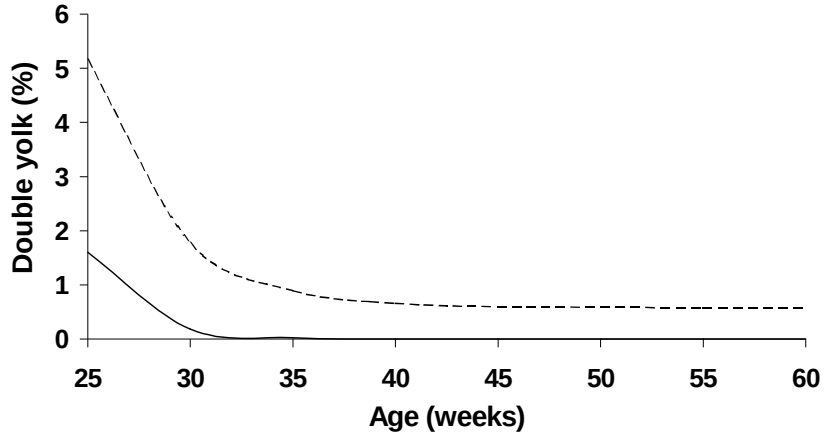


Figure 9.5 An illustration of the relationship between the expected occurrence of double yolked eggs (low _____ , medium ------) and broiler breeder hen age

9.2.3.4 *Soft-shelled eggs*

Soft-shelled eggs occur in young hens, especially when photostimulated early, and in older birds as the absorption of dietary calcium and its utilisation for shell formation become less efficient (Hansen *et al.,* 2003). In the model it is assumed that 32% of the flock will produce soft-shelled eggs at some stage of the laying period, this value having been obtained from experimental trials done with laying hens (Johnston, 2004). Two quadratic by linear functions are used to predict the percentage of soft shells for broiler breeders of all strains. The user can select between low (less than 3% to 30 weeks) (Equation 9.17) or medium (more than 3% to 30 weeks) (Equation 9.18) rates of soft shell production for the simulated flock. It is assumed that broiler breeders produce 4.5% soft shells from 19-29 weeks of age (Yu *et al.,* 1992).

$$SE = -6.36 - 4.509 /(1- 0.009463\ HA) + 0.01607\ HA \qquad \text{(Equation 9.17)}$$

$$SE = -10.55 – 8.45 / (1- 0.010099\ HA) + 0.02544\ HA \qquad \text{(Equation 9.18)}$$

where SE = % soft-shelled eggs and HA = hen age, in days.

The trend given by these functions are shown in Figure 9.6.

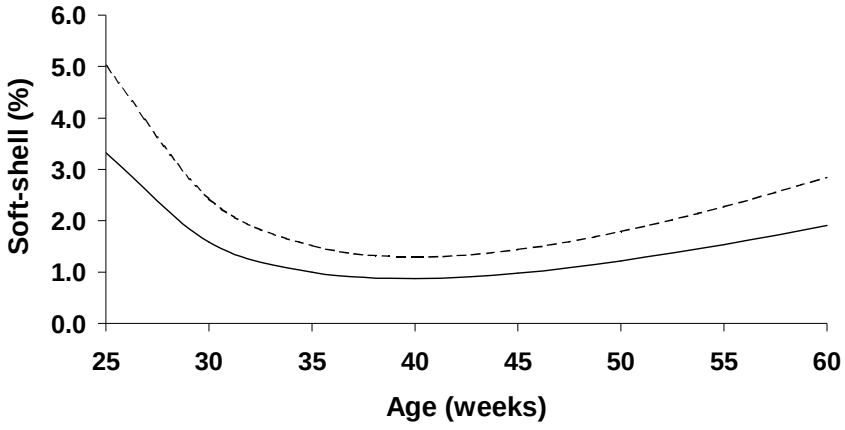


Figure 9.6 Relationship between the expected proportion of soft-shelled eggs (low _____ , medium -----) and broiler breeder hen age

9.2.3.5 *Internal ovulations*

Internal ovulations occur when the hen ovulates and the yolk, instead of entering the infundibulum, falls into the body cavity. The frequency of internal ovulation has been estimated in laying hens by studying sequence data and oviposition times (Johnston, 2004). A similar trend was adapted here for broiler breeders, and it assumes that more internal ovulations occur at onset of sexual maturity and towards the end of lay, due to some asynchrony between ovary and oviduct. The proportion of eggs ovulated internally at each age is estimated using a linear plus exponential equation, (Equation 9.19).

$$IO = -189.7 + 200\ (0.99899\ ^{\wedge}\ HA) + 0.142\ HA \qquad \text{(Equation 9.19)}$$

where IO = % internal ovulation and HA = hen age, in days.

While the proposed functions are useful for modelling purposes, it must be remembered that strain, nutrition, lighting programme and other factors influence the frequency of these irregularities in egg production (Johnston, 2004) so the Model has been designed to enable the user to adjust these frequencies.

9.2.3.6 *Sequence length*

Eggs are laid in sequences of one or more eggs. A sequence is defined as consecutive daily ovipositions separated by a pause of one day or more in duration (Etches, 1990). As a starting point the model assumes that 0.65 of the flock have one pause 78% of the time, or two pauses 22% of the time, that 0.23 of the flock have two or three pauses, 0.09 of the flock have three or four pauses, and that 0.03 of the flock have four or five pauses. This gives a mean pause length of about 1.6 d, which is in accordance with the finding of Robinson *et al*. (1990). The method creates a small number of low producing hens with frequent long pauses.

Egg production rates are positively correlated to the length of the prime sequence, i.e. hens that are laying at high rates lay long sequences (Robinson, 1993). The predicted mean sequence length is initially short at onset of lay, brought about by the quadratic-by-linear function used to predict changes in internal cycle length. The longest sequence, or prime

sequence, is seen in broiler breeders at about 34 weeks of age and is nine eggs in length (University of KwaZulu-Natal), which is less than the 20 eggs sequences found by Robinson (1992) (Figure 9.7).

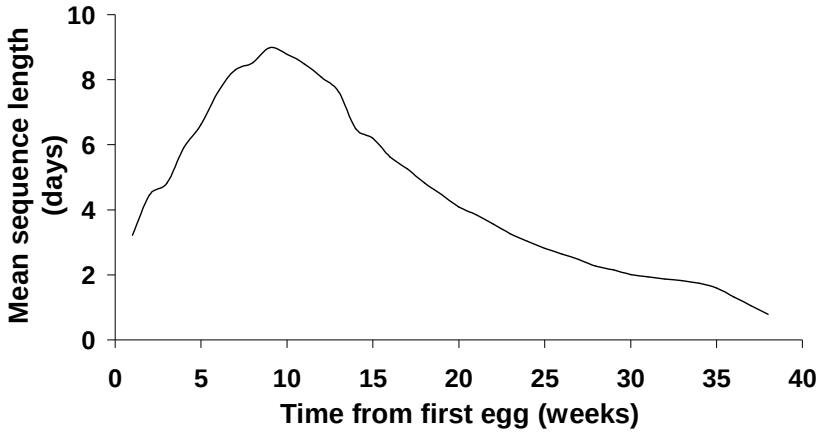


Figure 9.7 The predicted mean sequence length for a theoretical flock of broiler breeder hens photostimulated at 20 weeks.

This graph does not reveal the considerable variation among individuals. Figure 9.8 illustrates that a stochastic model may successfully introduce the required variation. The top third of the flock in terms of performance has a maximum mean sequence length of 12.8 eggs, compared to 5.3 and 7.7 for the middle and bottom thirds, respectively.

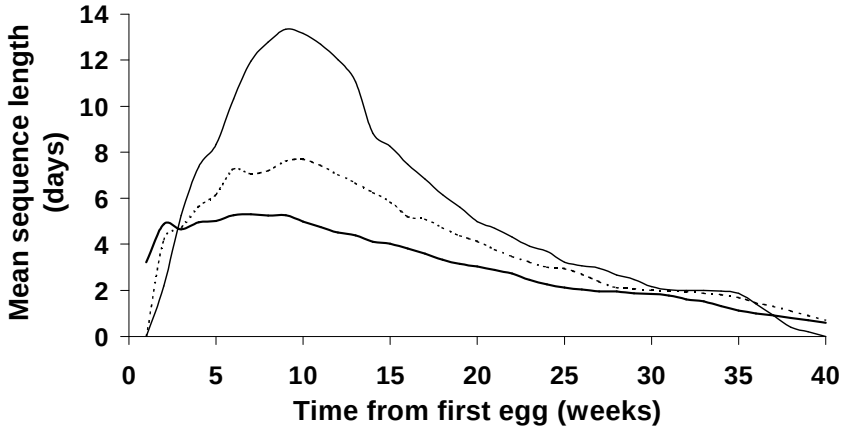


Figure 9.8 The predicted mean sequence lengths for a theoretical flock split into thirds according to their performance; top third (solid line), middle third (dotted line) and bottom third (bold line).

9.2.4 Predicting potential egg weight

Egg weight in the model is predicted as the sum of three components; yolk, albumen and shell. This is done for two reasons: because the component proportions change with increasing age (eggs contain proportionally more yolk and less albumen as the hen ages, see Chapter 8), and because the amino acid and energy contents of yolk and albumen differ, thus altering the amino acid and energy required per g egg. The parameters for Cobb and Ross breeders (Chapter 8) were used to predict the potential yolk, albumen and shell weights in the Breeder Model.

Potential yolk weight (YW_{pot}, g) is predicted from hen age (HA, d) using the following linear-by-linear function:

$$YW_{pot} = 28.083 + 34.2 / (1 – 0.01836 * HA) \quad \text{(Equation 9.20)}$$

Potential albumen (AW_{pot}, g) and shell (SW_{pot}, g) weights are then predicted using the allometric functions defined by Emmans and Fisher (1986):

$$AW_{pot} = a_1 \, YW_{pot}^{\,b1} \quad \text{(Equation 9.21)}$$

$$SW_{pot} = a_2 \, ECW^{\,b2} \quad \text{(Equation 9.22)}$$

where ECW = the weight of the egg contents, yolk plus albumen (g). Table 9.1 gives suggested values for the parameters *a* and *b* in equations 9.21 and 9.22.

Table 9.1 Estimates of the parameter values used in the allometric functions for predicting potential albumen from potential yolk weight and shell weight from egg content weight.

Strain	a_1	b1
Cobb	9.5257	0.5002
Ross	14.8768	0.3250
	a_2	b2
Cobb Ross	0.1707	0.8686

Mean potential egg weight (EW, g) is then estimated from Equation 9.23.

$$EW_{pot} = YW_{pot} + AW_{pot} + SW_{pot} \quad \text{(Equation 9.23)}$$

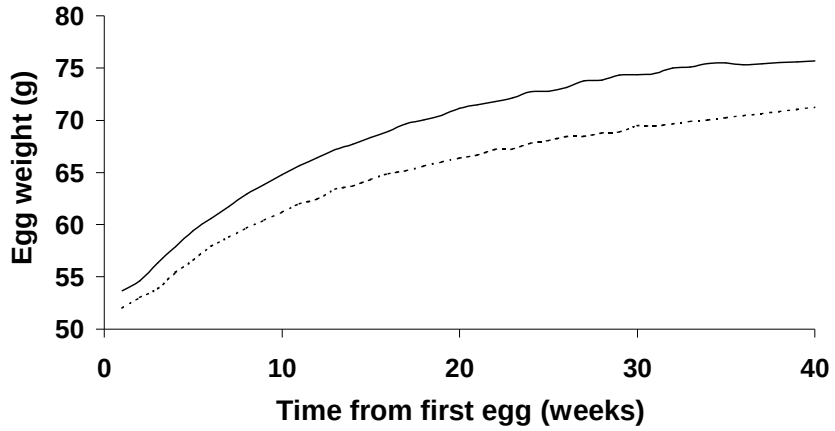


Figure 9.9 The predicted mean egg weight for a theoretical flock of Cobb (solid line) and Ross (dotted line) birds photostimulated at 20 weeks.

9.3 PREDICTING NUTRIENT REQUIREMENTS

The previous sections have shown that from a description of the genotype and state of the bird, the rate of egg production can be predicted. The next problem is to calculate the energy and amino acid requirements of the bird in terms similar to those used to describe the feed, in order to predict the desired and actual feed intakes.

9.3.1 Effective energy system

Emmans (1994) showed that the metabolisable energy (ME) scale is not a sufficiently accurate means of describing the energy content of a feedstuff, as it is unable to differentiate between the efficiency of utilisation 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 feed. The energy scale proposed by Emmans (1994), which accounts for the above deficiencies, is known as the effective energy (EE) scale and is the energy system used in the Breeder Model.

9.3.2 Effective energy content of a feed

The effective energy content of a feed is derived from the following equation (Emmans, 1994):

$$EEC = ME_n - w_d . FOM - 0.16 . w_u . DCP + k . DLIP . (w_l - w_{ll}) \quad \text{(Equation 9.24)}$$

where EEC = effective energy content (kJ/g), ME_n = ME corrected to zero nitrogen retention, i.e. ME – a. DCP (kJ/g), FOM = faecal (undigested) organic matter (g/d), DCP = digestible crude protein, (g/d), DLIP = dietary lipid (g/kg), w_d = work done in defecation, w_u = work done in excreting nitrogen, w_l = work done in depositing lipid from feed protein and carbohydrate, w_{ll} = work done in depositing lipid directly from feed lipid, and k = w_{ll} as a proportion of total body lipid deposition, i.e. $w_{ll}/(w_l + w_{ll})$. Substituting values from Table 9.2 gives:

$$EEC = ME_n - 3.8 . FOM - 4.67 . DCP + 12 . k . DLIP \quad \text{(Equation 9.25)}$$

Table 9.2 Estimated values of coefficients used in the Breeder Model (after Emmans, 1994)

Description	Value	Unit
a	34.4	kJ/g nitrogen
w_d	3.8	kJ/g FOM
w_u	29.2	kJ/ (g 0.16. DCP)
w_l	16.4	kJ/g lipid deposited
w_f	4.4	kJ/g lipid deposited
k	0.3	-

The variable k varies between zero, when there is no lipid deposited directly from feed lipid, to one, when all dietary lipid is deposited as body lipid. The value will vary according to the composition of the feed and the state of the animal. A constant value of 0.3 was assumed here.

The Breeder Model is linked directly to the feed formulation program, WinFeed, which uses the above equation to determine the EE content of a formulated feed. Examples of values for ME, DCP, DLIP, FOM, and hence EE, in a typical broiler breeder feed used in South Africa at present are given in Table 9.3.

Table 9.3 Suitable parameters assigned for a typical broiler breeder diet fed during the laying period

Parameters	Value	Unit
Metabolizable Energy (ME)	11.2	MJ/kg
Digestible Crude Protein (DCP)	129	g/kg
Dietary Lipid (DLIPID)	25	g/kg
Faecal Organic Matter (FOM)	216	g/kg
Effective energy (EE)	9.7	MJ/kg

The energy scale used to determine the energy content of the feed is also used to calculate the energy requirements of a breeder for maintenance and egg production.

9.3.3 Effective protein and digestible amino acids

The scale on which the protein and amino acids required by the bird are measured, and on which the protein and amino acids in the feed are described, must be the same. The Breeder Model expresses these in terms of digestibility. A certain amount of inefficiency exists when dietary digestible amino acids are converted into egg protein, with the result that ideal protein requirements need to be adjusted before being stated as actual requirements. The efficiency of conversion of dietary amino acid to egg protein for laying birds has been calculated to range between 0.47 and 0.85 (McDonald and Morris, 1985; Bowmaker and Gous, 1991). In this model allowance is made for possible differences in net effciency between amino acids for egg production and maintenance by allowing the user to change these values. The default efficiency values are 0.85 for egg production and 1.00 for maintenance (Fisher, 1998). Digestible amino acid requirements are calculated for arginine (arg), histidine (his), isoleucine (ile), leucine (leu), lysine (lys), methionine (met), phenylalanine (phe), threonine (thr), valine (val), methionine + cystine (met+cys), phenylalanine + tyrosine (phe+tyr) and tryptophan (trp).

Feeds are defined in terms of their contents of effective energy, digestible (or effective) protein and digestible amino acid contents.

9.3.4 Predicting maintenance requirements

Energy, protein and amino acids are required to supply the mechanisms and functions that maintain a bird in its current state. The problem is to quantify the rate at which a bird needs to be supplied with each of these nutrients considering its existing state and its genotype. These considerations are taken into account by Emmans and Fisher (1986) in their adaptation of Taylor's (1980) size scaling rule, which gives the following equation to predict effective energy (EE_m, MJ) (Equation 9.26), effective protein (EP_m, g) (Equation 9.27) and digestible amino acids (AA_m, mg) (Equation 9.28) requirements for maintenance of the feather-free body protein weight:

$$EE_m = m * BPm^{0.73} * u \qquad \text{(Equation 9.26)}$$

$$EP_m = m * BPm^{0.73} * u \qquad \text{(Equation 9.27)}$$

$$AA_m = (a * m * BPm^{0.73} * u) / e_m \qquad \text{(Equation 9.28)}$$

where m = nutrient requirement per maintenance unit (MJ/kg, g/kg or mg/kg), BPm = mature body protein weight (g/kg), u = P/Pm = degree of maturity in body protein, a = coefficient of amino acid for maintenance (mg/kg) and e_m = efficiency of amino acid utilisation for maintenance. For simplicity the breeder hen is considered to be at its mature size so that u is equal 1. The estimated values of m are 1.63 MJ/($Pm^{0.73}$) for effective energy and 0.008 kg/($Pm^{0.73}$) for effective protein (Emmans, 1988). The amino acid composition of ideal protein for maintenance is assumed to be the same as body protein (Fisher, 1998) and e_m is assumed to be equal to 1.

Measurement of total heat production includes the energy required for maintenance, and the energy spent in response to changes in environment. The major environmental factor that influences heat production is temperature. Because of a lack of literature on the effect of high temperatures in restricted laying birds, the Breeder Model is not programmed yet to evaluate the effect of high temperatures on either the nutrient requirements or the performance of broiler breeders. Under cold conditions, when heat production is insufficient to match the demand of the environment, the bird increases its heat production and less energy is available for productive purposes. The restricted bird needs to partition

energy differently, reducing rate of laying to accommodate the higher maintenance requirement (Chapter 7). A decrease in temperature from 19.5ºC to 9.9ºC will increase the daily maintenance requirement by 1.0 kJ AME /kg body weight per degree Celsius (Equation 9.29).

If $9.9 < T < 19.5$

then $EE_m = EE_m + ((T * BW) * 10\text{^-}3)$ (Equation 9.29)

with $T = 19.5 - T_{A,}$ in degree celsius,and T_A = actual room temperature, in degree Celsius.

The maintenance requirement for energy, protein or a digestible amino acid is given priority over these requirements for egg production.

9.3.5 Predicting the requirements for yolk and albumen production

The amount of energy required to produce yolk (EE_y, MJ) and albumen (EE_{alb}, MJ) is calculated as the product of the energy contained in each of these components (CEE_y and CEE_{alb}, MJ/kg) and their respective weights (YW and AW, g), (Equations 9.30 and 9.31).

$EE_y = CEE_y * YW / 1000$ (Equation 9.30)

$EE_{alb} = CEE_{alb} * AW / 1000$ (Equation 9.31)

where CEE_y = 25MJ/kg yolk and CEE_{alb} = 3.6MJ/kg albumen (Emmans and Fisher, 1986).

