Stochastic Model of Egg Production in Broiler Breeders

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ABSTRACT A stochastic model was developed to simulate the egg production of broiler breeders in response to changes in BW. The first step involved the construction of a diagram incorporating dependent and independent variables and their relationships to ovulation rate and egg production from 8 equations based on experimental results. The model was based on existing experimental data, and stochastic processes were invoked for 4 input parameters. Egg production curves and total egg production were simulated using inputs from a management manual, commercial trial data, and experimental results and were compared with actual rates of lay. The correlations between observed and predicted egg production were high (R^2 = 0.93 to 0.98). The assumptions made in developing the model were described and gaps in biological knowledge were identified.

Key words: stochastic model, broiler breeder, yellow follicle, body weight, egg production

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INTRODUCTION

The main output variable of economic importance in a broiler breeding enterprise—the number of hatching eggs produced—is highly variable and measured in large flocks of adult birds over a period of at least 40 wk. Experiments designed to investigate strategies to optimize the productivity of broiler breeders are also relatively long term and are expensive to conduct. If the prediction of outcomes were possible by modeling the production system, it would help in the design of experiments and possibly reduce the number of potential experiments required to solve a particular problem. Additionally, a computer simulation model would allow a technical advisor or breeding farm manager to predict the outcome of changes in the production of hatching eggs in response to modifications to husbandry practices, feed quantity or quality, advances in genetic potential or new technology, and the effects of variability in market conditions. Furthermore, if such a model used inputs that are regularly collected in commercial flocks, managers could use the model to monitor the progress of specific flocks, predict the consequences of management changes, or devise strategies to rectify mistakes in rearing or feeding practices.

Predicting rates of lay in broiler breeders is problematic because broiler breeders fed ad libitum are characterized by multiple ovulations that do not result in a hatching egg but are lost through internal ovulation and the production of soft-shelled and misshapen egg shells (van Middelkoop, 1971; Hocking et al., 1987). Feed restriction is practiced to control ovulation rate and improve the production of hatching eggs (Robinson et al., 1991; Yu et al., 1992; Hocking et al., 2002) by a physiological mechanism that is still not understood. If BW gains are excessive, productivity declines because too many ovulations occur, and conversely, if feed restriction is too severe, egg production will be low because there will be days when no yolk is ovulated and maximum rates of lay will not be achieved. Although BW and feed intake are closely related, research suggests that BW is the key factor affecting ovulation rates rather than feed intake per se (Hocking, 1993, 1996). However, when BW is similar in groups of birds, those consuming more feed will have more ovarian large yellow follicles (Hocking, 1993). For these reasons, feed restriction is continued throughout the life of commercial flocks of broiler breeders, and experimental results confirm the efficacy of common commercial practices that have been largely developed by empirical methods.

The main objective of this study was to develop a realistic biological model to simulate the responses in egg production rates of broiler breeders to changes in BW and BW gains. At its core, the model used existing experimental data on the relationship between these variables and the number of ovarian yellow follicles to predict changes in egg production. The results were compared with typical management and production data, the results from a commercial trial, and an experiment with large treatment differences in egg production to test the accuracy of prediction. Preliminary evaluation suggested that a reasonable precision was achieved in the realized estimations.

