EVALUATION OF MODELS FOR EGG PRODUCTION IN CHICKENS,

BY

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CERTIFICATION

This thesis entitled **"EVALUATION OF MODELS FOR EGG PRODUCTION IN CHICKENS"** by *OLUSOLA ONAOLAPO ONI*. meets the regulations governing the degree of Doctor of Philosophy of Ahmadu Bello University, Zaria, and is approved for its contribution to scientific knowledge and literary presentation.

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DECLARATION

I hereby declare that this thesis has been written by me and that it is a record of my own research work. It has not been presented in any previous application for higher degree. All quotations are indicated and the sources of information are specifically acknowledged by means of references.



Olusola O. ONI.

DEDICATION

Dedicated to the memory of my late father, Chief O.A. Oni and to my mother, Madam Amoke Allen.

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ABSTRACT

Data on the monthly egg production of 2 strains (A and B) of Rhode Island chickens (500 breeder hens per strain) were used to test the goodness of fit of six mathematical models, viz; Exponential, Parabolic exponential. Wood's Gamma and modified Gamma by McNally, Inverse polynomial and Linear regresion. Egg production was summarised for each hen into 28-d periods, starting from the day of first egg. The models were fitted to the mean results for periods of groups of hens.

The three best models with highest R^2 values were further compared on their ability to predict 52-week total egg production from part-production at 16, 20, and 24 weeks, on a hen-housed basis. The effect of cycle length on goodness of fit was also examined separately tor each of the three models.

The heritabilities. genetic and phenotypic relationships between egg production traits and curve parameters obtained from fitting the three models to 52-week laying records in the 2 strains were investigated. A total of 356 and 292 records for strain A and B respectively, were included in a variance component analysis of a two factor nested classification of dams within sire.

The egg production cycle (i.e. number of 28-d periods) varied from 9 to 15 periods in the 2 strains. The coefficients of determination (R^2) range from 0.16 to 0.95 for strain A and from 0.10 to 0.93 for strain B from fittings to mean egg production data lor groups of hens.

The results suggest that the 'best' three models that were chosen fitted 52 week laying records quite well, judging from their respective R^2 values, which were higher tor McNally (0.91 - 0.95) and Parabolic exponential (0.90 0.93) than for Wood (0.55 0.75). However, their ability to predict 52-week egg production from part-records of 16, 20 and 24 wks varied. The prediction of total production based on fit to 24 week of data was more

accurate for the McNally in strain A; while the Parabolic exponential performed better than the other 2 models in strain B. The McNally model consistently predicted less than the actual 52-week (except for 24-week data in strain B). But the other 2 models tended to over estimate production.

The estimates of heritabilities and correlations for production traits were moderately high, while the values obtained for curve parameters varied from low to moderate. The estimates of correlations of part-productions with 52-week production were comparatively higher than the values obtained for curve parameters with 52-week production.

The low estimates of heritability obtained for curve parameters indicate that it would be better to select on functions of the parameters (such as total or part-year production) which had higher estimates than the individual curve parameters.

The high genetic correlations between part-year production and total production suggests that selection for the latter based on the former would not diminish genetic progress. The decreased generation interval that would result from selection *on* part-record will probably more than offset the loss in efficiency if records are taken for about half of the full laying year.

It was concluded that based on the goodness of fit to 52-week production record and accuracy to predict full record egg production from part record, the McNally model gave the best results, and could therefore be said to have theoretical advantages over the other models. It may thus be found useful in decision making concerning replacement of layer flocks.

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1.0 INTRODUCTION

Poultry egg production is believed to be a complex quantitative trait which shows a considerable variation over time within the production cycle of a hen. Several methods of expressing egg production and its component characters have been investigated. Inspite of the application of different forms of analysis of variance it remained difficult to give a clear explanation of the variation in egg production over time. However, studies have shown that when egg producion in chickens is summarised on a weekly, bi-weekly or monthly basis, it generally increases to a peak and subsequently gradually decreases. This regularity, though not a steady process over time, is generally denoted as egg production curve in poultry. Therefore, a mathematical model describing such a curve would enable poultry breeders and commercial egg producers to analyse egg production process and to predict annual production from part records.

In commercial egg production, the number of important traits has increased over time and emphasis on the traits used in the selection of breeding stocks has varied due to changes in traits of economic importance. However, the primary trait in layer stocks has always been egg production. Therefore, it is of interest to study the egg-production curve and the possible changes that have occured in egg production as a long-term response to selection.

Several workers (McNally, 1971; Gavora et al., 1971; Timmermans, 1973; Mcmillan, 1981; Gavora et al. 1982, Johari, et al, 1986; Mcmillan et al., 1986; Yang et al 1989; Caston and Ware, 1990) have fitted equations of varying mathematical complexity to poultry egg production curves, expressing production as a function of calender time periods. Tokinson et al. (1969) pointed out that one of the major weaknesses of the conventional

analysis of egg production data is the failure to recognise the entire curves either by the analysis of production at each period or by accumulated production. Comparisons of the "goodness of fit" of these models based on the observed coefficient of determination (R^2), both for individual hens and group mean production totals have also been made (Timmermans, 1973, Gavora et al., 1982; Caston and Ware, 1990). It has been observed (Mcmillan et al., 1986) that although the comperative goodness of fit of model to data is a necessary criterion for its acceptance, however, depending on its intended use, other considerations become involved in the final choice. Consequently, for poultry egg production curves, the ability to predict whole record production from part-records, is one of such important criteria. This is because, the use of early partial records as a selection criterion for annual egg production has been proposed by many workers, since genetic gain measured against time would be improved as the parental age is reduced (Dickerson and Hazel, 1944). Prediction of egg production and egg size is necessary for economic projections for laying hens. Mathematical models provide one means of predictions, but they are sometimes inadequate due to poor extrapolative properties or abnormal deviations from expectations (Adams and Bell, 1980). Therefore, in assessing the relative merits of models describing poultry egg production records, the accuracy of predicting full record from part record production becomes highly important.

Furthermore, genetic analysis of the model parameters for heritability and correlations would aid in decision making with regard to whether it is better to select on individual parameters or function of the parameters (such as total egg production). For example, Timmermanns (1973) observed that the parameters in the compartmental model described by

Gavora et al., (1971) changed substantially in a selection experiment with two genetically different strains.

All of these investigation appeared to have been carried out mainly in the temperate regions. Thus, there is paucity of information on the nature of egg production curves in layer type chickens bred in tropical areas, where environmental factors are known to influence egg production tremendously. Therefore, this study attemps to provide such information based on knowledge gathered from previous works.

Hence, the objectives of this study are;

1. To evaluate the adequacy of six (6) mathematical models in describing egg production curves.
2. To examine the suitability of chosen models in predicting total 52-week egg production from part-record data.
3. To obtain genetic estimates (heritabilities and correlations) for curve parameters and production traits.

2.0 LITERATURE REVIEW

2.1 Evaluation of mathematical models of poultry egg Production

Total weekly, bi-weekly or monthly egg production from groups of hens, when plotted on a time scale, give curves that can be expressed mathematically. Several mathematical models describing egg production curve have therefore been suggested. Such mathematical models of poultry flock egg production usually combine increasing and decreasing terms to approximate the shape of egg production curve. Various workers have used common growth functions (Richards, 1969) as the increasing term. Thus, the monomolecular growth curve was incorporated into the compartmental model by McMillan et al., (1970), while Adams and Bell (1980), Mallard (1982), Cason and Britton (1988) and Yang et al. (1989) used the logistic growth curve. Similarly, Mallard (1982) tested an egg production curve using the Gompertz growth curve. On the other hand, the decreasing term of poultry egg-production models has often been e^{-bt}, where e is the base of natural logarithms, t is time, and b is a parameter estimated from observed data. This curvilinear term, suggested by Brody et al. (1923) has been tested in various models (Wood, 1967; McMillan et al., 1970; McNally, 1971; White et al., 1978; Mallard, 1982; Cason and Britton, 1988; Yang et al., 1989) and found to be applicable to the decline in poultry egg production with age. However, Adams and Bell (1980) used a straight line for the decreasing term, which was subtracted from the increasing term rather than being multiplied by it as in the case with the decreasing term. The following curves have been studied; Exponential (Brody et al., 1923), Parabolic exponential (Sikka, 1950), Gamma-type function (Wood, 1967), modified Gamma-type function (McNally, 1971), Inverse polynomial function (Nelder, 1966) and Linear regression.

2.1.1 Lactation models in Dairy cattle and their application to Poultry egg production curve

(a) Uses of lactation models

Several models have been proposed for the lactation curve in the last sixty years. The importance of Mathematical models for lactation curve in dairy cattle cannot be over-emphasized. Many studies have shown that models can be used to predict total lactation from partial records(Wood, 1969; Kellog et al. 1977; Schaeffer et al. 1977).

Similarly, the use of lactation models for extension is of value to dairy management (Wood, 1969). For example in Great Britain, predicted production is compared to actual production to determine the economic effect of changes in management in dairy cows.

Extension is also important for sire evaluation, as it allows for early proofs on young sires and more accurate proofs on sires in service. Models for lactation can be used to compare sires for transmission of curve characteristics. Wood (1968) used parameters in a mathematical model to compare sire-daughter groups for persistency in dairy cows.