The protein required for yolk (EP_y, g) and albumen (EP_{alb}, g) production is calculated as with the energy required, namely, as the product of the amounts of protein required (CEP_y and CEP_{alb}, kg/kg) and their respective weights (YW and AW, g), (Equation 9.32 and 9.33).

$EP_y = CEP_y * YW$ (Equation 9.32)

$EP_{alb} = CEP_{alb} * AW$ (Equation 9.33)

where CEP_y = 0.21 kg/kg yolk and CEP_{alb} = 0.13 kg/kg albumen (Emmans and Fisher, 1986).

The amounts of each digestible amino acid required for yolk (AA_y, mg) and albumen (AA_{alb}, mg) production are calculated from the nitrogen content of the yolk (NC_y, g N) and albumen (NC_{alb}, g N) produced, the amino acid composition of the yolk (CAA_y, mg/g N) and albumen (CAA_{alb}, mg/g N) and the efficiciency of amino acid utilisation for egg production (e_p), (Equation 9.34 and 9.35).

$$AA_y = (NC_y * CAA_y) / e_p \quad \text{(Equation 9.34)}$$

$$AA_{alb} = (NC_{alb} * CAA_{alb}) / e_p \quad \text{(Equation 9.35)}$$

Based on the assumption that yolk and albumen contain 27 and 17 g N/kg respectively, (Fisher, 1998) NC_y and NC_{alb} are calculated according to Equations 9.36 and 9.37.

$$NC_y = (YW * 27) / 1000 \quad \text{(Equation 9.36)}$$

$$NC_{alb} = (AW * 17) / 1000 \quad \text{(Equation 9.37)}$$

The amino acid compositions of yolk and albumen are assumed to be constant across ages and strains (Lunven, 1973).

The Breeder Model assumes that yolk production is a continuous process as long as an adequate supply of the essential nutrients is available. Albumen formation will only take place if there is sufficient of each amino acid and energy in the ‘albumen pool’ prior to ovulation, and that a successful ovulation takes place.

If there is no production of yolk or albumen on the day (YW = 0 and AW = 0, respectively), there is no nutrient requirement for egg production (Equations 9.38 and 9.39).

If YW = 0
then $EE_Y = 0$, $EP_y = 0$ and $AA_y = 0$ (Equation 9.38)

If AW = 0

then $EE_{alb} = 0$, $EP_{alb} = 0$ and $AA_{alb} = 0$ (Equation 9.39)

The energy (EER, MJ), protein (EPR, g) and amino acid (AAR, mg) requirements of a breeder are determined for each day of the laying period (Equation 9.40, 9.41 and 9.42).

$$EER = EE_m + EE_y + EE_{alb} \quad \text{(Equation 9.40)}$$

$$EPR = EP_m + EP_y + EP_{alb} \quad \text{(Equation 9.41)}$$

$$AAR = AA_m + AA_y + AA_{alb} \quad \text{(Equation 9.42)}$$

The problem of predicting requirements is to bring together the genetic variables and the values of nutritional constants, and then the composition of the feed will determine the desired feed intake.

9.3.6 Desired and actual feed intakes

The desired feed intake (DFI, g/d) is the amount of the given feed needed to satisfy the requirement (RQ, MJ/d or g/d) for the most limiting nutrient (Equation 9.43). It is assumed that minerals and vitamins are provided in sufficient amounts as so not to be considered limiting.

$$DFI = RQ / CFL_d \quad \text{(Equation 9.43)}$$

where CFL_d = concentration of first limiting nutrient in the feed (MJ/g or g/g).

If energy is most limiting, the desired feed intake in a thermally neutral environment is that required to satisfy energy (DFI_{EE}, g/d), (Equation 9.44).

$$DFI_{EE} = (EER / EEC) * 1000 \quad \text{(Equation 9.44)}$$

On the other hand, if an amino acid is the first limiting nutrient then the desired feed intake (DFI_{AA}, g) is based on the digestible amino acid requirements and the concentration of dietary digestible amino acids (AAC, g/kg), (Equation 9.45).

$$DFI_{AA} = AAR / AAC \quad \text{(Equation 9.45)}$$

In the case of broiler breeders food is not made available *ad libitum*, therefore the bird will seldom consume its desired amount, the actual intake in most cases being that decided upon by the farm manager. Other factors that may constrain food intake are the bulkiness of the feed and the inability to lose the heat generated, as a result of the processes of maintenance, food intake and digestion, and egg formation and production, to the environment, especially in hot conditions (Emmans and Fisher, 1986).

An important assumption made in the model is that a bird will attempt to consume sufficient of the given feed to meet its requirement for the first-limiting nutrient, and that it will stop eating once its requirement for this nutrient has been met (Emmans, 1987). However, because the amount of feed allocated daily to a broiler breeder is controlled, the birds with the greatest potential egg output may often be forced to consume less than the amount required. Depending on the amount of food allocated daily, it is possible that there will be hens whose requirements are lower than the amount of feed allocated, leading to some reasonable distribution of food among the flock. But the social hierarchy prevalent in all bird species may not be correlated with potential egg output and this aggressive characteristic, when displayed at the feed trough, is likely to prevent hens from accessing equal quantities of food each day. This characteristic has been incorporated into the model: an aggressiveness value (C_{agr}, %) is randomly specified for each hen at sexual maturity, the correlation between this value and potential egg output being specified by the user, and this value is kept constant for each hen over the laying period. The constrained feed intake (CFI, g) for each hen is calculated as the product of daily allocation of food (FI, g) specified by the user and C_{agr} (Equation 9.46).

$$CFI = FI * C_{agr} \quad \text{(Equation 9.46)}$$

The actual feed intake (AFI, g/d) of the bird will be the lesser of DFI and CFI.

For the Breeder Model to be successful it must be able to predict the daily response of a flock of breeder hens over the entire laying period to the daily nutrient allocation, under the prevailing environmental conditions. To accomplish this successfully, the response of an individual must be accurately predicted under such circumstances, before the population response can be predicted.

9.4 RESPONSE OF AN INDIVIDUAL TO A DAILY ALLOWANCE

The Breeder Model is embedded in the windows-based feed formulation program, WinFeed (EFG Software). Feed specifications are set up in the usual way, after which WinFeed determines the least-cost feed that would meet these specifications. The characteristics of this formulated feed are then passed, as input, to the Breeder Model. A daily intake of this feed and the number of days over which the feed is to be offered are specified by the user. It is possible to use an unlimited number of feeds, each of which may be fed over an unlimited number of days, thereby adding considerable flexibility to the manner in which the birds are fed during the laying period. The performance expected from this feed when given to a defined flock of broiler breeders in a given environment is then predicted by the model as the mean performance over that of each individual in the flock. Assuming that the environment is not a constraining factor, a hen that consumes sufficient of the most limiting amino acid (or energy), will produce an egg of its potential weight. The hen will fail to perform at its potential if the intake of one or more amino acids is less than required, or if insufficient energy is provided either in the feed or from body lipid reserves.

The Breeder Model assumes that feed is consumed early in the morning to meet the hen's requirements for body maintenance and daily yolk production, and to fill the albumen pool for use the following day. At the start of the day the (effective) energy available for maintenance and egg production (EE_{av}, MJ) is provided by the feed (EEC, MJ), the albumen pool ($EE_{albPool}$, MJ) and body lipid reserves (EE_{BLR}, MJ). The available protein (EP_{av}, g) and amino acids (AA_{av}, mg) are provided by the feed (EEP, g and AAC, mg) and the albumen pool ($EP_{albPool}$, g and $AA_{albPool}$, mg) (Equation 9.47, 9.48 and 9.49).

$$EE_{av} = EEC + EE_{albPool} + EE_{BLR} \quad \text{(Equation 9.47)}$$

$EP_{av} = EPC + EP_{albPool}$ (Equation 9.48)

$AA_{av} = AAC + AA_{albPool}$ (Equation 9.49)

The energy ($EE_{albPool}$, MJ), protein ($EP_{albPool}$, g) and amino acids ($AA_{albPool}$, mg) stored in the albumen pool will be the energy ($EE_{Potalb+1}$, MJ), protein ($EP_{Potalb+1}$, g) and amino acids ($AA_{Potalb+1}$, mg) required for potential albumen production the following day.

The assumption is made that the bird is fed once a day early in the morning. Egg output is dependent on the remainder of the nutrients consumed once the maintenance requirements have been met. Yolk is assumed to be produced continously at its potential, except when the bird lays the last egg of a clutch, in which case, yolk will be produced for a defined number of days before stopping until the next clutch starts. This number is specified by the user, with the default being two days. The reason for this constraint on yolk growth is that, if not applied, yolk size would be considerably bigger than the potential of the bird if ovulation ceased for periods exceeding three or four days before resuming. It is assumed that both energy and protein consumed in excess of requirement will be retained as body lipid.

Case 1: Supply of energy or amino acid is in excess of daily requirement.

If the intake of nutrients is in excess of the hen's requirements, as defined above, this excess is calculated as the balance of energy (EE_{bal}, MJ), protein (EP_{bal}, g) and amino acids (AA_{bal}, mg) at the end of the day (Equations 9.50, 9.51 and 9.52).

If $(EE_{av} - EER) > EE_{Potalb+1}$
then $EE_{albPool} = EE_{Potalb+1}$ and $EE_{bal} = EE_{av} - EER – EE_{albPool}$ (Equation 9.50)

If $(EP_{av} - EPR) > EP_{Potalb+1}$
then $EP_{albPool} = EP_{Potalb+1}$ and $EP_{bal} = EP_{av} - EPR – EP_{albPool}$ (Equation 9.51)

If $(AA_{av} - AAR) > AA_{Potalb+1}$
then $AA_{Potalb} = AA_{Potalb+1}$ and $AA_{bal} = AA_{av} - AAR – AA_{albPool}$ (Equation 9.52)

In this case the bird will lay an egg at its potential, the egg weight will be the potential for the age of bird, and the energy and protein above that used for maintenance and egg output will be deposited as lipid. Body lipid gain is calculated from the excess energy (EE_{bal-1} – EE_{BLR-1}, MJ) and protein (EP_{bal-1}, g) intakes, the energetic cost of body lipid deposition (CE_l, MJ/g), and the gross energy content of protein (GE_p, MJ/g). The gain in lipid weight is added to the body lipid weight of the previous day (BL_{-1}, g) to determine the new body lipid weight. The hen may deposit body lipid until a maximum, user-defined, daily rate of body lipid is reached (C_{BLD}). The default C_{BLD} value is 10g/d (Equations 9.53 and 9.54).

If $[(EE_{bal-1} – EE_{BLR-1})/CE_l] + [(EP_{bal-1} * GE_p) / CE_l] > C_{BLD}$
then $BL = BL_{-1} + C_{BLD}$ (Equation 9.53)

If $[(EE_{bal-1} – EE_{BLR-1})/CE_l] + [(EP_{bal-1} * GE_p) / CE_l] < C_{BLD}$
then $BL = BL_{-1} + [(EE_{bal-1} – EE_{BLR-1})/CE_l] + [(EP_{bal-1} * GE_p) / CE_l]$ (Equation 9.54)

where $CE_l = 0.055$MJ/g and $GE_p = 0.0238$MJ/g (Emmans, 1994).

Case 2: Supply of energy or an amino acid is insufficient to meet daily requirement

If the bird does not have sufficient nutrient reserves to satisfy the potential albumen production for the following day then the nutrient supply stored in the albumen pool will be equal to those in the balance (Equations 9.55, 9.56, and 9.57).

If $(EE_{av} - EER) < EE_{Potalb+1}$
then $EE_{bal} = EE_{av} – EER$ and $EE_{albPool} = EE_{bal}$ (Equation 9.55)

If $(EP_{av} - EPR) < EP_{Potalb+1}$
then $EP_{bal} = EP_{av} – EPR$ and $EE_{albPool} = EE_{bal}$ (Equation 9.56)

If $(AA_{av} - AAR) < AA_{Potalb+1}$
then $AA_{bal} = AA_{av} – AAR$ and $EE_{albPool} = EE_{bal}$ (Equation 9.57)

In all cases, the bird is made to use its body lipid reserves as an energy source before relying on the energy from the feed on the assumption that it has a genetically-determined

body lipid:protein ratio that it strives to maintain (Equation 9.58). The hen may use body lipid in this way until the minimum body lipid weight (MBL) is reached (Equation 9.59).

If ($EE_{bal-1} - EE_{BLR-1} < 0$ and $BL_{-1} + [(EE_{bal-1} - EE_{BLR-1}) / CE_l] + [(EP_{bal-1} * GE_p) / CE_l] > MBL$) then $BL = BL_{-1} + [(EE_{bal-1} - EE_{BLR-1}) / CE_l] + [(EP_{bal-1} * GE_p) / CE_l]$ (Equation 9.58)

If ($EE_{bal-1} - EE_{BLR-1} < 0$ and $BL_{-1} + [(EE_{bal-1} - EE_{BLR-1}) / CE_l] + [(EP_{bal-1} * GE_p) / CE_l] < MBL$) then $BL = MBL$ (Equation 9.59)

Where the feed and body lipid reserves are insufficient to meet the required energy intake for potential egg output, the hen will respond by reducing its egg size, and will continue to lay smaller eggs as long as sufficient energy can be supplied from the albumen pool to meet albumen formation. If not, it will stop laying. Egg weight may only decrease to a (user-defined) proportion (C_{EW}) of the potential egg weight, the default being 0.86 (Morris and Gous, 1988; Bowmaker and Gous, 1991), and is calculated using the potential egg weight (EW_{pot}, g), the amount of limiting energy stored in the albumen pool($EE_{albPool}$), the amount of limiting energy needed to produce the albumen at its potential ($EE_{albPool}$, mg) and C_{EW} (Equations 9.60 and 9.61).

If $[EW_{pot} - (EE_{albPool} * EW_{pot} / EE_{Potalb})] < C_{EW} * EW_{pot}$
then $EW = EE_{albPool} * EW_{pot} / EE_{Potalb}$ (Equation 9.60)

If $[EW_{pot} - (EE_{albPool} * EW_{pot} / EE_{Potalb})] \geq C_{EW} * EW_{pot}$
then $EW = 0$ (Equation 9.61)

The hen will start a new clutch once it has a sufficient energy supply from the albumen pool to lay an egg.

Where there is sufficient energy, but protein, or more specifically an amino acid, is limiting, the bird will respond in a similar way as described above, according to the degree of deficiency of the limiting amino acid. In calculating the DFI the most limiting amino acid(AA_{lim}, mg) would have been identified (Equation 9.62).

AA_{lim} = LARGEST (DFI) (Equation 9.62)

The hen will continue to lay eggs according to its ovulatory cycle, although these will be smaller than the potential, as long as there is a sufficient amino acid supply from the albumen pool to meet albumen formation. Egg weight is calculated from EW_{pot}, $AA_{albPool}$, $AA_{albPool}$ and C_{EW} (Equations 9.63 and 9.64).

If $[EW_{pot} - (AA_{albPool} * EW_{pot} / AA_{Potalb})] < C_{EW} * EW_{pot}$
then $EW = AA_{albPool} * EW_{pot} / AA_{Potalb}$ (Equation 9.63)

If $[EW_{pot} - (AA_{albPool} * EW_{pot} / AA_{Potalb})] \geq C_{EW} * EW_{pot}$
then $EW = 0$ (Equation 9.64)

When there is no egg production, yolk is produced for two days before stopping as albumen and shell productions do until the next clutch starts (Equation 9.65).

If $EW = 0$
then $YW = YW_{Pot}$ or 0, $AW = 0$, $SW = 0$ (Equation 9.65)

When energy or one or more amino acids are limiting, egg weight decreases by $(EW_{final} - EW_{initial}) / EW_{initial}$, and so yolk, albumen and shell will need to be decreased to the same extent (Equations 9.66, 9.67 and 9.68).

IF $EW = EE_{albPool} * EW_{pot} / EE_{Potalb}$ or $EW = AA_{albPool} * EW_{pot} / AA_{Potalb}$
then $YW = YW_{pot} – [(EW_{final} - EW_{initial}) / EW_{initial}]$ (Equation 9.66)
$AW = AW_{pot} - [(EW_{final} - EW_{initial}) / EW_{initial}]$ (Equation 9.67)
and $SW = SW_{pot} - [(EW_{final} - EW_{initial}) / EW_{initial}]$ (Equation 9.68)

This is accomplished by reducing the potential yolk weight by the required amount, which results in the allometric reduction in the weights of albumen and shell.

On pause days, dictated by the hen's ovulatory cycle, the hen has an opportunity to build up nutrient reserves, such as body lipid and albumen pool, which may be sufficient to allow her to lay an egg of a normal size once more. After a pause in production caused by an insufficient supply of nutrients the hen is assumed to start laying a new clutch once it again has a sufficient supply of the limiting amino acid.

Body protein (BPD, g) and lipid (BLD, g/d) depositions are calculated from Equations 9.69 and 9.70.

$$BPD = BP - BP_{-1} \quad \text{(Equation 9.69)}$$

$$BLD = BL - BL_{-1} \quad \text{(Equation 9.70)}$$

Body weight (BW, g) is calculated from the body weight of the previous day (BW_{-1}, g), and the body protein and lipid depositions (Equation 9.71).

$$BW = BW_{-1} + BPD + BLD \quad \text{(Equation 9.71)}$$

Body protein (BPC, %) and lipid (BLC, %) contents are calculated from body protein and lipid weights and body weight, (Equation 9.72 and 9.73).

$$BPC = (BP / BW) * 100 \quad \text{(Equation 9.72)}$$

$$BLC = (BL / BW) * 100 \quad \text{(Equation 9.73)}$$

Body protein weight (BP, g) is calculated from the body protein weight of the previous day (BP_{-1}, G) and the difference between the amount of protein in the albumen pool on this and the following morning (Equation 9.74).

$$BP = BP_{-1} + EP_{albpool} - EP_{albpool+1} \quad \text{(Equation 9.74)}$$

The amount of heat produced (HP, kJ/d) is estimated as the difference between the metabolisable energy (MEC, MJ) and effective energy (EEC, MJ) intakes (Equation 9.75).

$$HP = (MEC * AFI) - (EEC * AFI) \quad \text{(Equation 9.75)}$$

Up to this point the Breeder Model has assumed that the non-nutritional environment has had no constraint on egg production. The climatic environment does, however, have an important effect on egg output (Chapter 8). What will happen if the environment is too hot for the bird to rid itself of excess energy through heat dissipation? Similarly, how does the

bird partition energy when faced with low temperatures? These questions need to be answered if any relationship between the environment and egg production in broiler breeders is to be established. The Breeder Model is not yet programmed to evaluate the effect of high temperatures on performance of broiler breeders, as this will require further experimentation to quantify these effects. However, from Chapter 8 it is known that when the temperature decreases below 19.5ºC, the daily maintenance requirement increases by 1.0kJ AME / kg body weight per degree Celsius. If the bird has sufficient body lipid reserves, it will lay an egg at its potential; if not, the hen will respond by reducing egg size. The hen will continue to lay smaller eggs (C_{EW}) as long as it has sufficient energy supply from the albumen pool to meet albumen formation. If not, it will stop laying. The principles applied here are the same as those applied above when the daily energy supply is limiting.