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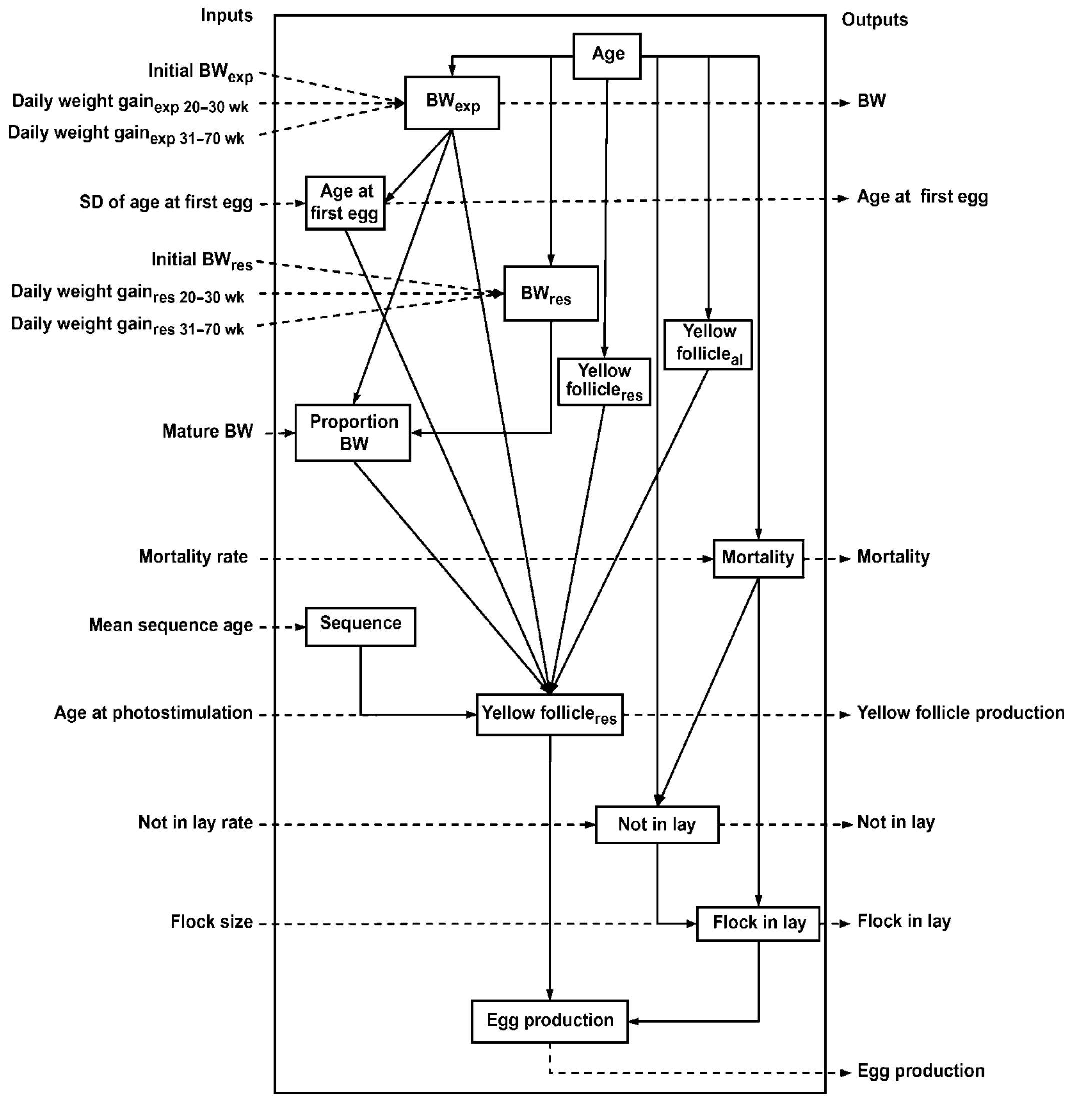

Figure 1. Schematic representation of sequences of events in a model of daily egg production in broiler breeders from 20 to 70 wk of age. Broken arrows represent input and output values. Subscripts: al = ad libitum; res = restricted; exp = experimental.

In addition, deficiencies were identified in the knowledge base and in areas of the underlying biology of reproduction in broiler breeders that are poorly described and warrant further experimental studies.

MATERIALS AND METHODS

Model Design

The model was developed using commercial modeling software (ModelMaker v4, A.P. Bensen Ltd., Wallingford, UK) and was designed to simulate the egg production of broiler breeders from 20 to 70 wk of age. The following input variables and relationships were assumed, largely based on research at the Roslin Institute using the same commercial line of females (Ross 1 or its modern equivalent, the Ross 308). The model is summarized diagrammatically in Figure 1. The relationships in this description were modeled daily between 20 and 70 wk of age.

Relationship Between BW and Yellow Follicle Number

Egg production is a reflection of ovarian activity and is directly related to the number of developing yellow follicles >8 mm in diameter (Hocking et al., 1987). The number of yellow follicles at the onset of lay (first egg) increases linearly with greater BW (Hocking et al., 1989; Hocking, 1993, 2004). A linear relationship between yellow follicle number and BW also exists for at least 6 wk after the onset of lay (Hocking, 1996). Ad libitum feeding for 14 d at 44 wk of age increased yellow follicle numbers (Robinson et al., 1993), and in the absence of contrary information, the number of yellow follicles was assumed to be linearly related to the difference in BW between a restricted bird and a bird fed ad libitum at the same age. Therefore, for a given age, t (d), the number of yellow follicles is given by the relationship (t subscripts are ignored for greater clarity):