(b) Description of proposed egg production models and related research

As the profile of egg production curve in poultry bears much resemblance to the curve of milk yield in dairy cattle, various workers have suggested the application of functions which have been found to fit lactation data in cattle as a basis for mathematical models for poultry egg production. Thus, the models which are described below have orginally been applied to lactation in dairy cattle, but their usefulness in describing egg production in poultry have also been confirmed.

i) Exponential Curve

Brody et al., (1923) were probably the first to suggest the curvilnear term as being applicable to the decline of egg production as poultry flocks age. Therefore, they described egg production using the exponential equation:

$$Y_t = ae^{-bt}$$

Where Y_t = egg production in time period t. and a and b are parameters.

Obviously, this model describes mainly the declining phase of egg production. Thus, the inability to describe both the inclining and declining phases at the same time has been considered as a major draw back to this model. Johari, et al., (1987) observed that R^2 values obtained for egg production curve analysis in White Leghorn varied from 1.7-13.9% when the model was fitted. The constant, b, has been used as a measure of persistency in lactation curve in cattle (Turner et al. 1923; Gaines, 1927; Gaines, 1931; Gooch, 1935, Sikka, 1950; Lennon and Mixner, 1958).

Shortly after their initial attempt to describe the scope of the lactation curve, Brody et al. (1924) suggested a second model:

$$M = a\exp(-K_1 t) - b\exp(-K_2 t)$$

The parameters are a, b, k_1 and k_2. The production in time period t is represented by M.

This model has the advantage of describing both inclining and declining phases of the lactation. Likewise, McMillan (1981) observed that total weekly or bi-weekly egg productions from groups of hens, when plotted on a time scale, give curves that can also be expressed mathematically as;

$$Y_1 = a(e^{-K2t} - e^{-K1t}),$$

which was similar to the equation of Brody et al. (1924).

Y_t represents the total group egg production during period t. The k_1 and k2 are instantaneous rates of increase and decrease, respectively in egg production. This equation is commonly referred to as a compartmental model and has been used extensively in phamacokinetic work (Wagner, 1971) to estimate drug concentrations in compartments of lung systems (blood, muscle etc) after administration by tablet or inoculin. McMillan (1981) reported that values for the coefficient of determination (R^2) indicate relatively good fits of the model to the data studied.

(ii) Parabolic Exponential

Sikka (1950) introduced the Parabolic Exponential model for lactation which is expressed as;

$$Y_t = ae^{(bt + ct2)}.$$

when applied to egg production curve Y_t = egg production in time period t, and A, b, c are parameters.

This model however describes the rising and falling phases of egg production curve in contrast to Exponential model. Johari et al., (1987) also reported a range of R^2 values of 34.3 to 73.3% when the model was fitted to hen housed egg production data of White Leghorn breed. For lactation, there was, however, no significant improvement over the exponential model in 52% of the lactation fits.

(iii) Gamma-type function

Like the preceeding models the incomplete gamma type function, generally called the Wood model, was not originally developed for poultry egg production, but milk production in dairy cattle. Wood (1967) used a gamma curve to describe both the initial increasing and subsequent declining phases of lactation curve and the model takes the form;

$$Y_t = at^b e^{-ct}$$

Where a, b, c are parameters and Y_t is the production in time period t.

Total production Y can be obtained by integrating the above equation. Simplification yields

$$Y = a\, c^{-(b+1)}\, \Gamma^{(b+1)}$$

where $\Gamma^{(b+1)} = b\, t^b e^{-t}\, dt$

This is why the model is referred to as a gamma curve. In the logarithmic forms

$$\ln(Y_t) = \ln(a) + b(\ln(t)) - ct.$$

Estimates of parameters can be obtained using linear least squares. When all parameters are positive, the model describes both the inclining and declining phases. Several workers have reported that the model gave good fits to egg production data with mean R^2 values ranging from 67.3% - 89.9% (Gavora et al. 1982; Johari et al., 1987 and Yang et al. 1989). Similarly, various authors have examined the ability of the model to predict total 50-wk production from partial records of varying length (McMillan et al., 1986; Yang et al., 1989). Compared to other models, it was reported that the Wood model was consistently farthest away from and below the actual value in its prediction (McMillan et al; 1986). Congleton et al., (1981) found this model unable to abruptly change from a positive to negative after an initial steep slope. They observed that there is no inflection point in the intial period for the model which leads to

greater systematic errors in model fitting. Wood (1968) has used the functions of this model to estimate persistency (s) of production. The persistency of lactation yield has been found to be a useful tool in assessing the productivity of a cow. It is a measure of how consistent a cow is able to maintain its level of peak production during the entire lactation. This parameter, persistency of yield (S) was calculated according Wood (1968) as:

$$S = -(b+c) \log_e t$$

which is a function of the rate of rise and decline from the peak. Higher values of S indicate higher persistency.

(iv) Modified Gamma-type function

McNally (1971) observed that the variation of the number of eggs produced by groups of hens with time over a laying year has the same general form as that of milk yield over a lactation. Thus, the function of Wood (1967) which was reported to provide a good fit to lactation data in cattle was adopted by McNally (1971). He presented a modification to describe poultry egg production by the addition of an extra term proportional to the square root of time to the right hand side of the equation earlier proposed by Wood (1967). The McNally's model is:

$$Y_t = at^b e^{(-ct+dt^{1/2})}$$

where a, b, c and d are parameters and Y_t is number of eggs in time period, t. This modified Gamma type model was reported by McNally (1971) to improve the fit to egg production giving multiple correlations ranging from 0.936 - 0.994 as compared to the values of 0.863 - 0.959 obtained with Woods's model when fitted to the same data set.

(v) Linear regression

In contrast to the other models, the Linear model is the simplest to deal with in terms of computing and interpretation.

The Linear equation is given by;

$$Y_t = m - kt$$

where m and k are constants determined by the fit of average total group egg production Y, over time,t. Gavora et al. (1982) observed that both the Compartmental and Wood models gave a better fit to the data than the Linear, with the Linear model explaining on the average only slightly more than one-half of the total variation in individual egg production. However, for hens without pronounced peak of egg production or where the highest production was observed in the first period, egg production data were generally fitted equally well to all the three models. This implies that both the exponential models approached a straight line over the actual time interval considered in such cases. Thus, records starting at the peak and then decreasing could be expected to be fitted as well or better by a Linear regression than by either Compartmental or Wood model. From this it would appear that for an optimum fit to individual egg production records it may be necessary to decide, on the basis of a preliminary examination of each record, which model is best suited for the pattern and only then proceed with the fit itself.

McMillan et al. (1986) reported that the predictive ability of the linear model was greatly improved when the eggs produced in the initial five weeks of production were omitted from the fitted regression. This was in contrast to the procedure adopted by Gavora et al., (1982), where the curve was fitted to the entire production period. Thus, they concluded that it is inappropriate to use early non-linear part of egg production curve when using a Linear model, even with data

synchronized on age at first egg. However, with this procedure, the Linear model cannot be compared fairly on an R^2 basis with the other models which incorporate data from the initial week of egg production and must account for the early part of the production curve not included within the range of the Linear regression model. However, in practice, it would not be difficult to record egg production over the first few weeks of lay, then fit a linear regression to data collected over specified period of production. The implication of the latter approach of fitting the linear regression to each of the phases of the curve is that it will be difficult to exactly determine the peak production.

(vi) Inverse Polynomial

The funciton described by Nelder (1966), which is expressed as;

$Y_t = t(a+bt+ct^2)^{-1}$

has been used to describe lactation curve in cattle and adapted to egg production data to describe egg production curve in White Leghorn by Johari et al. (1987). The parameters are a, b and c. As before, Y_t represents egg production in time period t, 'a' is the rising extreme of the curve (depicting peak production) and 'c' is the descending phase (rate of decline of production). After transformation linear least-squares can be used to obtain parameter estimates (Nelder, 1966). For lactation curve, Wood (1969) found the Gamma curve to explain more of the total variation than this model. In contrast, however, others (Singh, 1973, Yadav et al., 1977) found the inverse polynomial to be superior. Similarly, Johari et al. (1987) reported that for all egg production records studied, the best fitting curve was obtained with the Nelder's Inverse polynomial, with R^2 values ranging from 97.6 to 99.7% which was much more higher than values obtained for other models.

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(vii) Compartmental Model

This was originally applied to egg production in the fruit fly (Drosphila melanogaster) by McMillan et al. (1970a,b). They provided physiological interpretations for the model parameters and derived formulae for estimates of egg production during any given period of interest. The model is expressed in the following form:

$$Y_t = a(1-e^{-c\,(t-d)})e^{-bt}$$

The parameters are a, b c and d, where 'c' and 'b' are the instantaneous rates of increase and decrease, respectively in egg production of the group, and 'a' is the maximum potential egg production the group could achieve (McMillan, 1981). The time lag parameter 'd' relates to the age of sexual maturity (Gavora et al., 1982). The model implies that egg production is under the influence of two exponential components. Gavora et al. (1971) noted that when expressed on a weekly, bi-weekly or monthly basis, the shape of the poultry group egg production curves appeared to be similar to the pattern observed in Drosophila on a daily basis and found that the curve provided a satisfactory description of such data. They reported that initially the rate of production is increasing rapidly according to the component;

$$a(1-e^{-c(t-d)}).$$

This function describes the build up of some factor (or factors) which govern egg production. However, the actual build up does not tend asymptotically to 'a' and remain there but is dampened by some other factors which correspond to the component of decrease,

$$e^{-bt}.$$

This is the dominant component after egg producion has reached its maximum value. The compartmental model has been studied more extensively (Gavora et al., 1971; Timmermans,

1975; Macmillan, 1981) and has been described to have a stronger theoretical background than the Wood and McNally models (Cason and Britton, 1988). In all three models, egg production is represented as the product of various increasing terms and a common curvilinear decreasing term.