9.5 DEALING WITH A POPULATION

The description of the Breeder Model in the early part of this chapter describes events for one animal. However, the requirements for energy and each of the amino acid will vary between individuals within a flock. Each bird will have its own characteristic values for the inherited parameters that describe its potential, thus the response to a given daily nutrient supply will differ between these birds. The genetic parameters describing birds within the same population are assumed to be normally distributed, the default coefficients of variation for the various parameter estimates used in the Breeder Model being shown in Table 9.4. These coefficients of variation may be changed by the user.

Within a population of broiler breeders whose feed intake is restricted there is likely to be a distribution of feed intakes depending on the aggressiveness of each bird, and thus daily food intakes in the population have been made stochastic by allocating an agressiveness value to each hen at sexual maturity, the same value being kept for each hen over the laying period.

Table 9.4 Parameter estimates used in the Breeder Model

Parameter	CV (%)
Body weight at the start of the simulation	10
Initial body lipid weight	10
Initial body protein weight	3
Age at first egg	10
Yolk weight constant (a)	7
Agressiveness	10

9.6 FINANCIAL REPORT

For the Breeder Model to have any practical value an economic analysis of the inputs and outputs is necessary. The model does not yet predict an optimum economic solution, but instead shows the cumulative income, expenditure and margin from the predicted performance for a given set of nutritional and environmental conditions.

Income may be divided into hatching and unsettable egg revenues. Hatching eggs are those of acceptable size for the hatchery. A minimum of 50g and a maximum of 75g are the default hatching weight values (HW_{min} and HW_{max}, g, respectively). Any eggs smaller or larger than those acceptable for hatching, including double-yolked and soft-shelled eggs, are termed unsettable eggs. The daily income (INCOME, R/hen d) is calculated as the product of the number of hatching (EGG_{hat}) and unsettable (EGG_{uns}) eggs and their respective values (VAL_{EGGhat} and VAL_{EGGuns}, R/egg, respectively). The default value for a dozen hatching eggs is R 15.50 and a dozen unsettable eggs is R 2.40. On a pause day, there is no income. Cumulative income (CUMINCOME, R/hen d) is calculting from the cumulative income of the previous day ($CUMINCOME_{-1}$, R/hen) and the income of the day. All the above values may be altered by the user.

$$INCOME = EGG_{hat} * VAL_{EGGhat} \quad \text{(Equation 9.76)}$$

or

$$INCOME = EGG_{uns} * VAL_{EGGuns} \quad \text{(Equation 9.77)}$$

or

$$INCOME = 0 \quad \text{(Equation 9.78)}$$

and

$$CUMINCOME = CUMINCOME_{-1} + INCOME \quad \text{(Equation 9.79)}$$

Feed costs are calculated by linear programming (Winfeed) taking into account feed ingredient availability, analysis and costs. Feeding cost ($COST_{feed}$, R/hen d) is calculated on a daily basis from the actual feed intake and the cost of feed per kg ($COST_{feed/kg}$, R/kg),(Equation 9.80). The cumulative feed cost ($CUMCOST_{feed}$, R/hen) is calculated from the cumulative feed cost of the previous day ($CUMCOST_{feed-1}$, R/hen) and the feed cost of the day (Equation 9.81)

$$COST_{feed} = (AFI * COST_{feed/kg}) / 1000 \quad \text{(Equation 9.80)}$$

$$CUMCOST_{feed} = CUMCOST_{feed-1} + COST_{feed} \quad \text{(Equation 9.81)}$$

The cumulative margin (CUMMARGIN, R/hen) is the sum of the cumulative income and feed cost (Equation 9.82).

$$CUMMARGIN = CUMINCOME + CUMCOST_{feed} \quad \text{(Equation 9.82)}$$

The cumulative margin with hen depreciation ($CUMMARGIN_{depr}$, R/hen) is calculated from the value of the hen at the start of lay ($COST_{hen}$, R), the value of the culled (spent) hen ($VALUE_{culledhen}$, R) and the cumulative margin on the day (Equation 9.83).

$$CUMMARGIN = VALUE_{culledhen} - COST_{hen} + CUMMARGIN \quad \text{(Equation 9.83)}$$

9.7 CONCLUSION

The model described here is a mechanistic population model designed to evaluate the effects of nutrient intake on the performance of broiler breeders varying in potential performance, and housed in varying environmental conditions. Many interactions between the feed, the bird and the environment have had to be accounted for, and many physiological processes involved in egg production have been defined, some of which have not yet been fully described for broiler breeders. For example, as with laying hens (Johnston 2004), some of the top producing hens lay long egg sequences throughout their laying cycle, with few double-yolked or soft-shelled eggs, while others produce short egg

sequences even at peak production, with internal ovulations or gaps in the follicular hierarchy causing prolonged inter-sequence pauses. Also it is not known whether and for how long yolk growth continues after the bird has laid the last egg of a clutch, and what effect high temperatures have on egg production other than directly through a reduction in food intake. As a result, many assumptions have had to be made in constructing this model, which will need to be tested and corroborated if the model is to be developed further.

In the following chapter the model described above is used to simulate a number of scenarios as a means of demonstrating some principles of nutrient partitioning for egg production in broiler breeders.

CHAPTER 10

DEMONSTRATION OF SOME PRINCIPLES OF NUTRIENT PARTITIONING FOR EGG PRODUCTION IN BROILER BREEDERS USING THE MODEL

10.1 INTRODUCTION

The Breeder Model described in the previous chapter may be used to demonstrate potential interactions between model inputs and nutrient partitioning. Some illustrations are given below of the use of the programme described in Chapter 9.

Default values for the parameters used to predict yolk, albumen and shell weights for Cobb and Ross broiler breeders are given in the model, these having been determined as described in Chapter 8. Default values are also given for ovulation time, internal cycle length, the proportions of double-yolked and soft-shelled eggs and internal ovulations, with options being offered for different rates of the latter three abnormalities. Initial body weight and the proportions of body protein and lipid at the start of the simulation must also be defined. Because the model for the prediction of age at sexual maturity (AFE) following a constant photoperiod or a single change in photoperiod from 8 to 16h for broiler breeders, proposed by Lewis and Gous, is still under development, AFE is defined by the user in the current model and not the rearing photoperiod and body weight at 20 weeks.

The genotype used in all simulations presented below is described in Table 10.1. The feed composition/type, the daily allocation and the number of days over which the feed is to be offered are specified as feeding schedules, the number of which are defined by the user, while the daily temperature, the external cycle length (usually 24 hr) and the timing of dusk are inputs used to describe the environment. All constants, such as amino acid composition of yolk, albumen and body protein, their efficiencies of utilisation, minimum body lipid, Cew, and the nutritional constants to transform maintenance and egg production into quantitative requirements, are presented as defaults, but may also be changed by the user. Values of the constants used in the simulations presented below are given in Table 10.2.

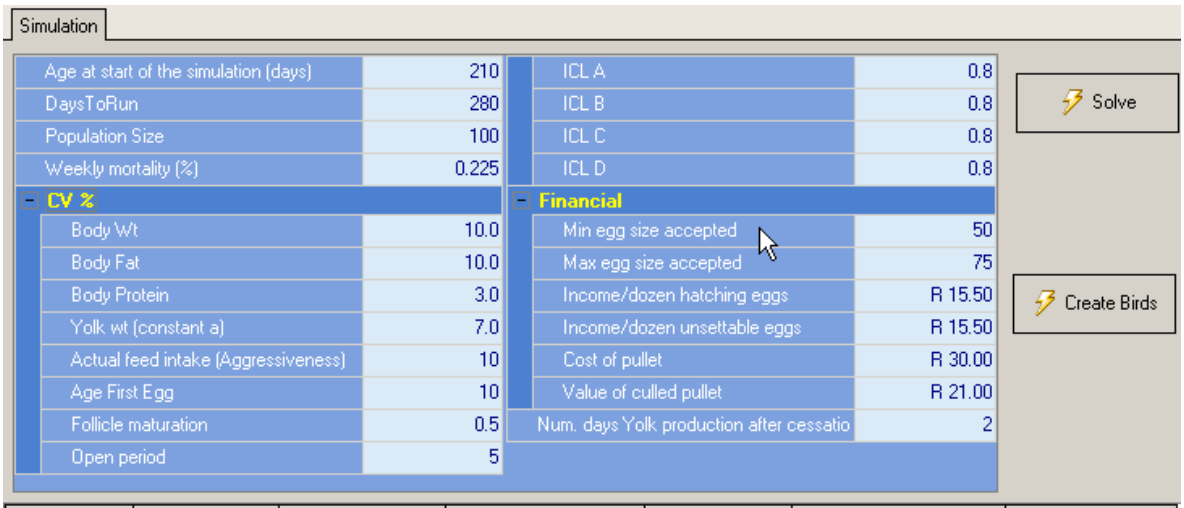
Table 10.1 Description of the genotype used at the start of each simulation

Strain		Cobb
Initial body weight (g)		3310
Initial body protein content (%)		18
Initial body lipid content (%)		14
Mean age at first egg (d)		210
Yolk weight (g) = a + b / (1 + c * hen age)		
	a	28.083
	b	34.2
	c	-0.01836
Albumen weight (g) = e YW ^{f}		
	e	9.5257
	f	0.5002
Shell weight (g) = g ECW ^{h}		
	g	0.1707
	h	0.8686
Ovulation time (h)		
	follicle maturation	28
	open period	8
Internal cycle length		
	Lag period	8.5
	A	23.05
	B	2.485
	C	0.0222
	D	0.98082
Doubled-yolked eggs (%) = a + b * c $^{\text{hen age}}$		
	proportion	0.36
	a	-0.00291
	b	74438
	c	0.940345
Soft-shelled eggs (%) = a + b / (1 + c * hen age) + d * hen age		
	Proportion	0.32
	a	-6.36
	b	-4.509
	c	-0.009463
	d	0.01607
Internal ovulation (%) = a + b * c $^{\text{hen age}}$ + d * hen age		
	Proportion	0.40
	a	-189.7
	b	200.0
	c	0.99899
	d	0.142

Once all inputs have been specified, the user conducts a simulated experiment by choosing one or more 'levels' from the genotype, feed schedule and environment. The simulation window (an example is given in Figure 10.1) enables the user to define the age of the flock at the start of the simulation, the number of days over which the simulation is to run, the population size, coefficients of variation, the length of time (d) that yolk material is deposited between the end of a clutch and the start of the next, and all the financial inputs. Using the means and coefficients of variation specified for initial body weight (BW_0), body

protein (BP_0) and body lipid (BL_0), for the yolk weight constant 'a', for AFE and for aggressiveness, the model creates a population of birds of the stipulated size. This population may be saved and used repeatedly, or replaced with a different population by re-randomization. Once the population has been created the simulation process is initiated and the outputs, in the form of tables of both individual and population mean performances, and graphs, are created.

Three simulation exercises follow: The first simulates the response of a flock of 100 broiler breeder hens to dietary lysine, while the second simulates the response of such a flock to an increment in food allocation. In the third exercise the effect of low temperatures is evaluated. These were chosen to demonstrate the extent to which the Breeder Model could simulate the results of similar trials that had been conducted previously at this University, and to test various aspects of the model, such as the effect of initial lipid content on the response under adverse conditions, and the effect of aggression at the feed trough on flock performance.



Bird No	BW0	BodyProtein0	Yolk Wt Constant (a)	Body Fat0	BirdAggressiveness	BirdAFE
1	3845.55	18.29	30.13	15.84	1.15	243
2	3617.42	18.19	28.85	13.91	0.96	181
3	3340.95	18.12	24.97	14.05	0.95	213
4	3453.89	18.00	31.53	14.52	1.12	221
5	3643.91	18.33	27.61	12.98	1.09	167
6	2842.66	19.03	26.38	16.90	1.01	221
7	3021.24	18.25	28.08	13.01	0.86	208
8	3536.75	17.27	28.42	14.74	1.04	217
9	4217.28	18.54	28.61	13.77	1.00	205
10	3290.97	17.87	28.79	13.64	1.11	185
11	3911.74	16.76	27.66	15.03	1.19	211
12	3246.51	19.41	30.08	11.49	0.86	207
13	2852.09	17.75	29.07	16.24	0.97	210
	AVG=3308.59	AVG=17.91	AVG=28.41	AVG=13.97	AVG=0.99	210

Figure 10.1 An example of the simulation window from the Breeder Model

Table 10.2 Constants used in each simulation

Minimum body lipid (%)	11
Maximum decrease in egg weight (Cew, g)	14
Protein	
Requirement for maintenance (kg/$BP^{0.73}$)	0.008
Requirement for yolk production (kg/kg yolk)	0.21
Requirement for albumen production (kg/kg albumen)	0.13
Requirement for shell production (kg/kg shell)	0.004
Energy	
Requirement for maintenance (MJ/$BP^{0.73}$)	1.63
Requirement for yolk production (MJ/kg yolk)	25.0
Requirement for albumen production (MJ/kg albumen)	3.6
Requirement for shell production (MJ/kg shell)	1.2
Nitrogen	
Nitrogen content in yolk (g N/kg yolk)	27.0
Nitrogen content in albumen (g N/kg albumen)	17.0
Nitrogen content in shell (g N/kg shell)	5.3
Eem coefficient at low temperature (kJ/kg/ºC)	1.0
Maximum body lipid deposition (g/d)	10

Amino acid composition				
Amino acid	Body protein	yolk	albumen	Efficiency of utilisation
Arginine	68	434	330	0.85
Histidine	26	148	132	0.85
Isoleucine	40	348	331	0.85
Leucine	71	548	521	0.85
Lysine	75	477	378	0.85
Methionine	25	175	240	0.85
Phenylalanine	40	261	368	0.85
Threonine	42	313	272	0.85
Valine	44	378	429	0.85
Methinine+cystine	36	338	418	0.85
Phenylalanine+tyrosine	71	514	625	0.85
Tryptophan	10	121	116	0.85
Aspartic acid		613	628	0.85
Serine		499	429	0.85
Glutamic acid		780	869	0.85
Proline		247	209	0.85
Glycine		170	205	0.85
Alanine		313	367	0.85

10.2 THE RESPONSE OF BROILER BREEDERS TO DIETARY LYSINE

10.2.1 Materials and methods

A simulated flock of 100 Cobb broiler breeder hens, aged 30 weeks, was used in two simulated trials, one running from 30 to 40 weeks of age, and the other from 50 to 60 weeks. The lighting regime used was 16L: 8D and the mean daily temperature were maintained at 22ºC.

In each trial the hens were offered 160g daily of one of seven lysine-limiting feeds (Table 10.3). The summit feed (F1) was designed to supply approximately 1248 and the dilution feed (F7) 368mg lysine/bird d at an intake of 160g. The highest lysine intake was calculated to provide 1.2 times the mean lysine requirement for a flock of broiler breeders aged 30 weeks, as suggested by Fisher (1998). The content of all other amino acids were calculated in a similar manner, the amounts in Feed 1 providing 1.4 times these requirements, thus ensuring that lysine was limiting. By diluting the summit feed with feed 7 (2.3g lysine/kg feed) in appropriate proportions, seven feeds containing 7.8, 6.2, 5.5, 4.7, 3.9 and 2.3g lysine/kg feed were produced. In both simulations, the birds were 'offered' 160g/d of a standard broiler breeder feed (11.5MJ AME/kg, 138.9g/kg CP, 28g/kg Ca^{2+}) until the start of the experimental period.

10.2.2 Results

The effects of the feeds on desired (DFI) and actual feed intakes (AFI), and on performance (rate of lay, egg weight and egg output) for the final four weeks of each trial are shown in Tables 10.4 and 10.5. Body weight, body weight gain, body lipid deposition, body protein and lipid contents for the final four weeks of each trial are shown in Tables 10.6 and 10.7.

The maximum rates of laying and egg output were achieved on the highest concentration of lysine, being 65.7%, and 44.4g/d, respectively, in Trial 1, and 46.1%, and 34.3g/d, respectively, in Trial 2. Rate of laying and egg output virtually ceased on the lowest lysine content in both trials.

Table 10.3 Composition (g/kg) of the summit and dilution feeds, both limiting in lysine. Amino acid contents are given as digestible.

Ingredient	F1 Summit	F7 Dilution
Maize	346.4	586.7
Sunflower 37	257.4	
Soybean full fat	99.3	
Wheat bran	80.1	202.3
Fish meal 65	39.6	
DL-methionine	0.2	
Vit + min premix	1.5	1.5
Monocalcium phosphate	5.4	7.3
Filler		25.7
Limestone	67.8	73.2
Salt	2.3	3.4
Oil-sunflower	100.0	100.0
Nutrient content (calculated)		
AME (MJ/kg)	13.0	13.0
Crude protein	174.1	6.3
Lysine	7.8	2.3
Methionine	3.9	1.3
Methionine + cysteine	6.7	2.8
Threonine	6.3	2.2
Tryptophan	2.0	0.7
Arginine	12.3	3.8
Isoleucine	7.5	2.2
Leucine	14.0	7.0
Histidine	4.6	2.2
Phenylalanine + tyrosine	12.9	5.2
Valine	8.9	3.2
Calcium	28.0	28.0
Phosphorus	3.5	3.5

Mean egg weights at the highest concentration of lysine were 67.3 and 74.5g for period 1 and 2, respectively. Egg weight declined as the lysine supply was reduced, but not to the same extent as did rate of lay (Figure 10.2).

The DFI increased in both periods as the dietary lysine content decreased, reaching 448 and 481g at the lowest concentration of lysine in trials 1 and 2, respectively. The constrained feed intake (CFI) on each feed in both trials is similar to the amount of food allocated to the birds each day, being 160g. The AFI increased from a minimum of 131 and 140g on feed 1 in Trials 1 and 2, respectively, in a curvilinear fashion, as illustrated in Figure 10.3, to a maximum of 159 and 160g on feed 7 in both trials.

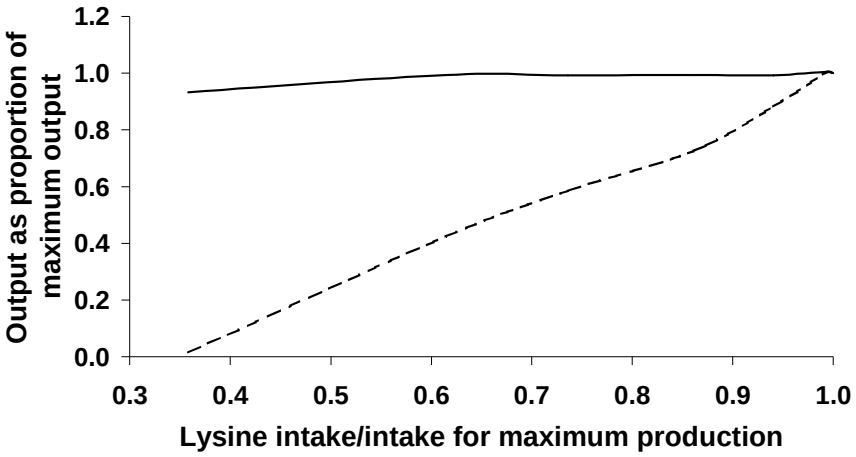


Figure 10.2 The relative effects on egg weight (dashed line) and rate of laying (solid line) of a decrease in the lysine intake of broiler breeder hens during the last four weeks of Trial 1. Egg weight and rate of laying are expressed as proportions of the maximum egg weight and rate of laying achieved in period 1; and lysine intake is expressed as a proportion of that required for maximum egg output.