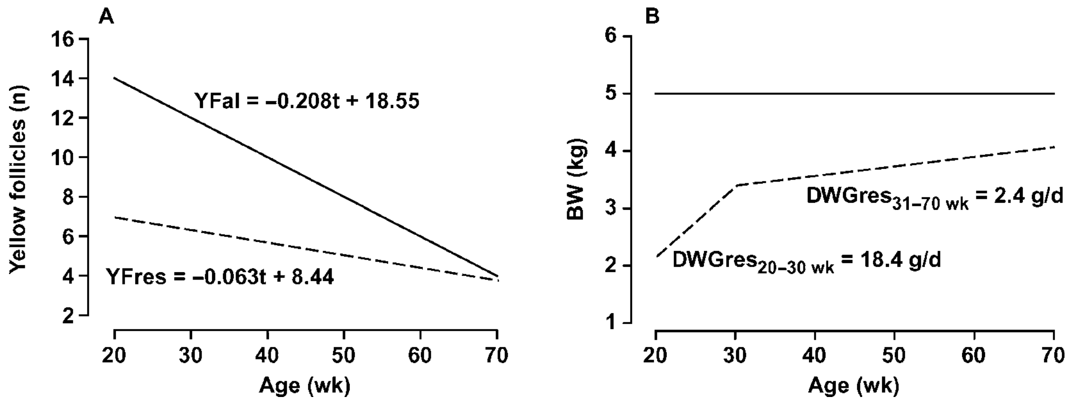

Figure 2. Assumed relationships with age of the number of yellow follicles (A) and BW (B) in broiler breeders fed ad libitum (solid line) or feed restricted (dotted line). DWG = daily weight gain; YF = number of yellow follicles; al = ad libitum; res = restricted.

$$\text{YFexp} = \text{YFres} + (\text{YFal} - \text{YFres}) \times \text{PrBW}, \quad [1]$$

where YFexp is the number of yellow follicles of an experimental (modeled) broiler breeder at age t, YFal is the number of yellow follicles of a bird fed ad libitum at age t, YFres is the number of yellow follicles in a conventional restricted broiler breeder at age t, and PrBW is the BW of the experimental bird as a proportion of the difference in BW between the conventional feed-restricted and ad libitum-fed bird at age t, where

$$\text{PrBW} = (\text{BWexp} - \text{BWres})/(\text{BWal} - \text{BWres}) \quad [2]$$

and BWexp is the BW of the feed-restricted experimental (modeled) bird, BWres is the BW of conventionally restricted broiler breeders, and BWal is the BW of broiler breeders fed ad libitum.

The numbers of yellow follicles at the onset of lay in conventionally restricted birds are typically between 5 and 7, and in birds fed ad libitum there is an average of at least 12 yellow follicles (Hocking et al., 1987, 1989; Hocking, 1993, 1996, 2004; Hocking and Robertson, 2005). Less information is available on the numbers of yellow follicles at the middle (40 wk) and end of lay. In an early study the numbers of yellow follicles in caged broiler breeders showed a rapid decline after the onset of lay, and at 60 wk there were about 4 yellow follicles in both ad libitum-fed and feed-restricted birds (Hocking et al., 1987). Yu et al. (1992) published similar data but the decline was less dramatic (9.0 and 6.9 yellow follicles compared with 7.3 and 5.6, respectively, in ad libitum-fed and feed-restricted birds at 33 and 60 wk), and yellow follicles were defined as those >10 mm in diameter. The numbers of yellow follicles at 47 wk were 10.4 and 7.6, respectively, in birds fed ad libitum and restricted (Waddington and Hocking, 1993) and post molt they were 7.5 and 7.3 (Hocking, 2004). For simplicity, we assume that the relationship between BW and yellow follicle numbers from 20 to 70 wk is linear and that the number of yellow follicles declines to 4 at 70 wk of age in both ad libitum-fed and feed-restricted birds (Figure 2, panel A).

Body weight at the start of the modeling process at 20 wk of age was taken as the recommended BW of commercially restricted broiler breeders from the Ross 308 Management Manual (Aviagen, 2001). Recommended BW gains from 20 to 70 wk were divided into 2 periods from 20 to 30 wk and 31 to 70 wk, respectively, based on recommended BW at 30 and 70 wk of age. Body weight gains were assumed to be linear within these 2 age periods, as illustrated in Figure 2, panel B.

For initial model development, data from the breeder's management manual was used to set the initial BW (IBWexp) of experimental birds at 20 wk of age and subsequent daily weight gains (DWGexp) to be the same as the model parameters for initial BW (IBWres) and daily weight gain (DWGres) of restricted birds. The CV of IBWexp was assumed to be 9% from the management manual.