However, whereas the other models are intrinsically linear and can thus be transformed, the compartmental model is non-linear and is not fitted with ease. Several workers have applied the model to egg production in poultry with fairly good results (Gavora, et al., 1971; Timmermans, 1973; McMillan, 1981; Gavora et al., 1982; McMillan, et al., 1986, Yang et al., 1989). Thus, Timmermans (1973) showed that this model gave a good fit to the observed poultry egg production data in constant environment. Gavara et al. (1982) summarized egg production data for each hen into 28 days periods, starting from the day of first egg, thus removing the influence of sexual maturity on egg production data; they found that the compartmental model gave an excellent description of synchronized egg production. The R^2 values reported in literature range from 0.673 - 0.98. Similarly, the Compartmental model performed quite well in its predictive ability which is comparable to the Linear model while the Wood model did not (McMillan et al., 1986). However, for production records that peaked more gradually, the difference between the Compartmental and Wood models was negligible with respect to the R^2 value. Furthermore, it was observed that for hens without any pronounced peak of production, or where the highest production was observed in the first period, egg production data were generally fitted equally well by all three models.

(viii) Modified Compartmental models

Several workers have attempted different modifications of the Compartmental model and have applied these to egg production data with fairly good results (Adams and Bell, 1980; Cason and Britton, 1988; Yang et al., 1989).

In proposing a new mathematical model of poultry egg production, Yang et al. (1989) observed that the compartmental model still has some limitations in its mathematical properties when applied to the mean egg production in groups of hens on the basis of hens' chronological age. There is a slowly increasing slope at the initial stage of the chronological egg production curve, and the length of the period varies with the uniformity of sexual maturity and egg production potential of the hens. Hence, the model cannot accurately characterize this short period of increase and retains considerable systematic errors in model fitting, allowing negative estimates of production. More importantly, most further applications of the mathematical models of poultry egg production, such as to predict annual egg production and to determine the optimum culling age of layers, depend on an egg production curve based on chronological age.

As both the compartmental model and Wood model have limitations in their arithmetical properties, new models that would give a better description of egg production on the basis of the hen's chronological age are needed.

Gavora et al. (1971) presented an idea that the increasing slope in group records would be a result of variation in the age of sexual maturity of individual hens forming the group. McMillan (1981) re-analysed the compartmental model for poultry by considering that the females begin their egg production at a maximum rate succeeded by an exponential decay, and incorporated the variation of sexual maturity, which was assumed to follow an exponential

distribution. It is not clear that the distribution of sexual maturity is exponential, nor that the change of egg production potential in laying hens is simply an exponentially declining process. However, the analysis allows the derivation of a new model, presented below;

$$Y_t = ae^{-bt}/[(1+e^{-c(t-d)})]$$

in which the biological interpretations of the relevant parameters are;

a = a scale parameter, b = the rate of decrease in laying ability, c = the reciprocal indicator of the variation in sexual maturity, and d = the mean age of sexual maturity of the hens. This model could be considered as a modification of compartmental model and hence called modified compartmental model.

The new model has an inflection point in the initial period of lay when the age of the flock approaches d in magnitude. The peak of fitted egg production curve occurs at;

$$t_{max} = d + |\ln(c-b) - \ln(b)|/c$$

and the peak production then is;

$$Y_{max} = [ab\, e^{\{b|\ln(b)-\ln(c-b)-bc|/c\}/c}]/c$$

when the age gets greater than t_{max}, the curve decreases gradually until the laying period ends.

A different type of model was suggested by Adams and Bell (1980), with egg production equal to the difference between a sigmoid increasing term and a linear decreasing term, but no comparative statistical information was given. They observed that a general function relating percent hen-day production (Y) to the age of the flock (X) is composed of two parts; a growth curve

$$Y_t = \frac{1.0}{.01+ar^{(x-b)}}$$

which describes the effect of maturation on production, and a detrimental linear aging effect

$$Y_2 = c(x-d)$$

which is subtracted from the growth curve to produce the general function

$$Y = Y_1 - Y_2$$

$$\{\text{ie } Y = \frac{1.0}{.01 + ar^{(x-b)}} - c(x-d)\}$$

for percent hen-day production versus age, where X = age of flock, Y = percent hen-day production, and a, b, c, d are constants to be evaluated.

However, Cason and Britton (1988) decided to make a three-way comparison between the compartmental model, the Adams-Bell model, and an invented model (referred to as a logistic model) incorporating features of each.

As usual, they expressed the compartmental as;

$$P = a(e^{-bt})(1-e^{-c(t-d)})$$

and the Adams-Bell model as;

$$P = .07|1/.01 + ar^{(t-b)}) - c(t-d)|$$

while the logistic model was expressed as;

$$P = a(e^{-bt}) \; |1/(1+e^{c+dt})|$$

In all models, P = egg production in time period t, t = age of flock in weeks, e = base of natural logarithms, and other letters represent constants to be evaluated.

The original Adams-Bell model predicted percentage egg production and was multiplied by .07 to convert to eggs on a per week basis. The Logistic model was invented in order to combine the decreasing term (e^{-bt-t}) of the compartmental model and in increasing term that is a logistic growth curve similar to the increasing term of the Adams-Bell model.

In the analysis of flock egg production curves using generalized growth functions, Cason and Ware (1990) confirmed that the logistic model proposed by Cason and Britton (1988) is identical to the modified Compartmental model of Yang et al., (1989). Also, they noted that the original Adams - Bell model performed only slightly better than the logistic model and predicted future production as well as linear regression did. Thus, they concluded that a two-parameter linear model represents a simple approach, compared with complex non-linear models with four to six parameters.

2.2 Predicting Poultry Egg production

One of the objectives in establishing a mathematical model of egg producion is to predict whole records production from part-record: the predictions play important roles in early selection, production planning, and economical decision making (Yang et al. 1989). Predictions of egg production and egg size is necessary for economic projections for laying hens.

For prediction of full record production from partial record data, McMillan et al., (1986) found both Compartmental and Linear models to be very accurate and deviations from prediction were reduced as the number of weeks in the partial record increased to 24 week. Also, they observed that the Linear model was superior to the Compartmental model for its predictive ability for one strain and equal for the other two strains. Consequently, they concluded that when the model is intended to predict full record egg producion from the partial record, the Linear model is better because of its simplicity.

Yang et al., (1989) compared the predictive abilities of three mathematical models, namely, the Wood, the Compartmental and the modified Compartmental developed by them. Their results suggest that both the modified Compartmental model and the Compartmental model have fairly good abilities to predict. The Wood model however, had the greatest errors in

prediction, and the predicted numbers were smaller than the actual values, similar to the results of McMillan et al., (1986). Thus, they reported that the new model proposed by them namely, the modified Compartmental model, not only has theoretical advantages over the Compartmental and Wood models, but also appears better in respect of its goodness of fit to the data and its ability to predict.

Similarly, Cason and Britton (1988) made a three-way comparison between the Compartmental model, the Adams-Bell model and an invented model (referred to as a logistic model) incorporating features of each. Their results showed that the Adams-Bell and logistic models yielded significantly smaller prediction errors than did the Compartmental model for the predicted total egg production based on fits to 24 wks of egg production data for first cycle flocks. However, there were no significant differences in prediction errors for molted flocks. The Compartmental model consistently predicted less than the actual total egg production, with Admas-Bell and Logistic models tending to over-estimate production. Thus, for complete or partial egg production data and for predicted egg production, Adams-Bell and Logistic models consistently out performed the Compartmental model when applied to first cycle flocks. They observed that as the Logistic model was identical to the Compartmental model except for an Adams-Bell- like increasing term, it appeared that mathematical properties of the increasing terms were important in differentiating between the Compartmental and Adam-Bell models.

Adams and Bell (1980) pointed out that although mathematical models provide a means of prediction, they are sometimes inadequate due to poor extrapolative properties or abnormal deviations from expectation. Models which do not fit data accurately or which do not extrapolate reasonably, cannot contribute to a reliable economic projection. Thus, the choice of model is

often difficult, especially when the purposes it serves are not clearly defined.

2.3 Genetic estimates for Curve parameters and relationships with egg production traits:

In commercial egg production, the number of important traits has increased over time and emphasis on the traits used in the selection of breeding stocks has varied due to changes in their economic importance. However, the primary trait in layer stock has always been egg production. The common objective of commercial breeders of laying stocks is to increase the number of egg produced per unit of time. The use of early partial egg records as a selection criterion for improving annual egg production has often been cited as a procedure for obtaining this objective in the shortest time (Bohren. 1970) Hence, it is of interest to study the egg-production curve and the possible changes that have occured in the production as a long-term response to selection. Therefore, with a careful analysis of the appropriate data it should be possible to obtain heritability estimates of the model parameters. This would aid in a decision making as to whether it is better to select on individual parameters or on functions of the parameters such as partial or total egg production.