Table 10.4 Mean desired and actual feed intakes, and laying performance, of broiler breeders over the last four weeks of a lysine response trial simulated over the period 30 – 40 weeks of age. Birds were allocated 160g of feed daily.

Feed	Dietary lysine content (g/kg feed)	Lysine intake (mg/bird d)	Desired feed intake (g/bird d)	Actual feed intake (g/bird d)	Rate of lay (/100 bird d)	Egg weight (g)	Egg output (g/bird d)
F1	7.8	1022	132	131	65.7	67.6	44.4
F2	7.0	1015	144	145	65.5	67.3	44.1
F3	6.2	961	166	155	57.8	66.8	38.6
F4	5.5	880	187	160	47.5	66.9	31.8
F5	4.7	752	217	160	38.3	66.8	25.6
F6	3.9	628	264	161	27.8	66.9	18.5
F7	2.3	366	448	159	1.0	62.8	0.6

Table 10.5 Mean responses in desired and actual feed intakes, and in laying performance of broiler breeders over the last four weeks of a lysine response trial simulated over the period 50 – 60 weeks of age. Birds were allocated 160g of feed daily.

Feed	Dietary lysine content (g/kg feed)	Lysine intake (mg/bird d)	Desired feed intake (g/bird d)	Actual feed intake (g/bird d)	Rate of lay (/100 bird d)	Egg weight (g)	Egg output (g/bird d)
F1	7.8	1092	141	140	46.1	74.5	34.3
F2	7.0	1057	157	151	45.7	74.2	33.9
F3	6.2	986	180	159	39.4	75.4	29.7
F4	5.5	886	202	161	37.3	75.6	28.2
F5	4.7	752	235	160	34.1	74.8	25.5
F6	3.9	628	283	161	23.2	74.3	17.2
F7	2.3	368	481	160	0.6	73.3	0.4

Table 10.6 Mean final body weight, weight gain, body lipid deposition, and body protein and lipid contents of broiler breeders over the last four weeks of a lysine response trial simulated over the period 30 – 40 weeks of age. Birds were allocated 160g of feed daily.

Feed	Lysine intake (mg/bird d	Final body weight (g)	Body weight gain (g/bird d)	Body lipid deposition (g/bird d)	Body protein content (g/kg)	Body lipid content (g/kg)
F1	1022	3361	0.0	0.0	178.0	149.0
F2	1015	3560	3.4	3.4	168.5	199.5
F3	961	3744	6.1	6.4	159.5	237.5
F4	880	3810	7.0	7.5	157.0	253.3
F5	752	3819	7.4	7.7	156.0	253.0
F6	628	3854	8.0	8.5	154.8	261.8
F7	366	3932	9.4	9.9	152.3	276.3

Table 10.7 Mean final body weight, weight gain, body lipid deposition, and body protein and lipid contents of broiler breeders over the last four weeks of a lysine response trial simulated over the period 50 – 60 weeks of age. Birds were allocated 160g of feed daily.

Feed	Lysine intake (mg/bird d	Final body weight (g)	Body weight gain (g/bird d)	Body lipid deposition (g/bird d)	Body protein content (g/kg)	Body lipid content (g/kg)
F1	1092	3688	1.8	1.8	162.5	227.5
F2	1057	3901	5.0	5.1	153.8	270.0
F3	986	4079	6.8	6.7	148.8	297.8
F4	886	4059	7.0	6.9	148.5	297.8
F5	752	4074	7.4	7.4	147.0	304.5
F6	628	4135	8.4	8.4	144.3	314.3
F7	368	4247	10.0	9.9	141.0	332.3

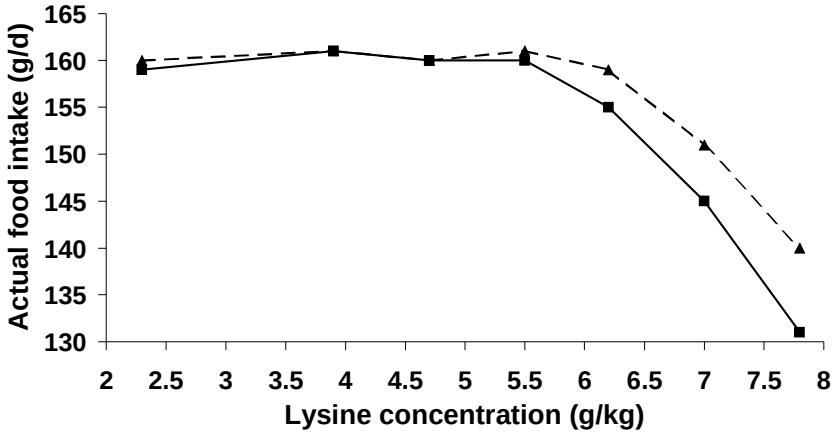


Figure 10.3 The effect of lysine concentration (g/kg) on the actual food intake (g) of broiler breeder hens in trials 1 (■, solid line) and 2 (▲, dashed line)

The mean body weight of birds at the start of the 10-week trial period was 3331g in Trial 1 and 3637g in Trial 2. The change in body weight during Trial 1 is illustrated in Figure 10.4. This trend was similar in Trial 2.

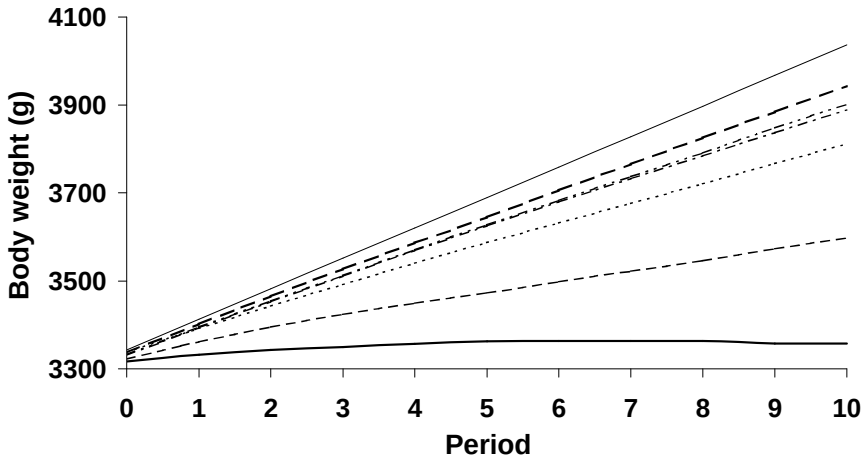


Figure 10.4 The change in body weight (g) of broiler breeders on feed 1 (bold line), 2 (dashed line), 3 (dotted line), 4 (1 dashed and 1 dotted line), 5 (1 dashed 2 dotted line), 6 (bold dashed line) and 7 (solid line) from 30 to 40 weeks of age.

Body weights of birds given feeds 1 to 7 increased by 0.0, 3.4, 6.1, 7.0, 7.4, 8.0 and 9.4g/d in Trial 1, and by 1.8, 5.0, 6.8, 7.0, 7.4, 8.4 and 10.0g/d in Trial 2, respectively, the increase being related to the concentration of the limiting lysine in the feed. The

composition of the weight gain was mainly lipid. The mean body lipid and protein contents at the start of the two trial periods were 145g lipid and 179g protein in Trial 1, and 218g lipid and 165g protein/kg body weight in Trial 2. Body lipid content increased as lysine concentration in the feed decreased, reaching 276 and 332g lipid/kg body weight in trials 1 and 2, respectively. This increase in body lipid resulted in a decrease in body protein concentration, from 178 to 152 in Trial 1 and from 163 to 141g/kg protein in Trial 2, although the weight of body protein remained constant throughout both trials, at around 600g/bird.

10.2.3 Discussion

The laying performance of birds in the two trials are generally in accordance with the findings of Morris and Gous (1988), Bowmaker and Gous (1991) and Goddard (1997), with rate of laying, egg output and egg weight decreasing with dietary lysine content. Rate of laying and egg weight were not affected to the same extent by the decrease in lysine intake: rate of lay declined almost linearly to 0.02 of the maximum, while egg weight, at the lowest point, was about 0.9 of the maximum. These values are similar to those published by Bowmaker and Gous (1991) for broiler breeders (0.2 for rate of laying and 0.8 for egg weight), except that the two variables were affected to the same extent until the amino acid supply was reduced to 0.64 of that required for maximum output. In the Breeder Model the user has the option to specify the maximum loss in weight that may be tolerated for an egg, and in this example the maximum was set at 14 %, but on average the egg weight did not decrease to this extent. This may be the reason that rate of lay decreased linearly and not at the same rate as egg weight up to 0.64 of the maximum requirement.

In the Breeder Model, AFI in a thermally neutral environment is taken as the lesser of the DFI and CFI. In a number of cases the mean AFI was lower than both the DFI and CFI (e.g. on feed 3 in Trial 1 the AFI was 155g whereas the CFI was 160g. This is explained by the fact that AFI varies depending on whether an egg is laid on the day or not. Not all birds of a population are constrained on a day, some may eat the DFI, while others may eat their CFI, giving a mean AFI smaller than the desired or constrained. An example of such is given in Table 10.8, where the mean of AFI is less than the means of either the CFI or DFI. This would happen only in a population of birds, and is not dependent on the degree of aggressiveness, where some birds consume more food than others.

Table 10.8 Constrained, desired and actual feed intakes of two individual birds.

BIRD	CFI	DFI	AFI
1	160	168	160
2	160	142	142
Mean	160	155	151

In both trials simulated here the food intake of birds on the highest concentrations of lysine was less than the feed allocated. This conforms to the theory that hens will consume only the amount of food required to meet their potential egg output after meeting the requirement for maintenance.

Whereas the maximum amount of food allocated to the birds each day is 160g, birds fed on the highest concentrations of lysine eat less food because most of them eat their DFI, decreasing as lysine concentration increases in the feed. The theory of food intake regulation proposed by Emmans (1981) suggesting that a bird will increase its voluntary food intake when the concentration of a nutrient in an otherwise well balanced diet is decreased, explains the results of AFI and DFI of both simulation. Because broiler breeder hens are restricted, they increased their AFI until reaching their CFI. However, Bowmaker and Gous (1991) observed a decrease in food intake with decreasing amino acid concentration of the diet using lysine and methionine as the first limiting amino acids. Goddard (1997) found that as the lysine concentration of the diet decreased to below 3g/kg food the food intake decreased. The reason for this decrease in food intake with decreasing first-limiting amino acid concentration was the need for the bird to remain in thermal balance with its environment (Emmans, 1981). The diets containing the lowest lysine concentrations have similar energy concentrations to feed 1, so the amount of energy consumed by the birds on these diets is far in excess of the amount required for egg production, considering the low egg output on diets with such low lysine concentrations. Only a small amount of energy would have been required to sustain such a low egg ouput and so the energy consumed in excess of this amount has been stored in body lipid, the body lipid content increasing as the lysine concentrations in the feed is reduced. However, Bowmaker and Gous (1991) and Goddard (1997) showed that broiler breeders consume less as first-limiting amino acid is reduced because of the imbalance that would be created by continuing to eat large amounts of a diet with such low amino acid concentrations. One of the limitations of the Breeder Model is that it does not show the decrease in AFI as first-

limiting amino acid in the diet is reduced. A further improvement of the model would be to add a biological mechanism that would allow birds to decrease their AFI, and for this we tried to decrease the maximum body lipid deposition under 10g/d, but without success as AFI stayed unchanged. The biological mechanism that allows the decrease in food intake as first-amino acid in the diet is reduced still need to be understood. The food intake aspect as first-limiting amino acid is reduced should be further pursued.

10.3 THE RESPONSE OF BROILER BREEDER HENS TO AN INCREMENT IN FOOD ALLOCATION

10.3.1 Materials and methods

100 Cobb broiler breeder hens were used in two simulations using the Breeder Model, the first from 30 to 40 weeks (Period 1), and the other, Period 2, from 50 to 60 weeks of age. The lighting regime used was 16L: 8D and the mean daily temperature was maintained at 22ºC.

In both periods the hens were offered 200, 180, 160, 140, 120 or 100g daily of a standard broiler breeder feed (Table 10.8). Measures of performance were rate of laying, egg weight, egg output (g/bird d), food intake, body weight and body lipid gain, and the contents of protein and lipid in the body at the end of each trial period.

Table 10.9 Composition (g/kg) of the broiler breeder feed. Amino acid contents are given as digestible.

Ingredient	Broiler breeder feed
Wheat bran	387.6
Maize	221.7
Sunflower 37	110.7
Soybean full fat	71.2
Fish meal 65	33.8
Vit + min premix	1.5
Limestone	71.0
Salt	2.4
Oil-sunflower	100.0
Nutrient content (calculated)	
AME (MJ/kg)	11.5
Crude protein	138.9
Lysine	6.5
Methionine	2.8
Methionine+cystine	5.2
Threonine	5.0
Tryptophane	1.7
Arginine	9.6
Isoleucine	5.6
Leucine	11.0
Histidine	4.0
Phenylalanine+tyrosine	10.5
Valine	6.9
Calcium	28.0
Phosphorus	3.5

10.3.2 Results

The effect of food allocation on CFI, DFI and AFI on performance (rate of lay, egg weight and egg output), for the final four weeks of each period, is summarised in Tables 10.10 and 10.11. By definition, the CFI was similar to the daily food allocation in both periods. The small differences that occurred in some cases, as, for example 202 g instead of 200g in Period 1, and 181g instead of 180 \g in Period 2, may be explained by the mean of the aggressiveness value being 1.02 and 1.01, respectively, instead of 1.00, this being a consequence of the random allocation of such values to each hen when generating the initial populations.

DFI was lowest (161 and 172g in Period 1 and 2 respectively) on the highest feed allocations, but increased to a maximum of 180g/d in both periods as the food allocation decreased below 140g/d. The AFI consumed, being the lesser of the DFI and DFI, equaled the food allocation up to 140g/d in both periods, but increased to a maximum of only 161

and 171g/d in Periods 1 and 2, respectively, even though the amounts offered were greater than this.

Rate of laying and egg output increased curvilinearly (Fig. 10.6) with food allocation in both periods, the magnitude of difference being lowest between the two highest food allocations in both periods. Figure 10.6 shows the trend for rate of laying. The maximum rate of laying and egg output achieved on the highest food allocation are 68 % and 46g/d, respectively, in Period 1, and 48% and 36g/d, respectively, in Period 2. Rate of laying and egg output declined considerably at the lower food allocations, being only 6 % and 4 g/d, respectively, in Period 1, and 21 % and 15 g/d, respectively, in Period 2.

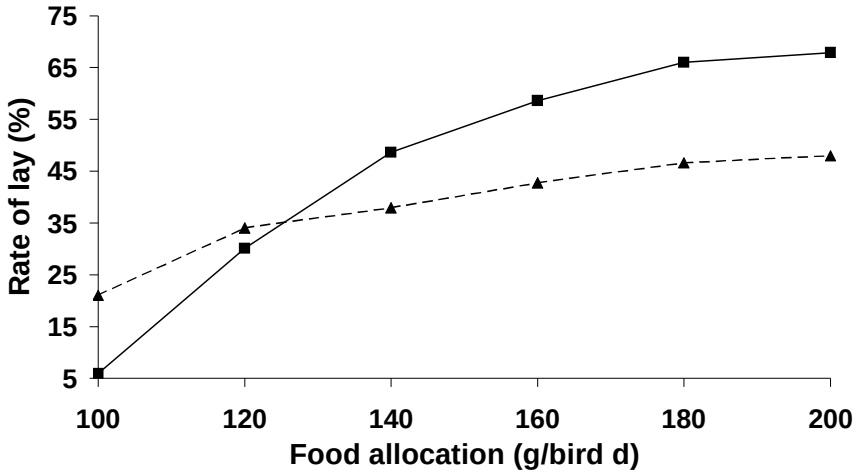


Figure 10.6 The response in rate of laying of broiler breeder hens to daily food allocation in Periods 1 (■, solid line) and 2 (▲, dashed line).

Egg weights increased curvilinearly with food allocation, but the increase was only 2.9 and 2.5% in Periods 1 and 2 respectively. Mean egg weight in Period 1 was 67.2g and in Period 2, 74.5g.

Table 10.10 Mean responses in constrained, desired and actual feed intakes, and in performance to food allocations over the last four weeks of period 1.

Food allocation (g/bird d)	Energy (MJ/d)	Protein (g/d)	Constrained feed intake (g/bird d)	Desired feed intake (g/bird d)	Actual feed intake (g/bird d)	Rate of lay (/100 bird d)	Egg weight (g)	Egg output (g/bird d)
100	1150	13.9	100	180	100	5.9	65.8	3.8
120	1369	16.5	119	169	119	30.1	67.2	20.2
140	1599	19.3	139	163	139	48.6	67.1	32.6
160	1771	21.4	161	161	154	58.6	67.4	39.5
180	1840	22.2	181	161	160	66.0	67.9	44.9
200	1852	22.4	202	161	161	67.9	67.7	46.0

Table 10.11 Mean responses in constrained, desired and actual feed intakes, and in performance to food allocations over the last four weeks of period 2.

Food allocation (g/bird d)	Energy (MJ/d)	Protein (g/d)	Constrained feed intake (g/bird d)	Desired feed intake (g/bird d)	Actual feed intake (g/bird d)	Rate of lay (/100 bird d)	Egg weight (g)	Egg output (g/bird d)
100	1150	13.9	100	180	100	21.0	73.0	15.3
120	1380	16.7	120	175	120	34.0	74.5	25.3
140	1610	19.5	140	173	140	37.9	74.7	28.3
160	1817	21.9	160	174	158	42.7	74.7	31.9
180	1932	23.3	181	173	168	46.6	75.2	35.1
200	1967	23.8	200	172	171	48.0	74.8	35.9

Table 10.12 Mean responses in body weight, body weight gain, body lipid deposition and body protein and lipid contents to food allocations over the last four weeks of period 1.

Food allocation (g/bird d)	Energy (MJ/d)	Protein (g/d)	Body weight (g)	Body weight gain (g/bird d)	Body lipid deposition (g/ bird d)	Body protein content (g/kg)	Body lipid content (g/kg)
100	1150	13.9	3205	-0.4	-0.4	186.0	112.0
120	1369	16.5	3315	-0.1	-0.2	181.8	139.0
140	1599	19.3	3480	1.2	1.2	175.5	166.8
160	1771	21.4	3424	1.4	1.7	174.5	172.5
180	1840	22.2	3434	1.2	1.1	175.5	169.0
200	1852	22.4	3449	0.8	0.9	174.3	170.8

Table 10.13 Mean responses in body weight, body weight gain, body fat deposition, and body protein and fat contents to food allocations over the last four weeks of period 2.