Relationship Between BW and Age at Onset of Lay

The application of equation [1] in the model is conditional on the beginning of ovarian activity, and the onset of lay and is affected by the interaction of genetic and physiological differences in sexual maturation and photoperiod. Sexual maturation was predicted on the basis of the relationship between the onset of lay and BW from the equation presented by Hocking (2004):

$$\text{AFE} = 288 - 51 \times \text{BWexp} + 4.6 \times (\text{BWexp})^2, \quad [3]$$

where AFE is age at first egg. The model predicted AFE conditional on a minimum BW of 2.0 kg, and the effect of photoperiod was modeled on the basis of 3 criteria, which were applied on a flock basis. First, it was assumed that no bird would start to lay before photostimulation; second, that a photoperiod of at least 12 h light in 24 h was photostimulatory (Dunn and Sharp, 1990); and third, that the minimum period from the start of photostimulation and the onset of lay was 14 d based on evidence from the management manual and experimental results

(Hocking et al., 2002). Finally, the AFE from equation [3] was amended by adding a random number drawn from a distribution with mean 0 and SD 7.5 d based on the variability in age at the onset of lay in the data set of Hocking et al. (2002) and Hocking (unpublished results).

Relationship Between Yellow Follicle Numbers and Egg Production

Egg production is related to the number of yellow follicles in a nonlinear manner, and rates of lay were modeled by 2 equations based on the predicted number of yellow follicles:

$$\text{EGG} = \text{YFexp}/6 \text{ if YFexp} \leq 6, \quad [4]$$

$$\text{EGG} = \{1 - [(\text{YFexp} - 6) \times \text{randn}(0.5,0.05)/6]\} \text{ if YF} > 6, \quad [5]$$

where EGG is the probability of producing an egg at any given day, YFexp is the predicted number of yellow follicles at time t from equation [1], randn is a ModelMaker function to generate a series of random numbers with a mean 0.5 and SD of 0.05, and 0.5 is the rate of egg production (number/hen per d) in ad libitum-fed multiple-ovulating broiler breeders.

Equations [4] and [5] are based on 2 assumptions. The first is that in birds with a single hierarchy each ovulation will result in an oviposition. The second equation predicts the probability that an egg will result from a multiple ovulation based on the following argument. Egg production from ad libitum-fed broiler breeders is typically about 50% during early lay (Hocking et al., 1987; Robinson et al., 1991; Yu et al., 1992; Renema et al., 2001a,b; Hocking, 2004). Assuming that birds fed ad libitum have a double hierarchy of yellow follicles, the rate of egg production from a multiple ovulation is approximately 0.5. However, this is likely to be a random process, and a stochastic element was incorporated into the equation for the prediction of rate of lay by assuming an arbitrary CV of 10% for the variability of the probability of a multiple ovulation resulting in the production of a hatching egg.

Effect of Sequence Length on Egg Production

The production of ovulable yellow follicles is not a continuous process but occurs in sequences interrupted by intersequence pauses, with different durations between pauses depending on the time from the onset of egg production (Robinson et al., 1990). Data on sequence length with age in broiler breeders were extracted from the mean curve of sequence length plotted against age from the paper by Robinson et al. (1990) and were modeled by a logistic equation in Genstat (VSN International Ltd., Hemel Hempstead, UK) as:

$$\text{SEQ} = 2.902 + 19.60/\{1 + \exp[0.03809 \times (\text{MSEQ})]\} \quad [6]$$

where SEQ is sequence length and MSEQ is the age of the flock (t) at the time at which the longest sequence occurred. The effect of sequence length on YFexp was modeled as an intersequence pause if a random number from a uniform distribution between 0 and 1 was greater than that predicted from equation [5].

Predicting Flock Egg Production

To determine egg production in a flock, it was necessary to calculate the proportion of birds that were in production (FLOCK), a term that is used synonymously with the probability of a hen housed at 20 wk being alive and in laying condition on a specified day. This is a function of the number of birds housed, mortality (MORT), and the proportion of birds that are not in lay (NOTLAY, i.e., have no ovulable yellow follicles) at time t and is modeled as:

$$\text{FLOCK} = (1 - \text{MORT} \times \text{t}) \text{ for age} <40 \text{ wk}, \quad [7]$$

$$\text{FLOCK} = (1 - \text{MORT} \times \text{t}) \times (1 - \text{NOTLAY} \times \text{t}) \text{ for age} >40 \text{ wk}. \quad [8]$$

Equation [4] or [5] was multiplied by FLOCK to obtain the rate of lay (EGGS) on the modeled day for an average bird.