However, reports have indicated that selection based on partial or whole record ingnores the possiblity that different periods within the record may have dissimilar genetic parameters. Data analysed by Flock (1977) supported this observation. He subdivided 48-wk egg production into six independent 8-wk periods. Heritability was highest in the first 8-wk period and lowest at peak production. Thus all parts of the record should not have equal weights, as when selection is based on a simple average. The implication of the heritability being highest in the first 8-week period is that improvement of annual egg production based on selection on part-year

production is feasible, since there is high genetic correlation between past-year and annual production. Therefore, using part-record production which is highly heritable, to select for annual total is desirable. Similarly, VanVleck and DooLittle (1964) reported that differences in sexual maturity influence the measure of egg production in the first, and to a lesser extent later months. They noted that intensity of production certainly enters into all monthly records, and is probably the primary influence on production after the second month until differences in persistency and viability begin to have a major effect which increase in improtance with time. Thus, they reported that the low heribability estimates from month two through six indicate that heritability of intensity of production is low.

With regards to estimates of correlation of monthly production with yearly total, VanVleck and DooLittle (1964) also reported that highest estimates were for the middle months and the lowest for the first two or three months. This probably implies that after the thrird month of production, essentially the same effects apparently contribute to monthly as to annual egg production. They therefore concluded that selection for total annual production based on production from a single month will not be satisfactory unless the month chosen is one in the later part of the laying year. If, however, cumulative records are used (such as part-production), the decreased generation interval resulting from selection on the part record will probably more than offset loss in efficiency if records are taken for about half of the full laying year. Conventionally, part-record production data for 16, 20 or 24 week are used as selection creterion for the improvement of annual egg production.

McMillan et al., (1990) reported on changes in egg production curves, 1950-70, using results from the North American random sample tests of multiple trait selected stocks, and they

observed that more modern strains have the genetic potential to mature earlier, come into egg production faster, peak higher and maintain egg production better than strains of earlier origin. It is also apparent from the egg weight data that this trait has improved inspite of the higher numbers of eggs produced within the laying cycle. Also, it was reported that the commercial layers improved genetically in the decade from 1970 to 1980. Egg production and viability are traits with very low heritabilities which require major selection effort to improve, yet they have shown genetic improvement. The genetically improved egg size is very unlikely to have resulted from chance as egg production and egg size are negatively correlated genetically in most layer stains (Gowe and FairFull, 1984). Thus, multiple trait selection appears to have been one of the major factors contributing to the continued improvement of egg producing poultry strains.

3.0 MATERIALS AND METHODS

3.1. Location of the Study

The study was conducted at the National Animal Production Research Institute (NAPRI), Shika, lying between latitudes 11 and 120N at an altitude of 640m. The area falls within the northern guinea savannah zones. The average annual precipitation is 1100mm, which spreads from late April or early May to mid-October, with a peak between June and September (wet season). The wet season is usually followed by 'harmattan', a period of cool, dry weather which lasts from mid-october to January (post rains). This is followed by dry, hot weather from February to May (pre-rains). The mean maximum temperature varies from 27 to 35°C depending on season, and the mean relative humidity during harmattan and wet season are 21 and 72% respectively.

3.2 Stock Composition and Management

3.2.1 Stock Composition: The hens used for this study were obtained from a random-bred population of breeder hens which form part of the poultry breeding flocks maintained at the institute. The birds comprised of two strains of Rhode Island breeder hens, termed strains A and B.

The initial stocks (Grand-parents) comprise two different strains (A & B) of egg-type chickens each with 2 lines (male and female lines). These birds, even though from different sources, were segregating for same type of colour genes i.e gold/silver. The males and females of the sire side were gold, while those of the dam side were silver. These initial stocks were

mated to produce F_1, using a checker board arrangement (Punnet Square matings). They were mated in all possible combinations, but keeping the sire and dam sides as discrete populations. This gave rise to $4F_1$ progeny genotypes for each side. The matings for the formation of F_2 were set up using a 4 x 4 diallelic crossing technique, to produce 16 different combinations in the F_2. After the formation of the F_2 generation, the genotypes were randomly mated for one more generation to produce the F_3, which formed the base generation.

The selection programme commenced with chicks after this F_3 generation.

3.2.2 Procedure for selection: The base generation was divided into six (6) populations (i.e 3 each for male line and female line) with about 500 birds per population. The populations are the control, single trait (egg number) and multiple trait (egg number and egg weight). In this base generation, because of lack of pedigree information, rate of lay (which was 120 days egg production for each hen) was used as a basis for the first generation for selection. The males were however selected on body conformation using phenotypic appearance. But from generation two, the selection programme was adjusted so as to concentrate selection on egg number only on four populations, with independent culling levels set on egg weight and body weights at housing and at maturity. Also, 1000 hens were used for the selection populations out of which 250 were selected. For the control populations, about 108 hens were randomly picked as parents for next generation from about 250 hens. Pen-mating was carried out by trap-nesting using a mating ratio of 1 male : 9 females. Thus, selection was practiced for a single trait, i.e. number of eggs up to 280 days of age (as opposed to 120 days egg production for each hen used during the 1st generation). The selection was based on an index which combines information on

individual production and the sire and the family averages.

The selection indexes used in this study were derived as per Hazel, (1943) and Osborne (1957a,b). The prediction of a female's breeding value is obtained from her own phenotype (performance) and the means of her full-sisters and half-sisters. Since virtually all the traits studied are manifested in females only, the information gathered in order to predict a male's breeding value is reduced to the means of his full-sisters and half-sisters. Thus , the general outline of the selection indexes are;

$$I(♀) = (P - X) + B_1 (D - X) + B_2 (S - X)$$

$$I(♂) = B_3 (D' - X) + B_4 (S' - X)$$

Where X = population mean for the trait.

P = a female breeding candidate's phenotypic value for the trait.

D and D' = average phenotypic values for the trait of full-sisters of a female and male breeding candidates, respectively.

S and S' = average phenotypic values for the trait of half-sisters of a female and male breeding candidates, respectively.

B_1 , B_2 , B_3 , B_4 = weighting factors

$$B_1 = \frac{2n(1-h^2)}{4+(n-2)h^2} \quad \text{and} \quad B_2 = \frac{4nd(1-h^2)(2-h^2)}{|4+(n-2)h^2||4+\{n(d+1)-2\}h^2|}$$

$$B_3 = \frac{nh^2}{4+(n-2)h^2} \quad \text{and} \quad B_4 = \frac{2ndh^2(2-h^2)}{|4+(n-2)h^2||4+\{n(d+1)-2\}h^2|}$$

Since the birds for each generation were usually hatched over more than one hatch, data

were usually corrected for hatch effects using Least squares procedures described by Harvey (1975) if hatch effect was found to be significant. The hatch corrected data were used in subsequent genetic analysis.

3.2.3 Stock Management

The birds were brooded and reared to 18 weeks of age in deep-litter floor pens. Floor space allowed per bird varied from 0.15 to 0.50m^2 depending on age of bird. Feed was provided based on body requirement from hatching until 18 weeks of age on standard diets or rations formulated at the Institute containing a minimum of 18 and 14% crude protein for chick and grower diets, respectively. They were then randomly placed in individual cages, 500 pullets for each strain. At laying, birds were fed ad-libitum on layer ration containing about 16% crude protein and drinking water was available at all times.

3.3. Data Collection

For each bird, egg production was summarised into 28-day periods, starting from the day the pullet laid the first egg which was always recorded. The individual hen records were grouped by record length in terms of the number of 28-d periods in the first production cycle. Within each group, mean egg production was calculated period by period. Egg production records from point of lay up to the 52nd week in lay were examined in this study.

3.4 Analytical Procedure

3.4.1 Screening of Data for Analysis: The individual hen records were then examined closely to determine whether the bird produced eggs in one or more "egg production cycles" or whether there was any irregularity in the egg production. Thus, if egg production in any one 28-d period (except the 1st two periods) decreased below a minimum of 50% of the mean of the two immediately preceeding periods, then, subsequent egg records for such hens were excluded from the analysis. These restrictions imposed were intended to eliminate;

(a) the records of hen which were either considered as starting a new egg production cycle beginning from the period in which sudden decrease occured (Gavora et al., 1982), or

(b) the effect of disease or other factors that may result in irregular egg production (McMillian et al., 1986).

After these restrictions, the total number of records remaining was 484 and 471 for strain A and B, respectively. For the estimation of genetic parameters, the data set was further edited to remove the records of hens with single offspring per dam from full model analysis, since such records may not be representative of the dam family concerned. The records edited out due to the above condition were 40 and 50 for strain A and B, respectively.

3.4.2 Models Fitted

Each model was fitted independently to data collected on each strain of breeder hens. Denoting egg production in the 28-d period starting from the day of 1st egg by Y_i, the following curves were studied;

(a) Linear regression.

$$Y_t = m - kt$$

(b) Exponential Curve (Brody et al., 1923)

$$Y_t = ae^{(-bt)}$$

(c) Parabolic exponential (Sikka, 1950)

$$Y_t = ae^{(bt + ct2)}$$

(d) Gamma type Function (Wood, 1967)

$$Y_t = at^b e^{(-ct)}$$

(e) Gamma type Function (McNally, 1971)

$$Y_t = at^b e^{(-ct + dt^{1/2})}$$

(f) Inverse polynomial (Nelder, 1966)

$$Y_t = t(a + bt + ct^2)^{-1}$$

To examine the fit of each equation to the data, the functions were transformed to the linear forms as follows;

(a) Exponential

$$Log_e Y_t = Log_e a - bt$$

(b) Parabolic exponential

$$Log_e Y_t = Log_e a + bt + ct^2$$

(c) Gamma type function (Wood)

$$Log_e Y_t = Log_e a + bLog_e t - ct$$

(d) Gamma type function (McNally)

$$Log_e Y_t = Log_e a + bLog_e t - ct + dt^{1/2}$$

(e) Inverse polymonial (Nelder)

$$1/Y_t = at^{-1} + b + ct$$

The latter were fitted to the 28-d mean egg production for groups of hens, within strain, over 52-weeks of production on a hen-housed basis, for the estimation of the curve parameters and R^2 values. In all the models, the constants a, b, c, d, m and k represent the model parameters as defined by the above equations and have their specific significance in each model. Generally, Y_t is the number of eggs laid by an individual or the average number of eggs laid by the group over the period, t; b and c represent the rate of increase and decline of production, respectively in egg production of the group, and a is the peak production the group could achieve.