Food allocation (g/bird d)	Energy (MJ/d)	Protein (g/d)	Body weight (g)	Body weight gain (g/bird d)	Body lipid deposition (g/ bird d)	Body protein content (g/kg)	Body lipid content (g/kg)
100	1150	13.9	3389	-2.1	-2.2	177.0	161.8
120	1380	16.7	3555	-0.8	-0.8	169.5	196.5
140	1610	19.5	3739	2.5	2.3	159.3	240.3
160	1817	21.9	3857	3.6	3.6	155.5	258.0
180	1932	23.3	3799	3.2	3.1	158.5	247.0
200	1967	23.8	3780	2.8	2.9	158.5	244.3

The effect of food allocations on body weight, body weight gain, body lipid deposition, and body protein and lipid contents for the final four weeks of each period is shown in Table 10.12 and 10.13. The mean body weight of birds at the start of each trial period was 3327 ± 332.7g and 3617 ± 361.7g. The change in body weight during the 10-weeks of Period 1 is illustrated in Fig. 10.7, the trend of change in body weight during the second period being essentially similar. Birds fed either 100 or 120g lost weight in both Period 1 (-0.4 and -0.2g/d, respectively) and 2 (-2.1 and –0.8g/d, respectively), while body weights of birds fed 140, 160, 180 and 200g increased by 1.2, 1.4, 1.2 and 0.8g/d in Period 1, respectively, and by 2.5, 3.6, 3.2 and 2.8g/d in Period 2. The composition of the weight lost and gained was almost entirely lipid. The mean body lipid and protein contents at the start of the two ten-week trial periods were 141g lipid and 180g protein, and 143g lipid and 180g protein/kg body weight, respectively. Body lipid content increased with food allocation, reaching 171 and 244g lipid /kg body weight in the two periods, respectively. Although body protein content decreased from 186 to 174g and from 177 to 159g/kg protein in the two periods as food allocation was reduced, the weight of body protein remained approximately 600g/bird throughout the ten-week period on all treatments in both trials.

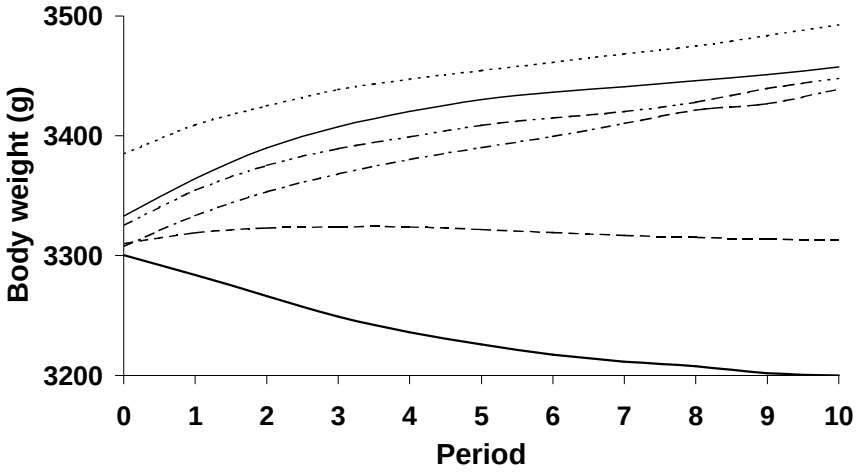


Figure 10.7 The change in body weight (g) of broiler breeders given a daily feed allocation of 100g (bold line), 120 (dashed line), 140 (dotted line), 160 (1 dashed and 1 dotted line), 180 (1 dashed 2 dotted line) or 200g (solid line) from 30 to 40 weeks of age.

10.3.3 Discussion

The objective of these simulations was to compare the responses of broiler breeders to an increment in food allocation with those described in Chapter 6 and the Cobb Production Manual (2005).

The theory of food intake in the model limits the food intake to that required to meet potential requirements; thus the hens offered intakes greater than 160g in Period 1 and 170g in Period 2 did not consume all that was allocated to them. DFI reached a maximum of 161 and 172g in Periods 1 and 2 on the highest feed allocations suggests that these intakes provided the birds with all the nutrients they required in order to lay at their potential. Of considerable interest was the observation that DFI increased to a maximum of 180g/d in both periods when the food allocation was below 140g/d. This is explained by the loss of body lipid on the lower feed allocations, resulting in less energy being available to the bird from lipid reserves. These extremely high food intakes would have been to meet the requirement for energy for maintenance, for egg output and to replenish the lipid reserves that were rapidly being depleted due to the low intakes of energy. Clearly, the CFI of 120 and 140g food/bird d were too low to allow the birds to meet these requirements, so body lipid content diminished over the ten-week periods. However, in the second period, when the birds were older and had higher lipid reserves, although the DFI on the lowest feed allocation was the same as in the earlier period, egg production could be sustained for a longer period, resulting in an increased egg output of over 11g/bird d. This result is in accordance with the results of the trial reported in Chapter 6, which demonstrated that egg production in breeders could be maintained for up to three weeks as long as sufficient body lipid reserves were present, and that sufficient dietary protein was fed to meet the requirements for amino acids during this time.

On the higher daily intakes the increase in body weight was due entirely to an increase in body lipid, which is in agreement with the findings of Pearson and Herron (1982) and Spratt and Leeson (1987). Although body protein content (in g/kg body weight) appeared to decrease as lipid content increased, the actual weight of body protein remained the same on all feed allocations. The theory incorporated into the model in this regard was that body protein content remained constant after the attainment of sexual maturity **(**Bennett and Leeson, 1990; Soller *et al.*, 1984**)** and that any changes that occurred would be in body

lipid only. This is very difficult to measure in adult broiler breeders; as to date there are no facilities or mechanisms available for measuring the chemical composition of a live breeder hen.

Breeding companies recommend that food intake should be reduced as the laying period progresses (Cobb Production Manual, 2005), on the grounds that egg production is falling and therefore the nutrient requirements of the hen should also be diminishing. However, the DFI in the second period in these simulations, where the feed allocations were very high, were more than 10g/d higher than those in the younger flock even though egg output was 10g/bird d lower in the second period. The higher DFI in the older hens is not because egg output is higher, nor because of a higher requirement for energy (as these hens would have considerable body lipid reserves from which to draw) so it is likely that this is a reflection of the observation of Wethli and Morris (1978) who found that laying hens required the same daily intakes of amino acids at an older age even though the egg output was much lower because the efficiency of utilisation of these amino acids is essentially reduced because of the large number of pause days when no egg is laid.

Maximum rates of lay in these simulations were 68% and 48% in Periods 1 and 2, respectively, which is too low for broiler breeders around 38 weeks of age but on target for breeder flocks around 58 weeks. According to the Cobb Production Manual (2005), breeder flocks of 38 weeks should reach a rate of lay of 75%, and peak rates of lay in excess of 80% are becoming more common. The ICL equation used in the population model of egg production, described in Chapter 9, therefore needs to be modified in order to increase the performance at peak production to around 80-85%. A later version of the model will allow users to choose a peak rate of laying and a rate of decline thereafter, but this has not been implemented at this stage.

Egg weight was reduced in size at an intake of 100g/d because the protein intake of 13.9g/d is not enough to sustain the yolk, and hence egg weight. This result is in accordance with the findings of Chapter 6, where eggs laid by hens given 80g/d (805kJ AME/d, 16.8g CP/d) were smaller than those laid by hens receiving adequate quantities of nutrients each day. The mean egg weights are lower than those suggested in the Cobb Production Manual (2005), but they are in accordance with the results of experimental conditions described in Chapter 8 (67.8g and 73.6g at 35 and 55 weeks of age).

It appears from these simulations that the Breeder Model gives satisfactory results regarding the responses of broiler breeders to food increments.

10.4 THE RESPONSES OF BROILER BREEDER HENS TO DIETARY ENERGY ALLOCATION AND ENVIRONMENTAL TEMPERATURE

10.4.1 Materials and methods

100 Cobb broiler breeder hens aged 30 weeks were used in four simulated trials running for ten weeks. Two body lipid contents (7 and 21%) and two coefficients representing the energy required for maintenance (CEE_m) (a value of 1.0kJ AME/d. kg W. ^oC, determined in Chapter 7, and one of 8.0, a value close to that suggested by Emmans (1974) for laying hens) were compared. The lighting regime used was 16L : 8D. Daily temperatures were set at 10, 12, 15, 18 and 20ºC. Each hen was allocated 160g daily of one of four feeds containing 12.5, 11.5, 10.5 or 9.5MJ AME_n/kg. The four feeds were formulated to provide the same minimum daily intakes of all essential amino acids according to the breeder's recommendations (Cobb Production Manual, 2005) (Table 10.14). The aggressiveness value for each hen was set to zero.

Table 10.14 Composition (g/kg) of the four feeds used in the simulation. Amino acid contents are given as digestible.

Ingredient	F1	F2	F3	F4
Maize	378.0	249.5	83.2	78.0
Sunflower 37	216.4	202.7	174.7	172.2
Wheat bran	175.3	319.8	472.4	506.4
Fish meal	56.6	47.6	9.8	
Soybean full fat		7.3	82.8	96.9
Vit + min premix	1.5	1.5	1.5	1.5
Monocalcium phosphate	2.2			
Limestone	68.0	69.6	72.9	73.8
Salt	1.9	2.0	2.7	2.9
Oil-sunflower	100.0	100.0	100.0	68.4
Nutrient content (calculated)				
AME (MJ/kg)	12.5	11.5	10.5	9.5
Crude protein	150.0	150.0	150.0	151.8
Lysine	6.5	6.5	6.5	6.5
Methionine	3.5	3.3	2.9	2.8
Methionine+cysteine	6.0	5.9	5.4	5.4
Threonine	5.4	5.4	5.3	5.3
Tryptophan	1.7	1.8	1.9	2.0
Arginine	10.2	10.4	10.9	11.1
Isoleucine	6.2	6.1	6.1	6.1
Leucine	12.5	11.7	10.8	10.9
Histidine	4.1	4.2	4.3	4.4
Phenylalanine+tyrosine	11.0	11.0	11.3	11.6
Valine	7.7	7.6	7.4	7.5
Calcium	28.0	28.0	28.0	28.0
Phosphorus	3.5	3.5	3.5	3.5

10.4.2 Results

The effects of temperature, dietary energy allocation and initial body lipid content on DFI and AFI over the final four weeks of each trial are given for CEE_m values of 1.0 and 8.0 in Table 10.15. With a CEE_m of 1.0kJ AME/d. kg W. ^oC, DFI increased from 197 to 215g/d on the 9.5MJ feed, and from 162 to 167g/d on the 10.5MJ feed, as temperature decreased from 20 to 10^{o}C when the initial body lipid content was 7%, but remained the same (159g/d) on the two higher AME feeds. With an initial body lipid content of 21% the increases in DFI were less pronounced on the low energy feeds, increasing by only 3g/d on the 9.5MJ feed and remaining at 159g/d on all other treatments. With a CEE_m = 8.0, the effect of temperature on DFI was far greater than with CEE_m = 1.0, increasing from 198 to 283g/d on the lowest energy feed when initial lipid content was 7%, and from 166 to 239g/d with an initial lipid content of 21%. As the ME of the feed increased, the difference

in DFI between the highest and lowest temperatures decreased, as with a CEE_m of 1.0, but was evident up to the 11.5MJ feed with an initial lipid content of 7% (a difference of 8g/d).

AFI was largely unaffected by temperature because each hen was constrained to an intake of 160g/d. There was a tendency for AFI to be marginally higher with the higher CEE_m, but the differences were only 1 or 2g/d.

The effects of temperature, dietary energy content, initial body lipid content and the value of CEE_m on performance (rate of lay, egg weight and egg output) over the final four weeks of each trial are shown in Table 10.16. With a CEE_m of 1.0 and an initial body lipid content of 7%, rate of lay, and hence egg output, decreased on all energy levels with environmental temperature. On the lowest ME feed the difference in rate of lay was 9.4 eggs/100 bird d (and 6.3g egg output/bird d), reducing to 1.0 egg and 0.6g/bird d on the highest ME feed. The rate of decline in egg production and output was less when the initial lipid content was 21%, whilst the means of these variables were always higher at all energy levels at the higher initial lipid content.

With a CEE_m of 8.0, production remained essentially the same at the highest temperature as when the coefficient was 1.0, but rate of lay and egg output were more severely affected by a decrease in temperature than at the lower CEE_m value. The responses in egg output to environmental temperature, on the four energy levels, are illustrated in Figure 10.7. Comparative decreases in production on the higher energy feeds were similar for both CEE_m coefficients.

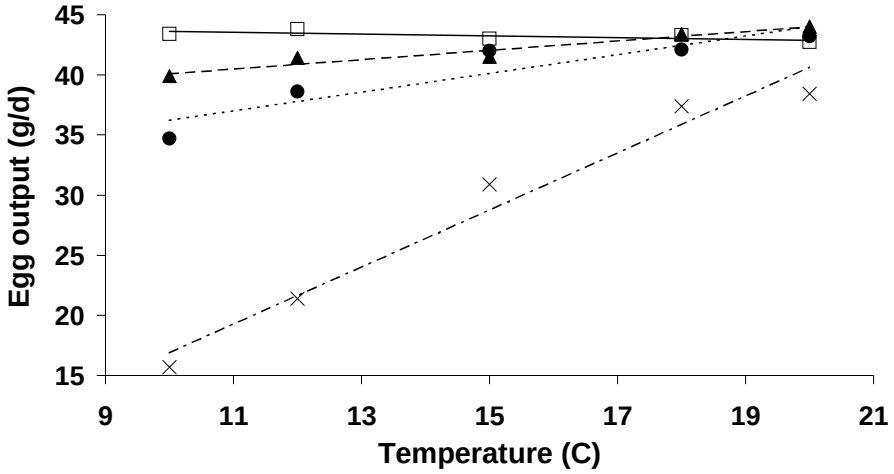


Figure 10.7 Observed relationship between egg output (g/d) and temperature (°C) using a CEE_m of 8.0kJ AME/d. kg W. ^oC and an initial body lipid content of 21% at four daily energy allocations (□ = 12.5; ▲ = 11.5; ● = 10.5; x = 9.5MJ ME/kg) with fitted equations (solid line = 12.5; dotted line = 11.5; dashed line =10.5; dotted and dashed line = 9.5). The slopes of the four regressions were -0.07 (±0.33), 0.39 (±1.66), 0.78 (±3.49) and 2.38 (±9.96) respectively.

Egg weight was unaffected by temperature, dietary energy content, initial body lipid content or value of CEE_m except for a linear increase of 0.4g/egg on the lowest energy feed, when initial body lipid content was 7% and CEE_m was 8.0. In this isolated case, egg weight increased as the environmental temperature decreased.

The mean daily changes in body weight and body lipid content, as influenced by dietary energy allocation, environmental temperature, initial body lipid content and two values of the coefficient CEE_m, over the final four weeks of each trial, are given in Table 10.17. The changes in body weight were similar to changes in body lipid content in all cases. Birds lost more weight on the lower energy feeds when the initial lipid content was 21% than at the lower content, and to a greater extent with CEE_m = 8.0 than 1.0. At the highest energy level, weight gain was the similar for both initial lipid contents at both CEE_m values, but with higher gains at low temperatures when CEE_m was 1.0 than 8.0.

Table 10.15 Mean responses in desired and actual feed intakes to temperature (T) and dietary energy allocation (ME) over the final four weeks of the ten-week simulation period, according to the coefficient of energy requirement for maintenance (CEE_m, kJ).

CEE_m=1.0	Desired feed intake (g)								Actual feed intake (g)							
ME (MJ/kg)	9.5		10.5		11.5		12.5		9.5		10.5		11.5		12.5	
	Initial body lipid (%)															
T (ºC)	7	21	7	21	7	21	7	21	7	21	7	21	7	21	7	21
10	215	169	167	159	159	159	159	159	160	158	158	156	156	156	156	157
12	209	170	164	159	158	158	159	159	159	158	158	156	156	156	156	156
15	206	169	163	159	159	159	159	159	159	158	157	156	156	157	155	156
18	201	166	162	159	159	159	158	159	159	158	158	156	156	156	156	156
20	197	166	162	159	159	159	159	159	159	158	157	156	156	156	156	156

CEE_m=8.0	Desired feed intake (g)								Actual feed intake (g)							
ME (MJ/kg)	9.5		10.5		11.5		12.5		9.5		10.5		11.5		12.5	
	Initial body lipid (%)															
T (ºC)	7	21	7	21	7	21	7	21	7	21	7	21	7	21	7	21
10	283	239	216	172	167	159	159	159	160	159	159	158	157	156	157	156
12	273	219	198	164	164	158	159	158	160	159	159	157	157	156	157	156
15	246	189	180	160	161	158	158	159	160	158	158	157	157	155	156	156
18	217	173	165	159	159	158	159	158	159	159	157	156	156	155	156	156
20	198	166	162	159	159	159	159	158	159	158	157	156	156	156	156	156

Table 10.16 Mean responses in rate of lay, egg weight and egg output to temperature (T) and dietary energy allocation (ME) over the final four weeks of the ten-week simulation period, according to the coefficient of energy requirement for maintenance (CEE_m, kJ).

CEE_m=1.0	Rate of lay (eggs/100 bird d)								Egg weight (g)							
ME (MJ/kg)	9.5		10.5		11.5		12.5		9.5		10.5		11.5		12.5	
	Initial body lipid (%)															
T (ºC)	7	21	7	21	7	21	7	21	7	21	7	21	7	21	7	21
10	28.5	56.8	55.1	65.0	62.0	64.8	62.8	66.2	67.6	67.0	67.3	66.9	67.0	67.4	67.2	67.0
12	32.4	57.4	56.9	63.7	62.5	63.8	63.2	66.6	67.1	67.3	66.8	67.3	67.1	67.1	67.1	67.0
15	34.4	58.5	57.7	63.9	63.6	65.7	62.3	64.1	66.9	67.1	67.2	67.2	67.0	67.4	67.1	67.3
18	35.8	58.6	57.8	64.8	63.0	64.8	64.1	65.2	67.6	67.0	67.3	66.9	67.3	67.3	67.2	66.6
20	37.9	60.2	60.4	66.0	64.5	65.3	63.8	64.7	67.5	66.9	66.8	67.1	66.9	67.2	67.0	67.2

CEE_m=1.0	Egg output (g/ bird d)							
ME (MJ/kg)	9.5		10.5		11.5		12.5	
	Initial body lipid (%)							
T (ºC)	7	21	7	21	7	21	7	21
10	19.3	38.0	38.0	43.5	41.5	43.7	42.2	44.4
12	21.7	38.7	38.1	42.9	41.9	42.8	42.4	44.6
15	23.0	39.2	38.8	42.9	42.6	44.3	41.8	43.2
18	24.2	39.2	38.9	43.4	42.4	43.6	43.1	43.5
20	25.6	40.2	40.3	44.3	43.2	43.9	42.8	43.5

Table 10.16 (continued) Mean responses in rate of lay, egg weight and egg output to temperature (T), dietary energy allocation (ME) and body lipid content (%) over the final four weeks of the ten-week simulation period, according to the coefficient of energy requirement for maintenance (CEE_m, kJ AME/d. kg W. ^oC).