The breeder manual suggests a mortality to 60 wk of 7% of the hens housed at 20 wk, and a linear rate of mortality of 0.000243 hens/d was assumed. Little information is available on the proportion of birds not in lay over time. Observations of birds in cages suggest that a few conventionally restricted broiler breeders cease laying after 40 wk and that the proportion increases until termination of the flock. In one study (P. M. Hocking, unpublished data), 20% of 50 dwarf broiler breeders were NOTLAY at 60 wk. Ciccone (2005) reported that 4 out of 30 conventional broiler breeders were not in lay at 60 wk. For initial modeling, a rate of increase in birds not in lay of 1%/wk from 40 wk of age (0.00143 hens/d), equivalent to 20% at 60 wk of age, was assumed.

Modeling Egg Production

The relationships among the 8 equations, inputs, and outputs are summarized in Figure 1. Estimates of parameters based on data to 60 wk were extrapolated to 70 wk of age by assuming linearity of the response. Initial parameters and input variables in the basic model are summarized in Table 1. Each run of the model simulated egg production from 20 to 70 wk of age at daily intervals and was repeated 500 times using the Monte Carlo option in ModelMaker. The output from each run was summarized using sample points at 7-d intervals from 20 to 70 wk, and results are the means of 500 runs for each set of parameters.

Model Validation

The model was validated by comparing simulated egg production with 3 sets of data. The first was the target BW,

Table 1. Standard input parameters and symbols used in a model of egg production in broiler breeders[1]

Input	Symbol	Value
Variation (SD) in age at first egg (d)	VAFE	7.5
BW gain (kg/hen per d)		
From 20 to 30 wk	$DWGres_{20–30}$	0.01840
From 31 to 70 wk	$DWGres_{31–70}$	0.00240
Initial BW (kg)	IBWres	2.1
Mature BW (kg)	BWal	5
Flock (number of birds at start)	FLOCK	1
Age at maximum sequence length (d)	MSEQ	87.5

[1]See Figure 1. al = ad libitum; res = restricted.

BW gains, and daily egg production from the breeder's manual (Aviagen, 2001). The second data set was from a commercial broiler breeder trial (Aviagen, 2005, unpublished data) and the third was from a published experiment (Hocking et al., 2002). The efficiency of the modeling process was assessed as the fit of the regression of predicted on actual weekly egg production, expressed as the multiple correlation coefficient (R^2) using the REG procedure in SAS (SAS Institute, Cary, NC).

Data Set 1: Aviagen Manual. Input parameters were taken from the management manual (Aviagen, 2001) and are summarized in Table 2. Egg production was available as hen-housed rates of lay to 62 wk of age.

Data Set 2: Aviagen Trial. The experiment consisted of 2,160 female and 216 male broiler breeders housed in 18 pens containing 12 males and 120 females. There were 3 treatments with 6 replicates. The treatments involved small modifications to the recommended feeding practice to peak rate of lay, and because treatment differences were very small, the data set was considered as 1. The birds were photostimulated at 20 wk of age by increasing the photoperiod to 11L:13D and by further increases of 1 h at 2-wk intervals to a final photoperiod of 15L:9D at 28 wk of age. Egg production was available as hen-housed rates of lay to 62 wk of age.

Data Set 3: Experimental Data. Experimental details were published in Hocking et al. (2002). Briefly, 3 groups of broiler breeders were fed ad libitum (**AL**), conventionally restricted (**CR**), or proportionally 1.28 times that of the restricted group to 15 wk of age and subsequently fed to achieve a BW similar to the CR birds at the onset of lay (**MR**). Data were used from birds fed on a conventional ("high protein") diet. The birds were fed ad libitum (**-AL**) after peak egg production at 38 wk of age or restricted (**-R**) as outlined in the management manual. Each pen housed 16 females and 1 male at 19 wk of age, when they were provided with an increased photoperiod of 11L:13D followed by 1-h increments at 2-wk intervals to 15L:9D at 27 wk of age. There were 3 replicates per treatment, and weekly data were available on hen day rates of egg production.

RESULTS

The plot of simulated egg production and the expected performance of this line from the management manual are presented in Figure 3, panel A. A reasonably good fit was obtained (R^2 = 0.94). The model tended to overestimate early egg production and underestimate the rate of lay from 42 to 62 wk of age. Overall egg production was overestimated by 6.5 eggs (Table 3).

The predicted and actual performance data from the Aviagen trial are presented in Figure 3, panel B. There was excellent agreement between the 2 data sets (R^2 = 0.98), and total egg production was underestimated by less than 3 eggs, a value similar to the SEM (Table 3).

Results of model validations with data from Hocking et al. (2002) are given in Table 3 and Figure 4. Good precision of prediction was obtained with CR-R and MR-R, but the model tended to overestimate the rate of lay after peak in CR-AL and MR-AL (Figure 4). The model did not fit the data for egg production of birds fed ad libitum throughout life (data not shown) because many birds went out of lay after 40 wk of age and rate of lay was very poor (Hocking et al., 2002).