3.4.3. Choice of models and their predictive abilities

The choice of model is often difficult, especially when the purpose it serves is not clearly defined. In the present study, the predictive aspect of the models was to be the main concern for determining the adequacy of the equations. Thus, the parameters used in assessing the suitability included both the general goodness of fit and the predictive ability of the models.

a) ***Criteria of goodness of fit***

(i) Coefficient of determination (R^2)

One of the criteria for judging the goodness of fit was the coefficient of determination, viz R^2 (Seber, 1977). This measures the amount of variability accounted for by the fitted model. High R^2 values indicate adequacy, while low values indicate inadequacy of the model.

Generally, an R^2 of about 70% or above is considered to indicate a good measure of fittness (Olorunju, 1991). The mean R^2 values of the individual egg production records will be compared by paired t-test between pairs of models within each egg production cycle length to allow for correlated measures. The effect of cycle length on goodness of fit of the models will be examined by a one-way analysis of variance of the R^2 values for the individual hen records within each model.

(ii) Predictive abilities of models

One of the objectives in establishing a mathematicall model of egg production is to predict whole record production from part-records. The predictions play important roles in early selelction, production planning, and economic decision making. Thus, the model that is able to make the most accurate prediction when compared to the actual will be more reliable. Part records can thus be used to predict the total egg production. A model that will serve this purpose will be an asset to the farmer and breeder. For the prediction of total 52-week egg production from part-record data of 16, 20 and 24 weeks, monthly mean egg production for each strain over the appropriate part record data was fitted separately with each of the models to be chosen and extrapolations of the areas under the resulting curvses to 52 weeks will be made. The predictive capacity of the models will be tested by comparing predicted total egg production based on fits of the three models to part-record data with actual total egg production using the following criteria;

a) **Error (%) in estimation of 52-wk egg number from part-record (24-wk):** This will be obtained by subtracting the predicted 52-wk egg number from the

observed. The resultant value was then divided by the observed value and multiplied by 100. This will give an estimate of the % deviation of the predicted 52 wk production from the observed.

b) **Deviation of estimated time of peak (expressed in number of 28-d periods)**: This will be obtained by subtracting the projected peroid of the estimated peak from the actual period of the observed peak. This gives an idea of whether the predicted time of peak using the models will be early, delayed or same as the observed time of peak.

c) **Deviation in estimated peak production (%)**: Similarly, this will be obtained by substracting the estimated peak production from the observed peak production. The resultant value is then divided by the observed peak value and multiplied by 100. This gives an indication of the % deviation of the predicted peak production from the actual peak production.

(iii) Ease of use

Furthermore, another consideration in the choice of model was the practical applicability and ease of use. Thus, any model chosen must not just provide parameter estimates, but must provide estimates that have biological interpretations (Yang, et al., 1989). Similarly, Seber (1977) reported that there is no use fitting a model that requires estimation of several parameters when it is possible to fit a model that requires fewer parameters that can equaly provide precise measure of fittness.

3.4.4 Estimation of variance components, heritability and correlations

A two-way nested random model (dams within sire) will be used to estimate the variance/ covariance components, using the mixed model least-squares and maximum likelihood (LSMLMW) computer programme (Harvey, 1990) from which the heritabilities and correlations will be derived by full-sib analysis. The model will be as follows;

$$Y_{ijk(m)} = \mu + S_i + D_{ij} + e_{ijk}$$

where, $Y_{ijk(m)}$ = Observation of m^{th} trait on the k^{th} hen in the ij^{th} dam group and i^{th} sire group.

μ = Overall population mean.

S_i = effect of the i^{th} sire; D_{ij} = effect of the j^{th} dam mated to the i^{th} sire.

e_{ijk} = error term associated with individual observation. It was further assumed that the S_i, d_{ij} and e_{ijk} were random variables, independently and identically distributed each with zero mean and variances S^2_m, D^2_m, and E^2_m, respectively. Covariance components betweeen traits m and m' can be denoted as $S_{m,m'}$, $D_{m,m'}$, and $E_{m,m'}$. Covariances will be calculated using the relationship;

$\sigma^2_{(m+m')} = \sigma^2_{(m)} + \sigma^2_{(m')} + 2Cov_{(m,m')}$ and so, $Cov_{(m,m')} = \frac{1}{2}\sigma^2_{(m+m')} - \sigma_{(m)} - \sigma_{(m')}$

Heritability will be be obtained from the estimated components of variance such as;

$$h^2_{s+d} = \frac{2(S^2 + D^2)}{T^2}, \text{ where } T^2 = S^2 + D^2 + E^2$$

Genetic and phenotypic correlations will be estimated using sire and dam components of covariances such as;

$$r_{g(s+d)} = \frac{S_{m,m'} + D_{m,m'}}{\{(S^2_m + D^2_m)(S^2_{m'} + D^2_{m'})\}^{1/2}}$$

$$r_{p(s+d)} = \frac{S_{m,m'} + D_{m,m'} + I_{m,m'}}{[(S^2_m + D^2_m + E^2_m)(S^2_{m'} + D^2_{m'} + E^2_{m'})]^{1/2}}$$

where, r_g = genetic correlation between traits m and m'

r_p = phenotypic correlation between traits m and m'

In view of the small number of data set for the full-sib analysis, a separate one-way random model will also be tested using a larger data set to estimate the variance/covariance components from which the heritabilities and correlations will be derived by paternal half-sib analysis, so as to provide data for comparative study with regard to the estimates and the standard errors.

The model is: $Y_{ij} = \mu + S_i + e_{ij}$

where Y_{ij} = Observation of j^{th} offspring of the i^{th} Sire

μ = Overall population mean

S_i = The effect of the i^{th} Sire

e_{ij} = Random error associated with individual observation.

and: $h^2_s = \frac{4S^2}{T^2}$

while, $r_{g(s)} = \frac{S_{mm'}}{(S^2_m . S^2_{m'})^{1/2}}$

and $r_{p(s)} = \frac{S_{m,m'} + E_{m,m'}}{[(S^2_m + E^2_m)(S^2_{m'} + E^2_{m'})]^{1/2}}$

S^2 may contain variance due to sex linkage and D^2 may contain variance due to maternal effects and variance due to interaction between the Sire and Dam genotypes. The estimates were computed for each trait.

The formulas to be used by the computer programme in calculation of estimates of Heritability, Genetic, Phenotypic and Environmental correlations are shown in Appendix A.

4. RESULTS

4.1: Egg Production length and Choice of Model

Egg production cycle length (i.e number of 28-d periods) varied from 9 to 15 periods, with about 71-84% of the birds having cycles with not less than 13 periods (Tables 1 and 2). The values of co-efficient of determination (R^2) range from 0.16 to 0.95 for strain A (Table 1); being maximum for cycle length 14 in Parabolic exponential and McNally, and minimum for cycle length 10 in linear regression. Similarly, for strain B the R^2 values range from 0.10 to 0.93 with Linear and exponential having the minimum values for cycles length 9, while McNally model had the maximum value for cycle length 13 and 14 (Table 2).

A comparison on the basis of R^2 shows that the mean egg production of the group (for all cycle lengths) in both strains was fitted best by the McNally model followed by Parabolic exponential and Wood model, respectively. Consequently, only these three models were entertained subsequently in this study. Generally, with increasing cycle length, the models result in adequate fit to group egg production data as evidenced by a somewhat higher R^2 for longer cycles, although the values for cycle length of 12 periods (and also for cycle length 11 periods in strain A) were consistently lower than the preceeding cycle length.

The average R^2 values from fitting the above three models to individual production records of different lengths are 0.59 $\pm$ 0.01 for the Parabolic exponential, 0.51 $\pm$ 0.01 for Wood and 0.63 $\pm$ 0.01 of McNally for strain A. While the values for strain B are 0.52 $\pm$ 0.01, 0.47 $\pm$ 0.01 and 0.56 $\pm$ 0.01, respectively.

Table 1: Estimates of coefficient of determination (R^2) for egg production data in strain A.

(Egg Prod. Cycle Length) No of 28-d periods	No. of Hens	Linear	Expon ential	Parabolic Exponential	Gamma Type (Wood)	Gamma Type (McNally)	Inverse Polynomial
9	4	0.42	0.46	0.74	0.58	0.88	0.54
10	8	0.16	0.19	0.94	0.77	0.95	0.64
11	19	0.40	0.40	0.92	0.75	0.93	0.59
12	47	0.29	0.30	0.79	0.58	0.82	0.44
13	104	0.49	0.46	0.87	0.68	0.90	0.54
14	211	0.57	0.55	0.95	0.80	0.95	0.67
15	91	0.62	0.62	0.93	0.83	0.94	0.73

Table 2: Estimates of coefficient of determination (R^2) for egg production data in strain B.