CEE_m=8.0	Rate of lay (eggs/100 bird d)								Egg weight (g)							
ME (MJ/kg)	9.5		10.5		11.5		12.5		9.5		10.5		11.5		12.5	
	Initial body lipid (%)															
T (^oC)	7	21	7	21	7	21	7	21	7	21	7	21	7	21	7	21
10	3.3	23.4	25.1	51.5	54.8	59.8	63.3	64.8	67.2	67.1	66.7	67.3	66.9	66.8	67.1	67.0
12	6.7	32.1	34.1	57.6	57.7	62.1	63.6	65.6	67.2	66.8	67.1	67.1	66.8	66.7	67.5	66.8
15	14.6	46.3	46.5	62.8	61.3	62.2	62.7	64.3	67.0	66.8	67.4	66.9	67.5	66.7	66.9	66.9
18	28.5	55.9	56.1	63.1	62.2	65.1	63.1	64.6	66.9	67.0	66.7	66.8	66.9	66.6	67.1	67.1
20	37.4	57.9	59.3	64.4	65.2	65.6	65.2	64.0	66.8	66.3	67.1	67.0	67.0	67.1	67.1	66.8

CEE_m=8.0	Egg output (g/ bird d)							
ME (MJ/kg)	9.5		10.5		11.5		12.5	
	Initial body lipid (%)							
T (^oC)	7	21	7	21	7	21	7	21
10	2.2	15.7	16.7	34.7	36.7	39.9	42.5	43.4
12	4.5	21.4	22.9	38.6	38.5	41.4	43.0	43.8
15	9.8	30.9	31.4	42.0	41.4	41.5	42.0	43.0
18	19.0	37.4	37.4	42.1	41.6	43.4	42.3	43.3
20	25.0	38.4	39.8	43.2	43.7	44.0	43.8	42.7

Table 10.17 Mean responses in body weight, body weight gain and body lipid deposition to temperature (T), dietary energy allocation (ME) and body lipid content (%) over the final four weeks of the ten-week simulation period, according to the coefficient of energy requirement for maintenance (CEE_m, kJ AME/d. kg W. ^oC).

CEE_m=8.0	Body weight gain (g/bird d)								Body lipid content (g/kg)							
ME (MJ/kg)	9.5		10.5		11.5		12.5		9.5		10.5		11.5		12.5	
	Initial body lipid (%)															
T (^oC)	7	21	7	21	7	21	7	21	7	21	7	21	7	21	7	21
10	0.1	-2.4	0.5	-1.5	1.5	1.0	3.8	3.4	114.0	149.5	120.0	192.8	129.3	232.3	155.0	268.5
12	-0.2	-2.4	0.4	-1.2	1.5	1.2	3.7	3.5	114.8	158.8	119.3	191.3	130.3	231.3	154.0	266.8
15	-0.3	-2.2	0.5	-1.2	1.5	1.4	3.9	3.8	115.0	152.0	120.0	199.3	130.8	232.3	155.3	272.0
18	-0.1	-2.6	0.6	-1.2	1.8	1.4	4.2	4.0	116.0	155.8	121.0	191.8	133.5	239.0	155.5	270.0
20	-0.2	-2.3	0.1	-1.2	1.3	1.3	4.0	3.9	115.0	159.3	118.5	199.3	132.0	234.8	156.5	272.0

CEE_m=8.0	Body weight gain (g/bird d)								Body lipid content (g/kg)							
ME (MJ/kg)	9.5		10.5		11.5		12.5		9.5		10.5		11.5		12.5	
	Initial body lipid (%)															
T (^oC)	7	21	7	21	7	21	7	21	7	21	7	21	7	21	7	21
10	0.0	-1.2	-0.2	-2.1	-0.1	-1.7	0.6	0.5	110.8	120.0	113.0	140.3	119.0	180.3	125.0	222.2
12	0.0	-1.7	0.1	-2.4	0.2	-1.2	1.4	1.4	111.0	126.0	114.0	149.0	118.0	194.3	130.0	233.0
15	0.1	-2.0	0.1	-2.4	0.8	0.0	2.4	2.6	112.0	135.5	114.0	164.5	123.0	213.3	140.0	246.8
18	-0.1	-2.4	0.2	-1.5	1.4	0.8	3.5	3.3	113.0	145.0	118.0	185.0	129.8	224.5	152.0	262.8
20	-0.1	-2.4	0.3	-1.2	1.7	1.3	4.1	3.8	116.0	154.8	122.0	196.3	130.5	237.3	156.5	272.0

10.4.3 Discussion

The objective of these four simulated trials was to compare the responses of broiler breeders to dietary energy allocation over a range of environmental temperatures with those described in the chamber trial in Chapter 7. Before the exercise was attempted it had been ascertained that the body lipid content of breeders at the start of such a trial would have a bearing on the response to feeds differing in ME content, so this initial condition was introduced into the exercise, as was the coefficient of energy required for maintenance, CEE_m, which had been determined in Chapter 7 to be 1 kJ AME/d. kg W. ^oC.

The feeds used in the exercise were designed to provide adequate quantities of the essential amino acids when fed at 160g/bird d, and as all feeds contained the same amounts of these amino acids, the responses measured in rate of lay and egg output would have been the result of differences in dietary energy intake, as only the energy contents of the feeds were made to vary between dietary treatments.

In Chapter 7 it was shown that breeders utilise body lipid as an energy source when the feed energy is inadequate to meet the requirements for maintenance and production, and in this exercise the additional body lipid stores (21 *vs.* 7%) reduced the need of the birds to increase their DFI as the environmental temperature was reduced. Similarly, the lower CEE_m coefficient reduced the need for DFI to increase at the lowest temperatures. However, because birds were allocated only 160g feed/d, birds were unable to meet their requirement for energy on the lowest energy feeds, the consequence of which is that egg production decreased to a lesser extent at these temperatures when the initial body lipid content was high, and CEE_m was low.

Rate of lay and egg output declined linearly in each trial throughout the range of temperatures used when hens were fed 11.5, 10.5 and 9.5MJ /kg, as was described in Chapter 7, indicating that the birds were using increasing amounts of dietary energy for maintenance as the temperature declined, leaving less available for production, while birds fed 12.5MJ/kg (2000kJ/d) maintained their performance at all temperatures. The decline in performance was greater on the low ME feeds. However, the rate of decline in performance using a CEE_m of 1 was lower compared to the results found in the chamber trial described in Chapter 7. This could be explained by the lower potential performance

simulated by the model. If the potential performance were higher, then the requirement for energy and the desired feed intake would be higher, and the effect of the low temperature would be greater. Thus, an improvement to the model would be to find the set of constants ICL A, B, C and D that represents a peak of production around 80-85% or enabling the user to choose the peak rate of lay and the rate of decline after peak.

The reduced rate of laying was accompanied by a decrease in body lipid content but with no change in egg weight, which is different compared to the results of the chamber trial. The response in egg weight is acceptable, as protein was not limiting. The response in body lipid content may be explained by the amount of lipid reserve available to the birds. The body protein and lipid deposition, or utilisation, leading to a change in body weight, is regarded as being a consequence of the nutrients consumed. Dietary protein consumed in excess of requirement, resulting from the lower production, is deaminated and converted to body lipid, but because the birds use lipid reserve as an energy source, there is no increase in body lipid content at the lower temperatures. The rate of lipid utilisation as an energy source was greater with the higher initial body lipid contents.

The results of these trials also show that at temperatures between 15 and 20ºC broiler breeders are capable of maintaining egg production on an energy intake as low as 1760kJ AME/d, as long as sufficient body lipid reserves are present. These lipid reserves would eventually become depleted, if the birds were maintained at these low temperatures. At energy intakes lower than 1760kJ, laying performance was depressed, as in the trial reported in Chapter 7, with a concomitant loss in body weight.

The results of simulations conducted here are, not surprisingly, in line with the theory incorporated into the Breeder Model, and in general are similar to those obtained from the trial reported in Chapter 7. Differences between the simulated and actual results provide opportunities for improving the accuracy of the Model through modifications in the theory. These modifications would need to include the ability to alter the potential laying performance of the hens, the choice of the most appropriate value of CEE_m, and the maximum daily rate at which body lipid may be used as an energy source.

GENERAL DISCUSSION

In this PhD project, different approaches were used to increase the knowledge of the physiological responses of broiler breeders to nutrient intake and environment. Data were obtained by performing a comprehensive review of the available literature on nutrient requirements of breeders during the laying period, through the development and testing of a model designed to simulate the response of broiler breeder hens to daily intakes of amino acids and energy, and by carrying out targeted experiments, designed to provide specific answers to questions raised during the modelling process.

The studies presented in Chapters 3 and 4 assessed the question regarding the determination of maintenance requirements, as outlined in Chapters 1 and 2. Emmans and Fisher (1986) and Fisher (1998) indicated that maintenance requirements for amino acids would be more accurately estimated if based on the protein content of the body than on body weight, so it was important to know how the body composition of broiler breeders changed during the laying period before calculating the maintenance requirement for each essential amino acid. The weight of body protein of 200-210 g/kg remained relatively stable throughout the laying period, so this value was used as the basis for calculating the maintenance requirements of broiler breeder hens at sexual maturity, which is in agreement with most of the previous reports on this subject. In these studies, it was also demonstrated that it should not be necessary to assume that protein growth is obligatory when determining nutrient requirements of broiler breeder hens, but that the change in feather weight is of such a magnitude that this should be considered when calculating amino acid requirements of these birds during the laying period, and that the improved method for determining maintenance requirements for amino acids in mature birds, suggested by Gous *et al*. (1984), has proved to be satisfactory for this purpose.

The study presented in Chapter 5 elucidated the question regarding the use of synthetic amino acids by restricted broiler breeders, as prior information had been available only for birds and animals fed at least twice-daily or *ad libitum*. The availability of synthetic amino acids permits nutritionists to comply better with constraints in linear programming (least cost formulation) when formulating feeds for broiler breeders, by lowering the cost of the feed and contributing to a reduced nitrogen excretion. However, the study indicated that synthetic amino acids should not be used in feeds for broiler breeders fed once or twice a

day as they appear to be utilised less efficiently, resulting in a reduced rate of lay compared with birds fed intact protein. It is likely that these amino acids are rapidly absorbed and metabolised before the intact protein has been digested and absorbed, resulting in an unbalanced mixture being available for incorporation into egg protein.

The studies presented in Chapters 6 and 7 focused on the determination of energy requirements, related specifically to the use of excess body lipid reserves as a means of maintaining laying performance. As outlined in Chapter 2, fattened broilers can make use of excess body lipid reserves providing that their protein intake is sufficiently high to allow this (Gous *et al*, 1992), and now evidence has been presented to show that broiler breeders are capable of maintaining egg production at an energy intake that is much lower than is recommended, by making use of their body lipid reserves as an energy source. A minimum amount of body lipid, of around 110g/kg body weight, is needed to maintain the birds (Wellock *et al*., 2003), which would provide the lower limit when calculating the extent to which lipid reserves are available. It was also demonstrated in Chapter 7 that 1.0kJ AME/kg W. ºC should be added to the maintenance requirement of broiler breeders to account for the additional energy required for cold thermogenesis at environmental temperatures below about 18ºC.

The Breeder Model functions and the processes and algorithms employed are described in Chapter 9. The model was initially developed in Microsoft Excel 2000 for one bird over a seven day period, and later it was rewritten in DELPHI C++ to simulate any number of birds over a defined period of up to 30 weeks in lay. The programming language DELPHI was used to facilitate model operation, especially speed, through a user-friendly interface. The Breeder Model is available on the CD at the back of the thesis, together with a description of how to load the programme. This version will be available to you for a one-year period. For any further information, please contact the programmers through the EFG Software web site (www.efgsoftware.net).

Modelling the nutrient partitioning of broiler breeders between maintenance, yolk and albumen production and obligatory growth of body tissues is complex, but an essential element in predicting the response of these birds to nutrient supply. In the present model this was simplified by assuming that there was no obligatory growth of body protein or lipid, and that changes in body lipid weight were a consequence of the way in which birds

were fed. The Reading Model (Fisher *et al*., 1973) is a partitioning model commonly used to determine optimum economic amino acid intakes of a population of laying hens, but being an empirical model, suffers from a number of shortcomings. Mechanistic models, such as the Breeder Model developed here, are better able to account for the many interactions and interdependencies between nutrient intake, environmental conditions, and performance, thereby prioritising the physiological response of breeders to nutrient intake. Some progress has been made in modelling the laying patterns of commercial laying hens (Johnston, 2004) and this same approach has been applied here to broiler breeders (Chapter 8), reflecting realistic egg and component weights for breeders of a given age and over the laying period, which may be used with confidence to predict the nutrient requirements of individual hens of a given strain. A necessary modification to this part of the model is that the ICL equation needs to be adjustable to obtain a peak production around 80-85%. The model developed here (Chapter 9) evaluates the effects of genotype, environment and feed composition and allocation on both the requirements and performance of a broiler breeder hen, and is the first comprehensive computerised, mechanistic, stochastic and dynamic breeder model of its kind to have been developed. It is capable of simulating the daily requirements for maintenance and egg production using model parameters such as age at maturity, initial live weight, initial body protein and lipid contents, mean clutch length, daily temperature, number of days over which the feed is to be offered, protein and amino acid contents of the feed, dietary effective energy and daily food allocation. Outputs provide information on a daily and weekly basis for an individual and a flock of breeders, with respect to potential and actual performance including yolk, albumen and shell weights, body lipid deposition and the current state of body protein and lipid. Also simulated are live weight, proportions of body protein and lipid, minimum body lipid weight, amount of body lipid reserves, egg weight, limiting amino acid in the feed, actual food consumption, heat production, income, expenditure and margin. The model simulates the above for an individual, but makes provision for the generation of a population of hens, using means and standard deviations of most of the parameters involved in describing an individual, and then simulates the response of each individual after which it calculates the mean response of the individuals making up the population. This is a more accurate method of simulating a population response than making use of empirical equations to predict responses.

The model has not been comprehensively tested or verified, but preliminary tests indicate that a good degree of conformity to observed results is obtained in the practical range of nutrient and environmental inputs. Before making use of the model as a means of making recommendations for feeds and feeding programmes, the model needs to be tested further. While the general structure of this model seems robust in its calculations, a number of improvements still need to be made. These are listed below.

An improvement to the model would be to predict the age at sexual maturity using the model developed by Lewis *et al.* (2007, in press), which takes account of the lighting programme used during rearing, and the 20-week body weight of the birds. At present, the user inputs a mean age at sexual maturity, which is not as satisfactory, but is nevertheless acceptable as a means of specifying this variable.

Many physiological processes are involved in egg production, some of which have not yet been fully described, as suggested by Johnston (2004) for laying hens. One of the most uncertain elements in the model concerns the controversy surrounding whether or not yolk production continues after the bird lays the last egg of a clutch. If yolk production does continue, the question is how many days does the yolk continue to be deposited, leading to an additional question of what the rate of production is for each ovum of a sequence? These elements merit further consideration and study in order to improve the accuracy in calculating nutrient requirements for yolk production.

The most difficult theoretical problem in the approach used here to calculate actual feed intake arises from variations between birds in feed intake. Access to the food trough, when a limited amount of food is supplied, is a function of the pecking order or position in the hierarchy of each hen that may prevent birds from accessing equal quantities of food each day. An aggressiveness value is attributed to each hen in order to alleviate this problem, which constitutes real progress in terms of modelling variation in feed intake in breeders, but this method may still lead to over- or under-estimation of the correct dietary levels of nutrients in case the desired feed intake is lesser. It would be essential to incorporate a variance/covariance matrix into the model to investigate the consequences of correlations between aggressiveness and potential rate of laying, for example.

There is still much that is not understood about the physiological mechanisms involved in regulation of food intake in laying hens. At high concentrations of the limiting amino acid, when adequate amounts of ME are present in the food, food intake is predicted to decline, but in practice this does not appear to happen. Conversely, when the limiting amino acid is severely deficient in the feed, in practice food intake decreases significantly (Bowmaker and Gous, 1991; Goddard, 1997), yet the model predicts that desired food intake will increase under these circumstances. The former case may be explained by essential nutrients other than amino acids, such as trace minerals or vitamins, becoming limiting and hence increasing the DFI. The present model considers amino acids and energy only, and may need to address the requirements for other nutrients in the future, if such anomalies are to be prevented. It is far more difficult to think of a mechanism that will reduce food intake on a reasonably well-balanced feed that is highly deficient in all amino acids. This decrease in food intake could not be explained by invoking the theory that unbalanced feeds cause a reduction in food intake (Harper *et al*., 1970) as these feeds are not severely unbalanced. No attempt was made in the model to balance heat production and loss to the environment, but this is unlikely to be lead to a solution of this problem. It would perhaps be fruitful to consider that in such feeds it is impossible to sustain reproductive performance, and hence the bird's requirements for egg production are reduced, thereby reducing DFI.

The interaction with the environment is a particularly difficult area to describe and to quantify, and has not been adequately quantified here. The effect of cold thermogenesis on maintenance energy requirements has been addressed, but not the effect of high temperatures on nutrient requirements and performance. In the broiler growth model of Emmans (1981) one of the most important criteria for constraining the food intake of broilers is the inability of birds to lose sufficient heat to the environment. Heat is generated by the processes of maintenance, feeding, feed processing, growth and excretion (Emmans, 1994), these being essentially the same in the laying hen, except that growth processes are replaced with the process of yolk and albumen production; the main difference being that hens package this energy in the form of an egg and then avoid this, so there is no need to store the products of this process. This has implications when balancing heat production and heat loss, which will have an effect on the constrained feed intake. Many unanswered questions still remain and need to be addressed for a more complete understanding of the

interaction between the breeder hen and its environment. Until such time as these effects are properly quantified environmental effects will be inaccurately estimated in the model.

While environmental temperature has a significant effect on maintenance energy requirement, the feather condition of the hen has also been shown to influence the extent to which the bird responds to environmental temperature (Neme *et al*., 2005). However, the effect of feather cover on ME requirement and intake may not be identical for all environmental temperatures. Several studies have shown that feathering affects heat production. O'Neil *et al*. (1971) found that the energy for maintenance in feathered roosters declined by 8.4 kJ/kg/day/ºC, while in non-feathered roosters the rate of decline was 26.3 kJ/kg/day/ºC between 15 to 34ºC. Studies by Lee *et al*. (1983) showed higher heat production (514J/kg $W^{0.75}$/min) in poorly-feathered chicken compared to normally feathered (484J/kg $W^{0.75}$/min). Peguri and Coon (1993) reported a significant interaction between feather cover and temperature on maintenance ME requirement. Feather loss is not a well-defined term, and is difficult to measure in a flock. Also, it is not known whether the feather loss from different parts of the body should be valued the same. Further study is needed in this regard before introducing a feather correction factor when estimating the calorie needs of a flock for maintenance. However, as discussed in Chapter 3, the change in feather weight is of such a magnitude that this should be considered when calculating amino acid requirements of these birds during the laying period, knowing the amount of each amino acid needed for 1kg of feather protein retained.

An aspects of the non-thermal environment that has been largely ignored is the disease aspect, which is an area where modelling could be further pursued. Two approaches to the effect of disease challenges on food intake have been proposed recently, both dealing with pigs: Wellock *et al*. (2006) reduced the rate of maturing parameter (B) in the Gompertz growth equation to simulate the resultant down-regulation of lean tissue growth brought about by a disease challenge, and Sandberg *et al*. (2006) predicted the effects of sub-clinical pathogen challenges of different doses and virulence on the relative food intake of animals by modelling the rate of reduction in food intake as a disease challenge progresses through the animal, enabling actual food intake to be predicted from the relative food intake and animal state. It may be worthwhile in the future to introduce such an option in the breeder model.