DISCUSSION

The main purpose of this study was to model the effects of changes in BW at the start of lay, subsequent BW gains, and variability in BW at the onset of lay on the production

Table 2. Input values used for model validation

		Aviagen		Hocking et al. (2002)[2]			
Input variable	Symbol[1]	Manual	Trial	CR-R	CR-AL	MR-R	MR-AL
Initial BW	IBWexp						
Mean, kg		2.155	2.121	2.113	2.113	2.443	2.443
SD		0.216	0.191	0.296	0.275	0.342	0.318
BW gain (kg/d)							
From 20 to 30 wk	$DWGexp_{20–30}$	0.0176	0.0168	0.0145	0.0139	0.0128	0.0137
From 31 to 70 wk	$DWGexp_{31–70}$	0.0030	0.0034	0.0024	0.0075	0.0020	0.0081
Mortality (n/hen day)[3]	MORT	0.00025	0.000114	—	—	—	—
Not in lay (n/hen day)[1]	NOTLAY	0.000715	0.000715	0.00214	0.00500	0.00214	0.00500

[1]Rate of decline in the proportion of birds not in lay (NOTLAY) from 40 wk of age. exp = experimental.

[2]Feeding during rearing: conventional feed restriction (CR) or modified (less severe) feed restriction (MR); feeding after peak egg production: ad libitum (-AL) or restricted (-R).

[3]Proportion of birds dead or culled from 20 wk of age. Egg production in the data of Hocking et al. (2002) are reported as hen day rates of lay, and mortality was therefore not modeled.

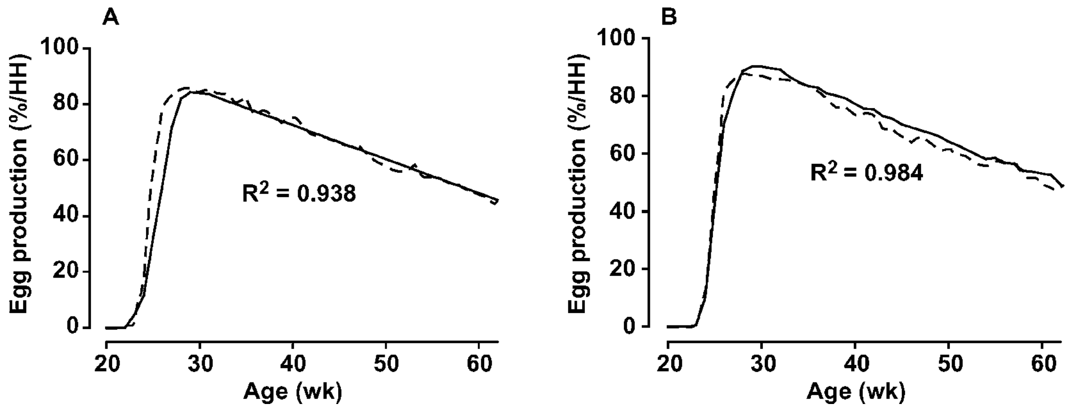

Figure 3. Predicted hen-housed egg production (%) with age of broiler breeders from a model based on experimental data (solid line) vs. observed data (dotted line). Data are from (A) Parent Stock Management Manual Ross 308 (Aviagen, 2001) and (B) trial data from Aviagen (2005, unpublished data). HH = hen housed.

of hatching eggs in broiler breeders. These data are readily available in commercial flocks and the rate of mortality can be observed or predicted.

In general, the precision of estimating egg production, considering the paucity of data on several of the input variables, was reasonably good and the effects of changes in the values of the input parameters on productivity when all other factors are held constant will be reported in a companion paper.

The precision of estimating egg production from targets in the management manual was underestimated and not as good as in the trial data. It is possible that the management manual is a conservative description of targets for average flocks, and it is pertinent that the prediction of initial rates of lay in the trial and experimental data were both better than targets in the management manual.

In principle, the model can be easily modified for turkeys, ducks, and laying hens provided that the biological inputs (relationships and parameters) are determined. The model is more general than statistical modeling as presented by several authors (e.g., Grossman and Koops, 2001). Biological modeling has the benefit of providing information on the separate physiological processes resulting in the characteristic egg production curves of avian species and has greater potential for modeling the effect of changes in flock management for optimum rates of lay. Several important model assumptions and requirements for critical data for model parameters were identified in this study, and a detailed consideration of these is given below.