(Egg Prod. Cycle Length) No of 28-d periods	No. of Hens	Linear	Expon ential	Parabolic Exponential	Gamma type (Wood)	Gamma type (McNally)	Inverse Polynomial
9	12	0.10	0.10	0.27	0.29	0.29	0.29
10	26	0.45	0.46	0.69	0.57	0.73	0.53
11	23	0.28	0.30	0.88	0.72	0.85	0.62
12	73	0.39	0.39	0.82	0.63	0.83	0.53
13	97	0.57	0.57	0.91	0.77	0.93	0.69
14	222	0.69	0.67	0.92	0.83	0.93	0.76
15	18	0.79	0.75	0.91	0.87	0.91	0.79

The parameter estimates and R^2 (%) values for each of the three models are shown in Tables 3 and 4. The McNally and Parabolic exponential have significantly ($P<0.001$) higher R^2 values (mean) for individual curves than the Wood model.

Although both the McNally and Parabolic exponential models gave a good fit to the group average egg production data (Table 1 and 2), the mean R^2 values obtained for the two models when fitted to the individual records differed significantly (Table 3 and 4).

The effect of egg production cycle length on the mean R^2 value on fitting the models to individual records, examined for each model separately, by a one-way analysis of variance was found to be non-significant ($P>0.05$) for the McNally and Parabolic exponential models (Tables 5 and 6), but significant ($P<0.05$) for the Wood model (Table 7) in strain A. However for strain B, the effect was non-significant ($P>0.05$) only of McNally (Table 9), but was significant ($P<0.01$) for both Wood and Parabolic exponential models (Table 8 and 10).

The effect of cycle length on the mean R^2 was investigated further within model by considering only hens with production cycle lengths 13, 14, and 15 periods (not shown). For strain A, there was no siginificant ($P>0.05$) influence of these production cycle lengths on the mean R^2 within models except for the Wood model in which there was significant ($P<0.05$) influence on mean R^2 between cycle length 13 and 14 periods. Similarly for strain B, the effect of cycle length was significant ($P<0.05$) on the mean R^2 between cycle length 13 and 14 periods and between 13 and 15 periods only in the Wood model.

Furthermore, the records of the 2 strains were pooled together and the effects of strain and production cycle length on each of the components of egg production curve and also the R^2 within each model were examined by Least-squares procedures. The Least-squares analysis of

variance is shown in Table 11 - 13 and the least-squares means in Tables 14 -16. There is considerable variation between models in the effects of strain and production cycle length on the traits examined. For example with Wood model, strain and production length did not show any significant difference for constant, a. but this component was significantly affected in Parabolic and McNally models.

Table 3: Estimates of model parameters of hen-housed egg production data for groups of hens having thirteen 28-d periods in strain A.

	Parameters*				Grp. Prod.	Indiv. curves
Model	a	b	c	d	R^2	R^2 (Mean)
Parabolic- Expon	2.807	0.087	-0.008	-	0.925±0.048	0.586±0.011[a]
Wood	2.953	0.327	0.090	-	0.753±0.088	0.509±0.010[b]
McNally	-1.005	-1.956	0.614	4.585	0.946±0.043	0.629±0.010[c]

*Constants determined by a least squares LIN-fitting programme.
a,b,c = within a column, means with different superscripts are significantly different ($P<0.001$)

Table 4: Estimates of model parameters of hen-housed egg production data for groups of hens having thirteen 28-d periods in strain B.

	Parameters*				Grp. Prod.	Indiv. curves
Model	a	b	c	d	R^2	R^2 (Mean)
Parabolic- Expon	2.768	0.078	-0.008	-	0.904±0.058	0.521±0.013[a]
Wood	2.908	0.315	0.092	-	0.772±0.091	0.470±0.012[b]
McNallly	-0.533	-1.673	0.550	3.994	0.907±0.062	0.564±0.012[c]

*Constants determined by a least squares LIN-fitting programme.
a,b,c = within a column, means with different superscripts are significantly different ($P<0.001$)

Table 5: Effect of egg production cycle on fitting the Parabolic exponential model to individual records in strain A.

Source	DF	MS	F-Value
Prod. Length	5	0.0543	1.16^{NS}
Error	474	0.0469	
Total	479		

^{NS} (Non-significant)

Table 6: Effect of egg production cycle on fitting the McNally model to individual records in strain A.

Source	DF	MS	F-Value
Prod. Length	5	0.0365	0.93^{NS}
Error	474	0.0393	
Total	479		

^{NS} (Non-significant)

Table 7: Effect of egg production cycle on fitting the Wood model to individual records in strain A.

Source	DF	MS	F-Value
Prod. Length	5	0.0203	2.86**
Error	474	0.0421	
Total	479		

** ($P < 0.01$)

Table 8: Effect of egg production cycle on fitting the Parabolic exponential model to individual records in strain B.

Source	DF	MS	F-Value
Prod. Length	5	0.1672	3.03**
Error	453	0.0552	
Total	458		

** ($P<0.01$)

Table 9: Effect of egg production cycle on fitting the McNally model to individual records in strain B.

Source	DF	MS	F-Value
Prod. Length	5	0.1008	2.09^{NS}
Error	453	0.0482	
Total	453		

^{NS} (Non-significant)

Table 10: Effect of egg production cycle on fitting the Wood model to individual records in strain B.

Source	DF	MS	F-Value
Prod. Length	5	0.2122	4.29***
Error	453	0.0495	
Total	458		

*** $P<0.001$

Table 11: Least squares analysis of variance of egg production parameters for the Parabolic Model.

Sources of variation	DF	Means Squares a	b	c	R^2
Strain	1	1.9670***	0.7270***	0.004***	1.5087***
Prod. Length	3	0.5128**	0 0678***	0.0009***	0.2388**
Error	933	0.1004	0.0107	0.0001	0.0510

** P<0.01, *** P<0.001

Table 12: Least squares analysis of variance of egg production parameters for the McNally Model.

Sources of variation	DF	Means Squares a	b	c	d	R^2
Strain	1	775.4043***	191.6783***	1055.9023***	22.2153***	1.5086***
Prod. Length	3	107.0459	13.8720	125.1446**	3.2541***	0.1200*
Error	934	21.5133	6.7358	29.2926	0.5100	0.0437

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

Table 13: Least squares analysis of variance of egg production parameters for the Wood Model.

Sources of variation	DF	Mean squares a	b	c	R^2
Strain	1	0.0816	8.7340***	0.3922**	0.6842***
Prod. Length	3	0.0865	0.1960	0.0203*	0.3360***
Error	933	0.0649	0.1279	0.0075	0.04611

* P<0.05 *** P<0.001

Table 14 Least squares means of the functions of egg production curve for the Parabolic model.

Classification	No.	a	b	c	R^2
Strain					
A	479	2.6128[a]	0.1583[a]	-0.0154[a]	0.5406[a]
B	459	2.7137[b]	0.0992[b]	-0.0108[b]	0.4687[b]
Prod. Length					
10	34	2.6594[bc]	0.1348[bc]	-0.0147[ac]	0.4493[a]
11	41	2.5901[c]	0.1550[b]	-0.0158[c]	0.5284[ac]
12	120	2.6621[c]	0.1258[bc]	-0.0122[a]	0.4881[a]
>=13	743	2.7415[b]	0.0994[c]	-0.0095[b]	0.5529[c]

Within each variable means followed by the same supercript are not significantly different.

Table 15: Least squares means of the functions of egg production curve for the McNally model.

Classification	No.	a	b	c	d	R^2
Strain						
A	479	-3.547[a]	-2.980[a]	7.368[a]	1.039[a]	0.600[a]
B	459	-1.580[b]	-2.026[b]	5.083[b]	0.704[b]	0.526[b]
Prod. Length						
10	34	-2.616a[b]	-2.467[b]	6.364[ab]	0.921[ac]	0.518[b]
11	41	-2.818a[b]	-2.468[b]	6.326[ab]	0.941[a]	0.585[ab]
12	120	-3.218[a]	-2.852[b]	6.998[a]	0.940[a]	0.55[2b]
>=13	743	-1.602[b]	-2.223[b]	5.215[b]	0.684[c]	0.596[a]

Within each variable means followed by the same supercript are not significantly different.

Table 16: Least squares means of the functions of egg production curve for the Wood model.

Classification	No.	a	b	c	S	R^2
Strain						
A	479	2.8705[a]	0.5484[a]	0.1491[a]	2.6504[a]	0.4630[a]
B	459	2.8922[a]	0.3533[b]	0.1071[b]	4.0523[b]	0.4183[b]
Prod. Length						
10	34	2.8954[b]	0.4370[ab]	0.1319[abc]	3.1475[ab]	0.3944[ac]
11	41	2.8424[b]	0.5361[b]	0.1509[a]	3.0951[a]	0.4785[ab]
12	120	2.8779[b]	0.4161[a]	0.1155[bc]	3.2243[ab]	0.4007[c]
>=13	743	2.9098[b]	0.4142[ab]	0.1140[c]	3.9386[b]	0.4890[b]

Within each variable means followed by the same supercript are not significantly different.

Several criteria of goodness of fit for the different models, including R^2 and errors of estimated 52-week egg number, estimated peak of egg production are presented in Tables 17 and 18. These results show that the McNally model has higher R^2, smaller errors of 52-week egg number and greater agreement of estimated peak with actual peak than the other two models. Thus, for complete or partial egg production data and for predicted egg production, the McNally model consistently out-performed the Wood and Parabolic exponental models.