Despite the fact that a number of improvements still need to be made, the current Breeder Model may be useful to the poultry community. As a teaching aid to poultry science students, it may be used to illustrate the complexity of interactions between genotype, feed and environment, and also to draw attention to the extent of variation within a population. Broiler breeder producers may change various inputs and see the responses of their birds to their specific environment. The model may assist nutritionists to demonstrate potential interactions between model inputs and nutrient partitioning in order to optimise nutrient requirements of specific genotypes. It has the potential to be used as an optimisation tool to assist nutritionists to feed broiler breeders more efficiently by: determining the optimum ratio between amino acids and energy; when (or whether) to switch from one feed composition to the next; what the optimum combination of nutrient density and feed allocation would be for different ingredient prices, etc. This simulation model may serve many purposes, including the development of ideas, interpretation of real life, prediction of responses, transfer of information, scrutinisation of existing knowledge, and formulation of experimental programmes.

In practice, model building is an iterative process and, in this sense, model building can never been completed (Pomar *et al*., 1991). However, in spite of all the shortcomings of the model described in this thesis and the suggestions for further improvements, it is believed that the Breeder Model provides a good base for modelling the nutrient requirements and performance of broiler breeders during the laying period.

ABSTRACT

Because the nutrient requirements of broiler breeders are dependent on the potential performance and state of the birds, which change with age, and on the environment in which the birds are kept, it is difficult to determine the composition and amount of feed to be allocated daily that will maximise returns on the varied broiler breeder farms on which the feeds are to be used.

Factors to be considered when optimising the daily feed allocation for a flock include, among others, the potential egg output of individuals at a time and over time, differences between genotypes in the amount of excess energy that may be stored as body lipid and utilised as an energy source, possible constraints placed on both food intake and egg output by the environment, and the aggressiveness of each bird at the feed trough. In attempting to model the performance of broiler breeders during the laying period it became clear that certain critical information was lacking on the response of broiler breeders to essential nutrients, under both ideal and constraining conditions. The first part of this thesis describes a series of experiments that were designed to obtain such information.

A computerised, mechanistic, stochastic and dynamic broiler breeder model, which evaluates the effects of genotype, environment and feed on both the requirements and performance of broiler breeders, is then described. Mean age at first egg, following a constant photoperiod or a single change in photoperiod from 8 to 16h is predicted from photoperiod, body weight at 20 weeks of age or age at transfer as suggested by Lewis (in press b). Egg production is predicted for a full laying period, including random occurrences of double-yolked and soft-shelled eggs and internal ovulations, using the population model of egg production developed for laying hens (Johnston, 2004) and adapted for broiler breeders. Yolk weight is predicted from hen age using an empirical equation appropriate for the genotype. Allometric functions are used to predict albumen weight from yolk weight, and shell weight from the weight of the egg contents. Egg weight is given by the sum of the three components. The effects of genotype, environment and feed on both the requirements and performance of broiler breeders during the laying period are simulated, and the over- and undersupply of nutrients are both addressed. The model will eventually prove useful to nutritionists wishing to optimise the feeding of flocks of broiler breeders during lay.

REFERENCES

AHN, D.U., KIM, S.M. & SHU, H. (1997) Effect of egg size and strain and age of hens on the solids content of chicken eggs. *Poultry Science*, **76**: 914-919.

AOAC (1975) Official methods of analysis (10th ed.). Association of Official Analytical Chemists, Inc., Arlington, Washington, USA.

ANDERSON, G.B.; BOLTON, W.; JONES, R.M. & DRAPER, M.H. (1978) Effect of age of the laying hen on the composition of the egg. *British Poultry Science*, **19**: 741-745.

ATTIA, Y.A., BURKE, W.H., YAMANI, K.A. & JENSEN, L.S. (1995) Daily energy allotments and performance of broiler breeders. 2. Females. *Poultry Science*, **74**: 261-270.

ARC (1975) *The nutrients requirements of farm livestock, poultry*, 2. ed. (Agricultural Research Council, London).

BACH-KNUDSEN, K.E. & JORGENSEN, H. (1986). Use of synthetic amino acids in pig and poultry diets. In: *Recent Advances in Animal Nutrition*, (Eds) HARESIGN, W. & COLE, D.J.A., Butterworths, London. pp. 215-225.

BAKER, D.H. & IZQUIERDO, O.A. (1985). Effect of meal frequency and spaced crystalline lysine ingestion on the utilization of dietary lysine by chickens. *Nutrition Research*, **5**: 1103-1112.

BALNAVE, D., FARRELL, D.J. & CUMMING, R.B. (1978a) The minimum metabolizable energy requirements of laying hens. *World's Poultry Science Journal*, **34**: 149-154.

BALNAVE, D., FARRELL, D.J., WOLFENDEN, J.B. & CUMMING, R.B. (1978b) The effect of ovariectomy on liver metabolism and maintenance energy requirement of hens. *British Poultry Science*, **19**: 583-590.

BATTERHAM, E.S. (1974) The effect of frequency of feeding on the utilization of free lysine by growing pigs. *British Journal of Nutrition*, **31**: 237-242.

BATTERHAM, E.S. & O'NEILL, G.H. (1978) The effect of frequency of feeding on the response by growing pigs to supplements of free lysine. *British Journal of Nutrition*, **39**: 265-270.

BATTERHAM, E.S. & MURISON, R.D. (1981) Utilisation of free lysine by growing pigs. *British Journal of Nutrition*, **46**: 87-92.

BENNETT, C.D. & LEESON, S. (1990) Body composition of the broiler breeder pullet. *Poultry Science*, **69**: 715-720.

BLACK, J.L. DAVIES, G.T. & FLEMMING, J.F. (1993) Role of computer simulation in the application of knowledge to animal industries. *Australian Journal of Agricultural Research,* **44**: 541-555.

BLACK, J.L., FLEMMING, J.F. & DAVIES, G.T. (1989) Role of computer simulation in the application of knowledge to animal industries. *Proceeding of the 50th Minnesota Nutrition Conference*. pp 5-18.

BLACK, J.L. (1995) The evolution of animal growth models. In: *Modelling growth in the pig,* (Eds) MOUGHAN, P.J., VERSTEGEN, M.W.A. & VISSER-REYNEVELD, M.I. Wageningen Pers, Wageningen, The Netherlands. pp 3-9.

BLAIR, R., McCOWAN, M.M. & BOLTON, W. (1976) Effects of food regulation during the growing and laying stages on the productivity of broiler breeders. *British Poultry Science*, **17**: 215-223.

BLAXTER, K.L. (1989) *Energy metabolism in animal and man*. Cambridge. 336p.

BORNSTEIN, S., HURWITZ, S. & LEV, Y. (1979) The amino acid and energy requirements of broiler breeder hens. *Poultry Science*, **58**: 104-116.

BOORMAN, K.N. & BURGESS, A.D. (1986) Responses to amino acids. In: *Nutrient Requirements of Poultry and Nutritional Research*, (Eds) FISHER, C. & BOORMAN, K.N., Butterworth, Oxford. pp 99-123.

BURNHAM, D. & GOUS, R.M. (1992) Isoleucine requirements of the chicken: requirement for maintenance. *British Poultry Science*, **33**: 59-69.

BOWMAKER, J.E. (1986) The nutrition of the female broiler breeder. MSc thesis, University of Natal, South Africa.

BOWMAKER, J.E. & GOUS, R.M. (1989) A quantification of reproductive changes and nutrient requirements of broiler breeder pullets at sexual maturity. *British Poultry Science*, **30**: 663-675.

BOWMAKER, J.E. & GOUS, R.M. (1991) The response of broiler breeder hens to dietary lysine and methionine. *British Poultry Science,* **32**: 1069-1088.

BROCKINGTON, N.R. (1979) *Computer modelling in Agriculture*. Clarendon Press, Oxford.

BURNHAM, D. & GOUS, R.M. (1992) Isoleucine requirements of the chicken: requirement for maintenance. *British Poultry Science*, **33**: 59-69.

CAVE, N.A.G., VAN WAMBEKE, F. & DE GROOTE, G. (1990) Protein and sulfur amino acid requirements of broiler breeder hens. 1. Maintenance. *Archiv Geflugelkunde*, **54**: 115-119.

CHANDLER, N.J. (2005) Feather meal: its nutritional value and use in diary and beef rations.http://www.engormix.com/feather_meal_its_nutritional_e_articles_79_GDL.htm

CHWALIBOG, A. (1992) Factorial estimation of energy requirements for egg production. *Poultry Science,* **71**: 509-515.

CHWALIBOG, A. & BALDWIN, R.L. (1995) Systems to predict the energy and protein requirements of laying fowl. *World's Poultry Science Journal,* **51**: 187-196.

CIACCIARIELLO, M. & GOUS, R.M. (2005) To what extent can the age at sexual maturity of broiler breeders be reduced? *South African Journal of Animal Science,* **35:** 73-82.

CLARK, F.A., GOUS, R.M. & MORRIS, T.R. (1982) Response of broilers to well-balanced protein mixtures. *British Poultry Science*, **23**: 433-446.

COBB (2005) Cobb 500 Production Manual.

COOK, H., FRANK, G.R., GIESTING, D.W. & EASTER, R.A. (1983) The influence of meal frequency and lysine supplementation of a low protein diet on nitrogen retention of growing pigs. *Journal of Animal Science*, **57** (supp. 1):240 – 241 (Abstr.).

COON, G. (2004). The ideal amino acid requirements and profile for broilers, layers and broiler breeders. *American Soybean Association Technical Report,* Casablanca, Morocco.

COTTERILL, O.J.; STEPHENSON, A.B. & FUNK, E.M. (1962) Factors affecting the yield of egg products from shell eggs. Proceeding, 12th World's Poultry Congress, Sydney, 443-447 (as cited by Fletcher *et al.* (1981)).

CURNOW, R.N. (1993) A smooth population response curve based on an abrupt threshold and plateau model for individuals. *Biometrics*, **29**: 1-10.

DAVIS, R.H., HASSAN, O.E. M. & SYKES, A.H. (1972) The adaptation of energy utilization in the laying hen to warm and cool ambient temperature. *Journal of Agriculture Science,* **79**: 363-369.

DE GROOTE, G. (1974) Utilisation of metabolizable energy. In: *Energy requirements of poultry*, (Eds) MORRIS, T. R.; FREEMAN, B. M. Proceedings of Poultry Science, Edinburgh, pp. 113-133.

DENNISON, C. & GOUS, R.M. (1980) Amino acid concentrations in some South African feed ingredients. *South African Journal of Animal Science*, **10**: 9-18.

DOZIER, W.A. (2003) Nutritional considerations for broiler breeders. *Poultry Digest Online* Volume **4**, Number **2**.

EDWARDS, H.M.III, BAKER, D.H., FERNANDEZ, S.R. & PARSONS, C.M. (1997) Maintenance threonine requirement and efficiency of its use for accretion of whole-body threonine and protein in young chicks. *British Journal of Nutrition*, **78**: 111-119.

EDWARDS, H.M.III, FERNANDEZ S. R. & BAKER, D. H (1999) Maintenance lysine requirement and efficiency of using lysine for accretion of whole-body lysine and protein in young chicks. *Poultry Science*, **78**: 1412-1417.

EMMANS, G. C. (1974) The effect of temperature on performance of laying hens. In: *Energy requirements of poultry*. (Eds) MORRIS, T. R.; FREEMAN, B. M. Proceedings of Poultry Science, Edinburgh, pp. 79-90.

EMMANS, G.C. (1981) Computer simulation in poultry nutrition. In: *3rd European Symposium on Poultry Nutrition*. Peebles, Scotland.

EMMANS, G.C. & FISHER, C. (1986) Problems in nutritional theory. In: *Nutrient requirements of poultry and nutritional research*, (Eds) FISHER, C. & BOORMAN, K.N., Butterworths, London. pp 9-40.

EMMANS, G.C. (1987) The genetic variables and efficiency constants. International Poultry Breeder's Conference, Ayr.

EMMANS, G.C. & OLDHAM, J.D. (1988) Modelling of growth and nutrition in different species. In: *Modelling of Livestock Production Systems*. (Eds) KARVER, S. & VAN ARENDONK, J.A.M., Kluwer Academic Publishers, Dordrecht. pp 13-21.

EMMANS, G.C. (1989) The growth of turkeys. In: *Recent Advances in Turkey Science*. (Eds) NIXEY, C. & GREY, T.C., Butterworths, London. pp 135-166.

EMMANS, G.C. (1994) Effective energy: a concept of energy utilization applied across species. *British Journal of Nutrition*, **71**: 801-821.

ETCHES, R.J. & SCHOCH, J.P. (1984) A mathematical representation of the ovulatory cycle of the domestic hen. *British Poultry Science*, **25**: 65-76.

FERGUSSON, N.S. (1996) A description of the genotype of pigs using simulation modelling. *PhD Thesis*, University of Natal, South Africa.

FERGUSON, N.S., GATES, R.S., TARABA, J.L., CANTOR, A.H. PESCATORE, A.J., STRAW, M.L., FORD, M.J. & BURNHAM, D.J. (1998) The effect of dietary

protein and phosphorus on ammonia concnetration and litter composition in broilers. Poultry Science **77**: 1085 – 1093.

FISHER, C & MORRIS, T.R (1967) Some effects of changing protein. *British Poultry Science*, **8**: 153-161.

FISHER, C., MORRIS, T. R. & JENNINGS, R. C. (1973) A model for the description and prediction of the response of laying hens to amino acid intake. *British Poultry Science*, **14**: 469-484.

FISHER, C. (1980) Protein deposition in poultry. In: *Protein deposition in animals*, (Eds) BUTTERY, P.J. & LINDSAY, D.B., Butterworths, London. pp 251-270.

FISHER, C. (1982) Energy values of compound poultry feeds, Occasional Publication No. **2** (Roslin, Agricultural Research Council's Poultry Research Centre).

FISHER, C. (1983) The physiological basis of the amino acid requirements of poultry. In: *Protein metabolism and nutrition*, (Eds) ARANAL, M., PION, R. & BONINI, D., Les Colloques de l'INRA, No 16, Nouzilly, France. pp 385-404.

FISHER, C. (1994) Responses of laying hens to amino acids. In: *Amino acids in farm animal*. (Eds) D'Mello, J.P.F., CAB International, Wallingford, UK. pp 245-279.

FISHER, C. (1998) Amino acid requirements of broiler breeders. *Poultry Science*, **77**: 124-133.

FISHER, C. (2000) Advances in feed evaluation for poultry. In: *Feed evaluation, principles and practice*, (Eds) MOUGHAN, P.J., VERSTEGEN, M.W.A. & VISSER-REYNEVELD, M.I., Veenman drukkers, Wageningen, The Netherlands. pp 243-268.

FLETCHER, D.L., BRITTON, W.M., PESTI, G.M., RAHN, A.P. & SAVAGE, S.I. (1981) The influence of layer flock age on egg component yields and solids content. *Poultry Science*, **60**: 983-987.

FLETCHER, D.L., BRITTON, W.M., PESTI, G.M., RAHN, A.P. & SAVAGE, S.I. (1983) The relationship of layer flock age and egg weight on egg components yields and solids content. *Poultry Science*, **62**: 1800-1805.

FRAPS, R.M. (1955) Egg production and fertility in poultry. In: *Progress in the physiology of farms animals*, (Eds) Hammond, J., Butterworths, London. pp 661-740.

GENSTAT, (1997) Genstat 5 (Release 5.1) Committee of the Statistic Department, Rothamsted Experimental Station. Oxford, Clarendon Press.

GENSTAT (2005) Genstat 8 (Release 8.1) *Committee of the Statistic Department*. (Oxford: Rothamsted Experimental Station, Clarendon Press).

GILBERT, A.B. (1972) The activity of the ovary in relation to egg production, in: FREEMAN, B.M. & LAKE, P.E. (Eds) *Egg formation and production*, pp. 3-22 (Edinburgh, Poultry Science Symposium Number Eight).

GODDARD, L.L. (1997) Matching the nutritional requirements to performance in broiler breeder hens. *MSc thesis*, University of Natal, South Africa.

GOUS, R.M. Department of Animal and Poultry Science, University of KwaZulu-Natal, PO Box X01, Pietermaritzburg, 3201, South Africa.

GOUS, R.M. FISHER, C. & BROADBENT, L.A. (1984) Measurements of the amino acid requirement for maintenance of adult cockerels. Proceeding of the 17th World's Poultry Congress, Helsinki, Finland.

GOUS, R.M. (1986) Measurement of response in nutritional experiments. In: *Nutritional Requirements and Nutritional Theory*, (Eds) FISHER, C. & BOORMAN, K.N., Butterworths, London. pp 41-57.

GOUS, R.M., EMMANS, G.C. & FISHER, C. (1992) The response of broilers to feeds differing in protein content following a period of fattening. *Thirteenth annual meeting of the Southern Poultry Science Society, Atlanta, Georgia.*

GOUS, R.M. (2002) Optimising broiler performance with the use of simulation models. In: *4th International Poultry Symposium*. NuTec Explicit Nutrition, Southern Africa (Pty) Ltd.

HAN, K. & LEE, J.H. (2000) The role of synthetic amino acids in monogastric animal production: a review. *Asian-Australasian Journal of Animal Science*, Vol. **13**, No. **4**: 543-560.

HANSEN, K.K., KITTOK, R.J., SARATH, G., TOOMBS, C.F., CACERES, N. & BECK, M.M. (2003) Estrogen receptor-α population change with age in commercial laying hens. *Poultry Science*, **82**: 1624-1629.

HARMS, R.H. & IVEY, F.J. (1992) An evaluation of the protein and lysine requirement for broiler breeder hens. *Journal of Applied Poultry Research*, **1**: 308-314.

HARMS, R.H. & HUSSEIN, S.M. (1993) Variation in yolk:albumen ratio in hen eggs from commercial flocks. *Journal of Applied Poultry Research*, **2**: 166-170.

HARMS, R.H. & RUSSELL, G.B. (1995) A re-evaluation of the protein and lysine requirement for broiler breeder hens. *Poultry Science*, **74**: 581-585.

HARPER, A.E., BENEVENGA, N.J. & WOLHEUTER, R.M. (1970) Effects of ingestion of disproportionate amounts of amino acids. *Physiological reviews,* **50**: 480-497.

HECK, A., ONAGBESAN, O., TONA, K., METAYER, S., PUTTERFLAM, J., JEGO, Y., TREVIDY, J.J., DECUYPERE, E., WILLIAMS, J., PICARD, M. & BRUGGEMAN, V. (2004) Effects of *ad libitum* feeding on performance of different strains of broiler breeders. *British Poultry Science,* **45**: 695-703.

HOCKING, P.M., GILBERT, A.B., WALKER, M. & WADDINGTON, D. (1987) Ovarian follicular structure of White Leghorns fed *ad libitum* and dwarf and normal broiler breeders fed *ad libitum* or restricted until point of lay. *British Poultry Science*, **28**: 493-506.

HURWITZ, S. & BORNSTEIN, S. (1973) The protein and amino acid requirements of laying hens: suggested model calculations. *Poultry Science*, **52**: 1124-1134.

HURWITZ, L., WEISEIBERG, M., FISHER, U., BARTOV, I, RIESENFEED, G., SHARVIT, M., MIR, A. & BORNSTEIN, S. (1980) The energy requirements and performance of growing chickens and turkeys as affect by environment temperature. *Poultry Science,* **59**: 229-2299.

HUSSEIN, S.M., HARMS, R.H. & JANKY, D.M. (1993) Effect on the yolk to albumen ratio in chicken eggs. *Poultry Science,* **72**: 594-597.