Table 3. Means and SE of predicted and observed total egg production for 6 data sets

Data	Total eggs: Predicted	Total eggs: Observed
Aviagen manual (2001)[1]	180.7 ± 0.79	174.2
Aviagen trial (2005, unpublished data)[1]	185.0 ± 0.76	187.9 ± 1.64
Hocking et al. (2002)[2]		
CR-R	152.5 ± 1.13	154.9 ± 2.38
MR-R	162.3 ± 1.01	159.4 ± 2.29
CR-AL	145.8 ± 0.82	149.0 ± 2.46
MR-AL	150.7 ± 0.61	131.9 ± 2.32

[1]Production period: 62 wk.

[2]Production period: 60 wk. CR = conventional feed restriction, MR = modified (increased) feeding during rearing; –R = restricted and –AL = ad libitum feeding after peak rate of lay (38 wk).

Sequence Length

The data from Robinson et al. (1990) were initially modeled by a Gaussian distribution that was an excellent fit to the data but tended to overestimate early egg production. Possibly this was the case because the sequence data were based on records of egg production and are therefore a mixture of the effects of individual differences in AFE and multiple ovulations in addition to gaps in the sequence caused by a failure to recruit a follicle into the yellow hierarchy. It was assumed that the maximum sequence length in the data set would apply from the onset of lay of individual birds, and the data were modeled by the logistic equation using the data of Robinson et al. (1990) from the time of maximum sequence length only. This device gave realistic predictions of early egg production in our data. Obtaining experimental data to support this assumption is currently difficult and would probably involve invasive techniques such as recording daily hormone cycles, imaging techniques, or sequential slaughter.

Relationships Among Daily Weight Gain, Age, and Yellow Follicle Numbers

Body weight gains were divided into 2 parts that corresponded to distinct phases in commercial management practices leading up to peak rate of lay, with more generous feeding, and post peak feeding, when BW gains were comparatively small. Daily weight gain during the laying period could be modeled by a quadratic relationship or with 3 or more linear equations. Nevertheless, the current model provided reasonably good predictions of the laying curve and represents a simple solution to the problem of describing these relationships that approximates normal commercial practices. Daily weight gains are easily