Predicted egg production curves can be constructed by inserting the estimated parameter values into the model equations. For example, in strain A, the model equations for the three chosen models for hens having thirteen 28-d periods can be expressed as follows:

Parabolic exponential: $Y_t = ae(bt+ct^2)$

$$Y_t = 2.807\ e^{(0.087t - 0.0082)} \qquad (R^2 = 0.925 \pm 0.048)$$

Wood: $Y_t = at^b e(-ct)$

$$Y_t = 2.953t^{0.327}\ e^{(0.09t)} \qquad (R^2 = 0.75 \pm 0.088)$$

McNally: $Y_t = at^b\ e^{(-ct \pm dt^{1/2})}$

$$Y_t = -1.005\ t^{1.956}\ e(-0.614t\ +\ 4.585t^{1/2}) \quad (R^2 = 0.946 \pm 0.043)$$

Similarly, for strain B, the model equations are as follows:

Parabolic exponential:

$$Y_t = 2.768\ e^{(0.078t - 0.0082)} \qquad (R^2 = 0.904 \pm 0.058)$$

Wood:

$$Y_t = 2.908 + ^{0.315}\ e^{(0.092t)} \qquad (R^2 = 0.772 \pm 0.091)$$

McNally:

$$Y_t = 0.533t^{1.673}\ e^{(0.55t + 3.994t^{1/2})} \qquad (R^2\ 0.907 \pm 0.062).$$

Figures 1, 2, 3 and 4 show the mean egg production of the groups of hens with thirteen 28-d periods; Figures 5 and 6 show model curves as fitted to first 24 week of data but extended to end of production (i.e. 52 week). Figures 7 - 9 show fittings to individual hens.

Figures 1 and 2 show that the Parabolic exponential, Wood and McNally models fitted data points very closely compared to other models. However, Figures 3 and 4 show that the mean egg production of the group was fitted best by the McNally model. The Parabolic exponential was only slightly worse mainly because it failed to fit the observed initial production as well as the McNally model did. The Wood model on the other hand gave a substantially worse fit than the other two models. Figure 7 represents a curve from a hen with egg production record that peaked more gradually. On the other hand, Fig. 8 represents a hen with an irregular egg production data, while Fig. 9 represents a hen which maintained a high egg production throughout the period considered. The R^2 values for the egg production data in Fig 8 and 9 are similar for all the models, but comparatively low to the values obtained for Fig 7, although the data seemed to be fitted quite well by the models.

Table 17: Goodness of fit of three models fitted to egg production data for groups of hens having thirteen 28-d periods in strain A.

Variable	Parabolic-Exponential	Wood	McNally
R^2	0.93	0.75	0.95
Error (%) in Estimatation of 52-week egg No. from part record (24week)	12.26	13.01	(-)1.13
Deviation of estimated time of peak (i.e. No of 28-d periods)	-2	-3	-1
Deviation in estimated peak production(%)	2.27	2.76	1.85

Table 18: Goodness of fit of three models fitted to egg production data for groups of hens having thirteen 28-d periods in strain B.

Variable	Parabolic-exponential	Wood	McNally
R^2	0.91	0.77	0.93
Error (%) in Estimatation of 52-week egg No. from part record (24week)	0.67	13.30	3.00
Deviation of estimated time of peak (i.e. No of 28-d periods)	-2	-4	-1
Deviation in estimated peak production(%)	-0.35	2.10	0.05