HUYGHEBAERT, G., DE GROOTE, G., BUTLER, E.A. & MORRIS, T.R. (1991a) Optimum isoleucine requirement of laying hens and the effect of age. *British Poultry Science*, **32**: 471-481.

HUYGHEBAERT, G. & BUTLER, E.A. (1991b) Optimum threonine requirement of laying hens. *British Poultry Science*, **32**: 575-582.

ISHIBASHI, T. (1972) Amino acid requirements for maintenance of the adult roosters. *Japanese Journal of Zootechnical Science*, **44** : 39-49.

JENNINGS, R.C., FISHER, C. & MORRIS, T.R. (1972) Changes in the protein requirements of pullets during the first laying year. *British Poultry Science,* **13**: 279-281.

JOHNSON, R.J. & FARRELL, D.J. (1983) Energy metabolism of groups of broiler breeders in open-circuit respiration chambers. *British Poultry Science,* **24**: 439-453.

JOHNSTON, S.A. (2004) Modelling egg production in laying hens. *PhD Thesis*, University of KwaZulu-Natal, South Africa.

JOHNSTON, S.A. & GOUS, R.M. (in press) A mechanistic, stochastic population model of egg production.

JOSEPH, N.S., ROBINSON, F.E., RENEMA, R.A. & ZUIDHOF, M.J. (2002) Responses of two strains of female broiler breeders to a mid-cycle increase in photoperiod. *Poultry Science*, **81:** 745-754.

KATANBAF, M.N., DUNNINGTON, E.A. & SIEGEL, P.B. (1989) Restricted feeding in early and late-feathering chickens: Growth and physiological responses. Poultry Science, **68**: 344-351.

KERR, B.J. & KIDD, M.T. (1999a) Amino acid supplementation of low protein broiler diets. 1. Glutamic acid and indispensable amino acid supplementation. *Journal Applied of Poultry Research*, **8**: 298 – 309.

KERR, B.J. & KIDD, M.T. (1999b) Amino acid supplementation of low protein broiler diets. 2. Formulation on an ideal amino acid basis. *Journal Applied of Poultry Research*, **8**: 310 - 320.

KIM, J.D. & HAN, In K. (1996) Effects of synthetic amino acid on performance and reduction in N excretion of brown layers. The study on the development of low-pollution diet and the method to enhance using synthetic amino acids. Seoul National University, Korea.

KLEYN, F.J. (1987) An application of the systems approach to egg production. *MSc Thesis*. University of Natal, South Africa.

LEE, B.D., MORRISON, W.D., LEESON, S. & BARLEY, H.S. (1983) Effects of feather cover and insulative jackets on metabolic rate of laying hens. *Poultry Science*, **62**: 1129-1132.

LEESON, S. & LEWIS, D. (1973) Multiple linear regression equations for the prediction of food intake in the laying fowl. *British Poultry Science*, **14**: 598-608.

LEESON, S. & LOPEZ, G. (1994) Protein nutrition of broiler breeders. Proc. Arkansas Nutr. Conf., p248-255. Fayetteville, Ark.

LEESON, S., & SUMMERS, J.D (1983) Consequence of increased feed allowance for growing broiler breeders pullets as a means of stimulating early maturity. *Poultry Science*, **62**: 6-11.

LEESON, S. & SUMMERS, J. D. (1997) *Commercial Poultry Nutrition*, 2nd Ed. (Eds) ITHACA: M. L., SCOTT & ASS. 355p.

LEESON, S. (1999) Protein nutrition of broiler breeders. *Simposio International Sobre Nutricao de Aves. Campinas*, SP-Brazil. WPSA-Brazilian Branch.

LEESON, S. & SUMMER, J.D. *Broiler breeder production*. 2000, Guelph: University books. 334p.

LEVEILLE, G.A. & FISHER, H. 1958. The amino acid requirements for maintenance in the adult rooster. I. Nitrogen and energy requirements in normal and protein-depleted animals receiving whole egg protein and amino acid diets. *Journal of. Nutrition*, **66**: 441-453.

LEVEILLE, G. A. & FISHER, H. (1959) Amino acid requirements for maintenance in the adult roosters II. The requirements for glutamic acid, histidine, lysine and arginine. *Journal of Nutrition*, **72**: 8-15.

LEVEILLE, G. A. & FISHER, H. (1960) Amino acid requirements for maintenance in the adult roosters IV. The requirements for methionine, cystine, phenylalanine, tyrosine and tryptophan; the adequacy of the determined requirements. *Journal of Nutrition*, **72**: 8-15.

LEWIS, P.D., GOUS, R.M. & MORRIS, T.R (in press) A model to predict age at sexual maturity in broiler breeders given a single increment photoperiod.

LEWIS, P.D., MORRIS, T.R. & PERRY, G.C. (1998) A model for the effect of constant photoperiods on the rate of sexual maturation in pullets. *British Poultry Science*, **39:** 147-151.

LEWIS**,** P.D., CIACCIARIELLO, M. & GOUS, R.M. (2003) Photorefractoriness in broiler breeders: Sexual maturity and egg production evidence. *British Poultry Science*, **44:** 634-642.

LEWIS, P.D., BACKHOUSE, D. & GOUS, R.M. (2004) Constant photoperiods and sexual maturity in broiler breeder pullets. *British Poultry Science*, **45:** 557-560.

LEWIS, P.D. & MORRIS, T.R. (2005) Change in the effect of constant photoperiods on the rate of sexual maturation in modern genotypes of domestic pullet. *British Poultry Science*, **46:** 584-586.

LEWIS**,** P.D. (2006a) A review of lighting for broiler breeders. *British Poultry Science.* **47:** 393-404.

LEWIS, P.D. & MORRIS, T.R. (2006b) Photoperiod: Conventional programmes. In: *Poultry Lighting the theory and practice*, (Eds) Andover, Northcot. Pp 23-55.

LOPEZ, G. & LEESON, S. (1995) Response of broiler breeders to low-protein diets 1. Adult breeder performance. *Poultry Science*, **74**: 685-695.

LUITING, P. (1990) Genetic variation of energy partitioning in laying hens: causes of variation in residual feed consumption. *World's Poultry Science Journal*, **46**: 133-152.

LUNVEN, P., LE COLEMENT DE ST MARCQ, C., CARNOVALE, E. & FRATONI, A. (1973) Amino acid composition of hen's egg. *British Journal of Nutrition*, **30**: 189-194.

MARION, W.W., NORDSKOG, A.W., TOLMAN, H.S. & FORSYTHE, R.H. (1964) Egg composition as influenced by breeding, egg size, age and season. *Poultry Science*, **43**: 255-264.

MCDONALD, M.W. & MORRIS, T.R. (1985) Quantitative review of optimum amino acid intake for young laying pullets. *British Poultry Science*, **26**: 253-264.

MCDANIEL, G.R., BRAKE, J. & ECKMAN, M.K. (1981) Factors affecting broiler breeder performance. 4. The interrelationship of some reproductive traits. *Poultry Science*, **60**: 1792-1797.

MILLER, D.S. & PAYNE, P.R. (1961) Problems in the prediction of protein values of diets: caloric restriction. Journal of Nutrition 75: 225-330.

MORRIS, T.R. & BLACKBURN, H.A. (1982) The shape of the response curve relating protein intake to egg output for flocks of laying hens. *British Poultry Science*. **23**: 405-424.

MORRIS, T.R. & GOUS, R.M. (1988) Partitioning of the response to protein between egg number and egg weight. *British Poultry Science*, **29**: 93-99.

NEME, R.; SAKOMURA, N.K.; FIALHO, F.B.; FREITAS, E.R. & FUKAYAMA, E.H. (2005) Modelling energy utilization for laying type pullets. *Brazilian Journal of Poultry Science*, **v.7, n.1:** 39-46.

NRC (1981) *Effect of environment on nutrient requirements of domestic animals*, National Academy of Sciences, Washington, DC.

NRC (1984) Committee on Animal Nutrition. Subcommittee on Poultry Nutrition. *Nutrient Requirements of Poultry*, 8. ed. National Academy of Sciences, Washington, DC.

NRC (1994) Committee on Animal Nutrition. Subcommittee on Poultry Nutrition. *Nutrient Requirements of Poultry*, 9. ed. (National Academy of Sciences, Washington, DC).

O'NEILL, S.J.B., BALNAVE, D. & JACKSON, N. (1971) The influence of feathering and environmental temperature on the heat production and efficiency of utilization of metabolisable energy by mature cockerel. *Journal Agricultural Science*, **7**: 293-305.

PEARSON, R.A. & HERRON, K.M. (1980) Feeding standards during lay and reproductive performance of broiler breeders. *British Poultry Science*, **21**: 171-181.

PEARSON, R.A. & HERRON, K.M. (1981) Effects of energy and protein allowance during lay on the reproductive performance of broiler breeder hens. *British Poultry Science*, **22**: 227-239.

PEARSON, R.A. & HERRON, K.M. (1982) Relationship between energy and protein intakes and laying characteristics in individual-cages broiler breeder hens. *British Poultry Science*, **23**: 145-159.

PEGURI, A. & COON, C.N. (1988) Development and evaluation of prediction equations for metabolizable energy and true metabolizable energy intake for Dekalb XL-Link White Leghorn hen. In: *Proceeding of Minnesota Nutrition Conference and Degussa Technology Symposium*. Bloming, pp. 79-90. (cited by Rabello *et al.*, in press).

PEGURI, A. & COON, C.N. (1993) Effect of feather coverage and temperature on layer performance. *Poultry Science*, **72:** 1318-1329.

PILBROW, P.J. & MORRIS, T.R. (1974) Comparison of lysine requirements amongst eight stocks of laying fowls. *British Poultry Science*, **15**: 51-73.

POMAR, C.; HARRIS, D.L. & MINVIELLE, F. (1991) Computer simulation model of swine production systems. 1. Modelling the growth of young swine. *Journal Of Animal Science*, **69**: 1468-1488.

RABALLO, C.B.V. (2001) Equações de predicão das exigências de energia e proteína para reprodutoras pesadas na fase de produção. Jaboticabal, SP:FCAV/UNESP. Tese (Doutorado em Zootecnia) – Faculdade de Ciências Agrárias e Veterinárias/Universidade Estadual Paulista. (cited by Sakomura, 2004).

RABELLO, C.B.V., SAKOMURA, N.K., LONGO, F.A., COUTO, H.P. & PACHECO, C.R. (in press) Energy model for broiler breeder hens. Modelling energy utilization in broiler breeder hens.

REDDY, R.P. (1996) The effect of long-term selection on growth of poultry. *Poultry Science*, **75**: 1164-1167.

RENDEN, J.A., OATES, S.S. & WEST, M.S. (1991) Performance of two male broiler breeder strains raised and maintained on various constant photoschedules. *Poultry Science*, **70:** 1602-1609.

RENEMA, R.A., ROBINSON, F.E, NEWCOMBE, M. & McKAY, R.I. (1999) Effect of body weight and feed allocation during sexual maturation in broiler breeder hens. 1. Growth and carcass characteristics. *Poultry Science*, **78**: 619-628.

RENEMA, R.A., ROBINSON, F.E. & GOERZEN, P.R. (2001) Effects of altering growth curve and age at photostimulation in female broiler breeders. 1. Reproductive development. *Canadian Journal of Animal Science*, **81**: 467-476.

ROBINSON, F.E., WILSON, J.L., YU, M.W., FASENKO, G.M. & HARDING, R.T. (1993) The relationship between body weight and reproductive efficiency in meat-type chickens. *Poultry Science*, **72**: 912-922.

ROBINSON, F.E., WAUTIER, T.A., HARDIN, R.T., ROBINSON, N.A., WILSON, J.L., NEWCOMBE, M. & MCKAY, R.I. (1996) Effects of age at photostimulation on reproductive efficiency and carcass characteristics. 1. Broiler breeder hens. *Canadian Journal of Animal Science*, **76:** 275-282.

ROBINSON, F.E. (2002) Management for control of ovarian development in broiler breeders. *The Poultry Informed Professional*. No. 59.

ROMANOFF, A.L. & ROMANOFF, A.J. (1949) *The avian egg*. New York, John Wiley and Sons, Inc.

ROSS BREEDERS LIMITED (1995) Parent stock management manual for Ross 308. Ross Breeder Ltd., Newbridge, UK.

ROSSI, M. & POMPEI, C. (1995) Changes in some egg components and analytical values due to hen age. *Poultry Science*, **74**: 152-160.

SAKOMURA, N.K. & COON, N.C. (2003) Amino acid requirements for maintenance of broiler breeder pullets. *Proceeding of the 14th European Symposium of Poultry Nutrition*, Lillehammer, Norway.

SAKOMURA, N.K., SILVA, R., COUTO, H.P., COON, C. & PACHECO, C.R. (2003) Modeling metabolizable energy utilization in broiler breeder pullets. *Poultry Science*, **82**: 419-427.

SAKOMURA, N.K. (2004) Modeling energy utilization in broiler breeders, laying hens and broilers. *Brazilian Journal of Poultry Science*, **6**: 1-11.

SAKOMURA, N.K., LONGO, F.A., OVIEDO-RONDO, E.O., BOA-VIAGEN, C. & FERRAUDO, A. (2005) Modeling energy utilization and growth parameter description for broiler chickens. *Poultry Science*, **84**: 1363-1369.

SAKOMURA, N.K., BASAGLIA, R. & FORTES, C.M.L.S., (in press). Modelos para Determinar as Exigências de Energia Metabolizável para Poedeiras. Revista Brasileira de Zootecnia. (cited by Sakomura, 2004).

SANDBERG, F.; EMMANS, G.C. & KYRIAZAKIS, I. (2006) A model for predicting food intake of growing animals during exposure to pathogens. *Journal of Animal Science*, 84: 1552-1566.

SAVORY, C.J.; MAROS, K. & RUTTER, S.M. (1993) Assessment of hunger in growing broiler breeders in relation to a commercial restricted feeding programme. *Animal Welfare*, **2**: 131-152.

SHANNON, D.W.F.S. (1981) The effect of short-term changes in methionine supply on egg production. *Poultry Science* **60**: 1729-1730 (cited by Fisher, 2000).

SIBBALD, I. (1976) A biossay for true metabolizable energy in feedingstuffs. *Poultry Science*, **55**: 303-308.

SIBBALD, I.R. (1976) The effect of the duration of starvation of the assay bird on true metabolizable energy values. *Poultry Science*, **55**:1578-1579.

SIBBALD, I.R. (1979) The gross energy of avian eggs. *Poultry Science*, **68**: 404-409.

SOLLER, M., EITAN, Y. & BRODY, T. (1984) Effect of diet and early quantitative feed restriction on the minimum weight requirement for onset of sexual maturity in White Rock broiler breeders. *Poultry Science*, **63**: 1255-1261.

SPRATT, R.S. & LEESON, S. (1987) Broiler breeder performance in response to diet protein and energy. *Poultry Science*, **68**: 683-693.

SPRATT, R.S., BAYLEY, H.S., McBRIDE, B.W. & LEESON, S. (1990) Energy metabolism of broiler breeder hens. 1. The partition of dietary energy intake. *Poultry Science*, **65**: 1339-1347.

TAYLOR, St. C.S. (1980) Genetic scaling rules in animal growth. *Animal Production*, **30**: 161-165.

TESS, M.W., DICKERSON, G.E., NIENABER, J.A., YEN, J.T. & FERREL, C.L. (1984) Energy costs of protein and fat deposition in pigs fed *ad libitum*. *Journal of Animal Science*, **58**: 111-122.

VIEIRA, S.L. & MORAN, JR. (1998) Eggs and chicks from broiler breeders of extremely different age. *Journal of Applied Poultry Research*, **7**: 372-376.

WAIBEL, P.E., CARLSON, C.W., BRANNON, J.A. & NOLL, S.A. (2000) Identification of limiting amino acids after methionine and lysine with growing turkeys fed low protein diets. *Poultry Science*, **79**: 1290 – 1298.

WALDROUP, P.W., HAZEN, K.R., BUSSELL, W.D. & JOHNSON, Z.B. (1976a) Studies on the daily protein and amino acid needs of broiler breeder hens. *Poultry Science*, **55**: 2342-2347.

WALDROUP, P.W., JOHNSON, Z. & BUSSELL, W. (1976b) Estimating daily nutrient requirements for broiler breeder hens. *Feedstuffs*, **48** (28): 19.

WALZ, O.P. (1980) *Zeitschrift fu Tierphysiologie, Tierernahrung und Futtermittelkunde*, **46**: 113-124 (as cited by Bach-Knudsen and Jorgensen (1986)).

WALZ, O.P. (1983) *Zeitschrift fu Tierphysiologie, Tierernahrung und Futtermittelkunde*, **49**: 181-194 (as cited by Bach-Knudsen and Jorgensen (1986)).

WEHTLI, E. & MORRIS, T.R. (1978) Effects of age on the tryptophan requirements of laying hens. *British Poultry Science*, **19**: 559-565.

WELLOCK, I.J., EMMANS, G.C. & KYRIAZAKIS, I. (2003) Modelling the effects of thermal environment and dietary composition on pg performance: modellogic and concept. *Animal Science*, **77**: 255-266.

WELLOCK, I.J., EMMANS, G.C. & KYRIAZAKIS, I. (2006) The effects of social stressors on the performance of growing pigs. In: *Mechanistic modelling in pig and poultry production*, (Eds) GOUS, R.M., MORRIS, T.R. & FISHER, C. CABI, Wallingford, UK. pp. 54-75.

WILLIAMS, J.B. & SHARP, P.J. (1978) Ovarian morphology and rates of ovarian follicular development in laying broiler breeders and commercial egg-producing hens. *Poultry Science*, **19**: 387-395.

WILSON, H.R. & HARMS, R.H. (1984) Evaluation of nutrient specification for broiler breeders. *Poultry Science*, **63**: 1400-1406.

WILSON, H.R. & HARMS, R.H. (1986) Performance of broiler breeders as affected by body weight during the breeding season. *Poultry Science*, **65**: 1052-1057.

WILSON, J.L., ROBINSON, F.E, ROBINSON, N.A.& HARDIN, R.T. (1995) Effects of feed allocation on female broiler breeders. *Journal of Applied Poultry Research*, **4**: 193-202.

WHITTEMORE, C.T. (1981) Animal production response prediction. In: *Computers in Animal Production*. British Society of Animal Production, Occasional Publication No 5, London. pp 47-63.

YANNAKOPOULOS, A.L., TSERVENI-GOUSI, A.S. & CHRISTAKI, E. (1998) Effect of natural zeolite on yolk:albumen ratio in hen eggs. *British Poultry Science*, **39**: 506-510.

YU, M.W, ROBINSON, F.E., CHARLES, R.G. and WEINGERDT, R. (1992) Effect of feed allowance during rearing and breeding on female broiler breeders. 2. Ovarian morphology and production. *Poultry Science*, **71**: 1750-1761.

YEN, J.T., KERR, B.J., EASTER, R.A. & PARKHURST, A.M. (2004) Difference in rates of net portal absorption between crystalline and protein-bound lysine and threonine in growing pigs fed once daily. *Journal of Animal Science*, **82**: 1079– 1090.

ZHANG, B. & COON, C. N. (1994) Nutrient modelling for laying hens. *Journal of Applied Poultry Research*, **6**: 416-431.