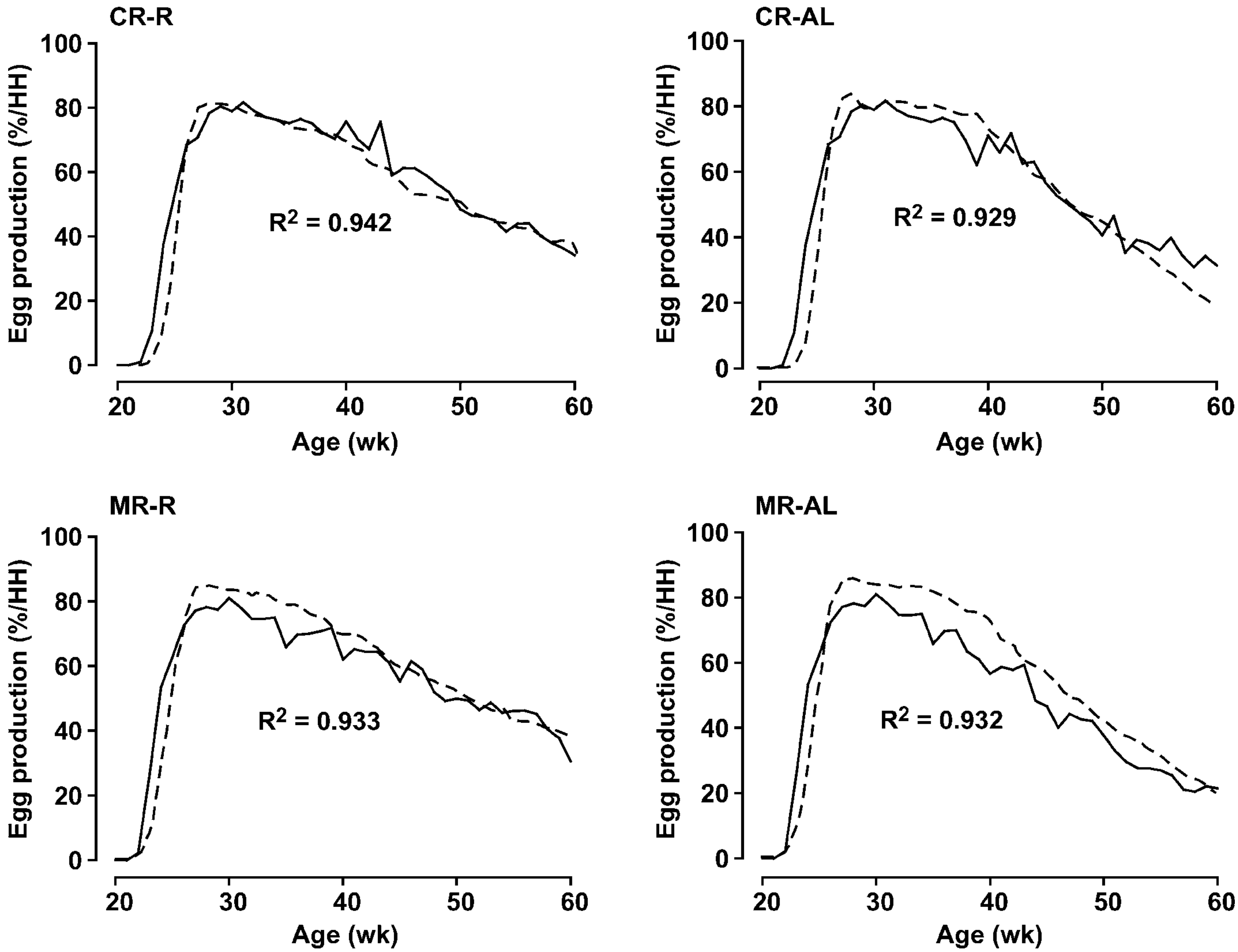

Figure 4. Predicted (dotted line) and observed (solid line) rates of lay of broiler breeders on conventional restricted (CR) or more generous modified restricted (MR) feeding programs during rearing that were feed restricted (–R) or fed ad libitum (–AL) after the peak of egg production (original data from Hocking et al., 2002). HH = hen housed.

obtained from existing data, whereas determining the numbers of yellow follicles at regular intervals from broiler breeders kept in floor pens would involve sacrificing the birds but would not be technically difficult.

The linear relationship between BW and the number of yellow follicles at the onset of lay and in the early laying period is well documented (Hocking et al., 1989; Hocking, 1993, 2004). In the absence of information to the contrary, it was assumed that this would hold true at all ages and that the number of follicles would be bounded by an upper limit defined by the number of yellow follicles in broiler breeders fed ad libitum throughout the rearing and breeding periods. Further research is required to confirm that the relationship between BW and the number of yellow follicles is linear between 30 and 70 wk of age. More data on the numbers of yellow follicles at different ages in conventionally restricted birds are also required to confirm or refute the linear relationship between yellow follicles and age and to confirm the numbers of yellow follicles in birds in lay at the end of the production cycle. Further information on the same statistics for birds fed ad libitum, although useful, is probably not critical for the prediction of productivity in feed-restricted birds to attain BW close to those of conventionally restricted birds.

Proportion of Birds Not in Lay

Modeling the rate of decline of egg production after 40 wk of age was strongly dependent on the assumed rate of increase in the proportion of birds that were not in laying condition (NOTLAY). The original model with NOTLAY of 20% failed to fit the experimental data for CR-AL and MR-AL and post peak rates of lay were overestimated. These birds were fed ad libitum after peak rate of lay and the optimum NOTLAY value was modeled by iteration. In birds fed ad libitum throughout life, egg production declined precipitously after 40 wk of age and the birds were apparently not in lay (Hocking et al., 2002). The same process was probably occurring in the feed-restricted birds fed ad libitum after peak, because at 60 wk of age the decrease in egg production and increase in BW approached the levels in birds fed ad libitum throughout the experiment. Taken together, our results strongly implicate the importance of NOTLAY in determining rates of lay after peak and its significance in determining total egg production. Further research is required to define the effects of BW, feed allocation, lighting, strain, and genetic selection for persistency on the value of this parameter.

In future developments, we plan to model the effects of different rearing treatments, specifically growth rate at different ages, on subsequent egg production and to include egg weight as an output. Feed intakes and nutrient responses may also be incorporated and will lead to the development of an economic model for the evaluation of different management strategies.

CONCLUSIONS

A stochastic model of egg production based on biological principles was developed that simulates with acceptable precision the egg production of feed-restricted broiler breeders. The model can be used to evaluate the effect of differences in initial BW and subsequent rate of gain at different ages. The effects of changes in variability in initial BW and age at first egg may also be evaluated. The model has proved useful in identifying deficiencies in the reliability of information on model parameters and their relative importance. Further research to provide these data will result in a more robust and generally applicable model of egg production in broiler breeders. The model can be adapted for other poultry species and laying hens with the availability of appropriate biological relationships among egg production and ovarian activity, BW and BW gains, mortality, and persistency (proportion of birds in lay) at different ages.

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