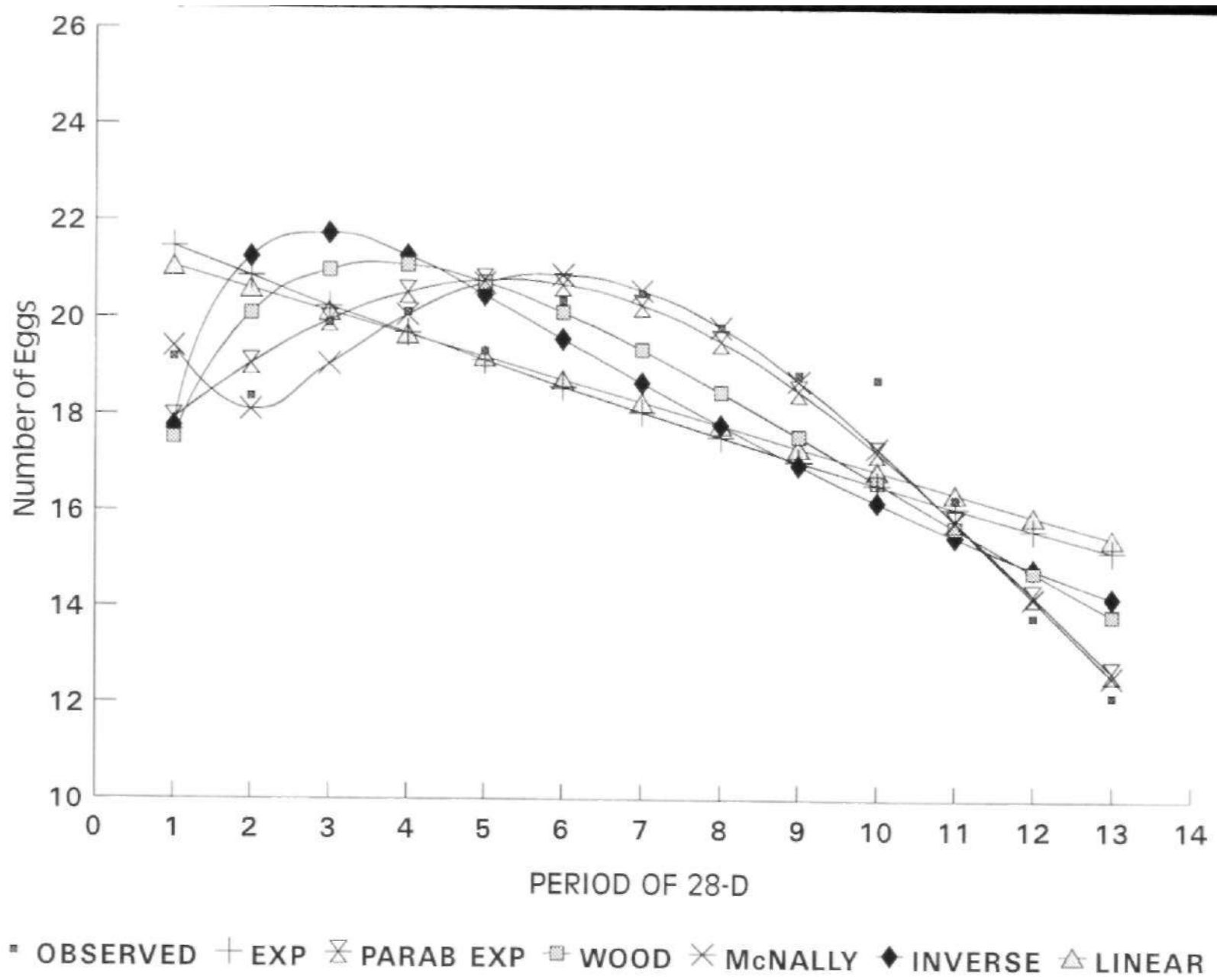


Fig.1 Fitted egg production Models for Strain A

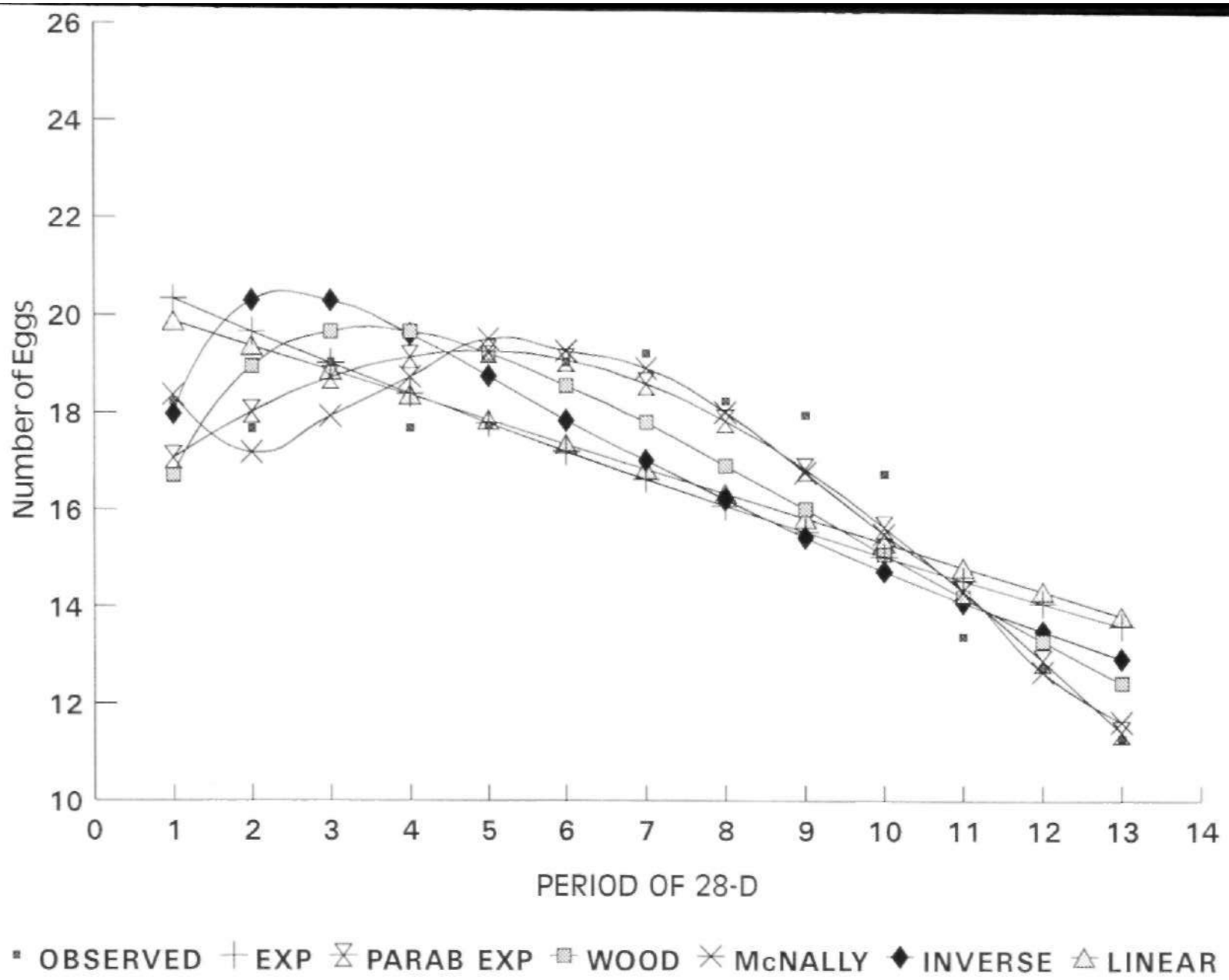


Fig. 2 Fitted egg production models for strain B

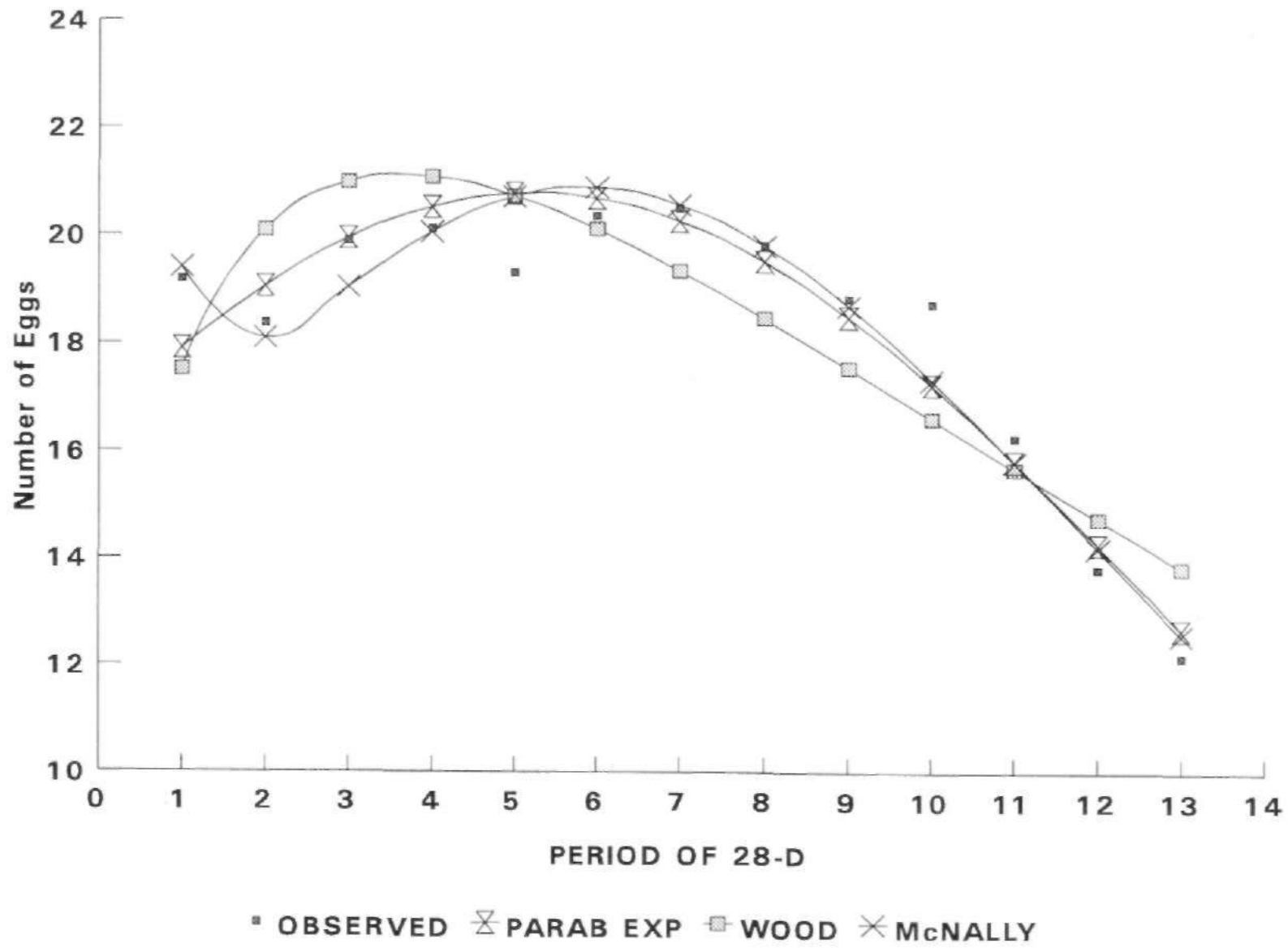


Fig.3 Best fitting egg production models for Strain A

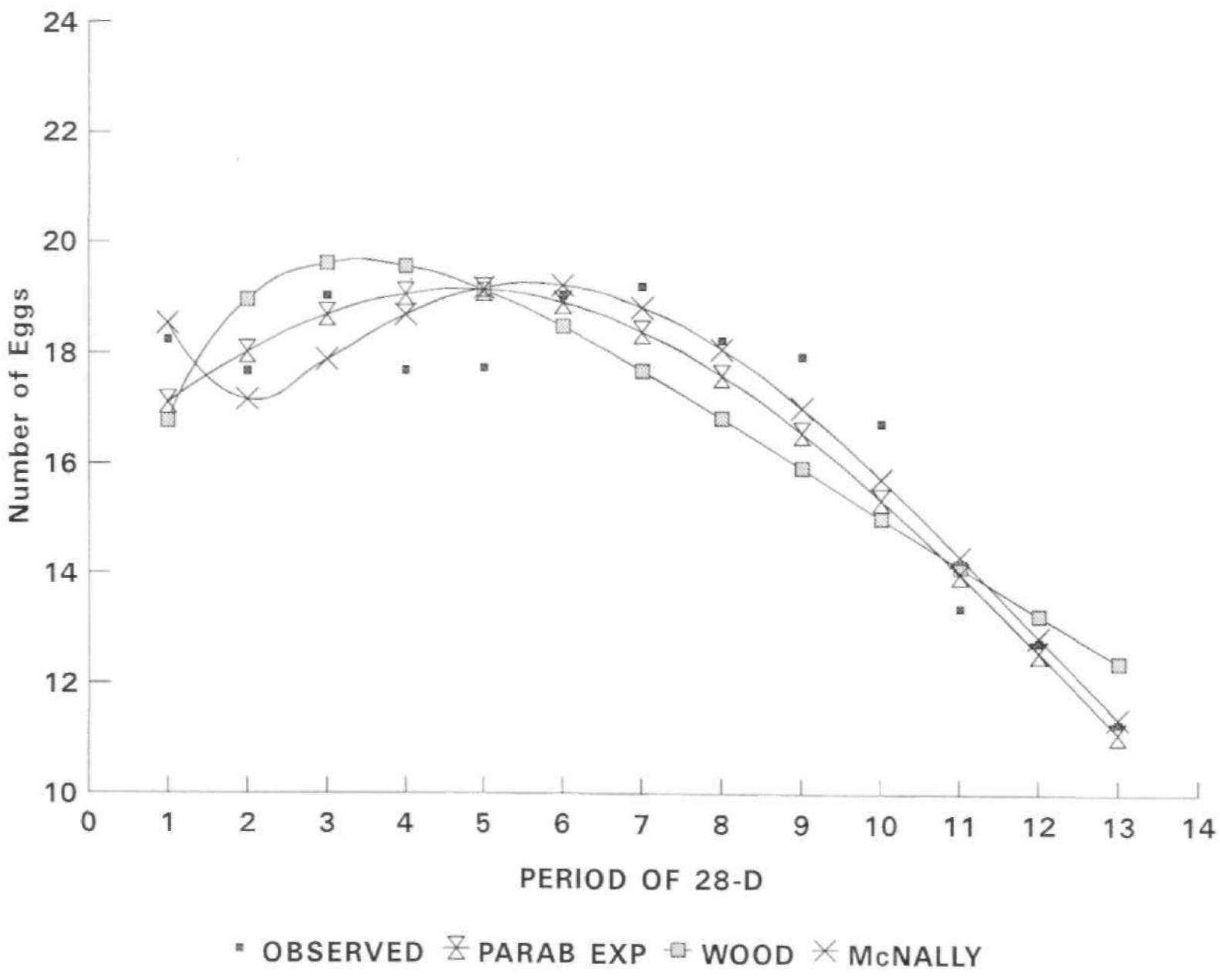


Fig.4 Best fitting egg production models for Strain B

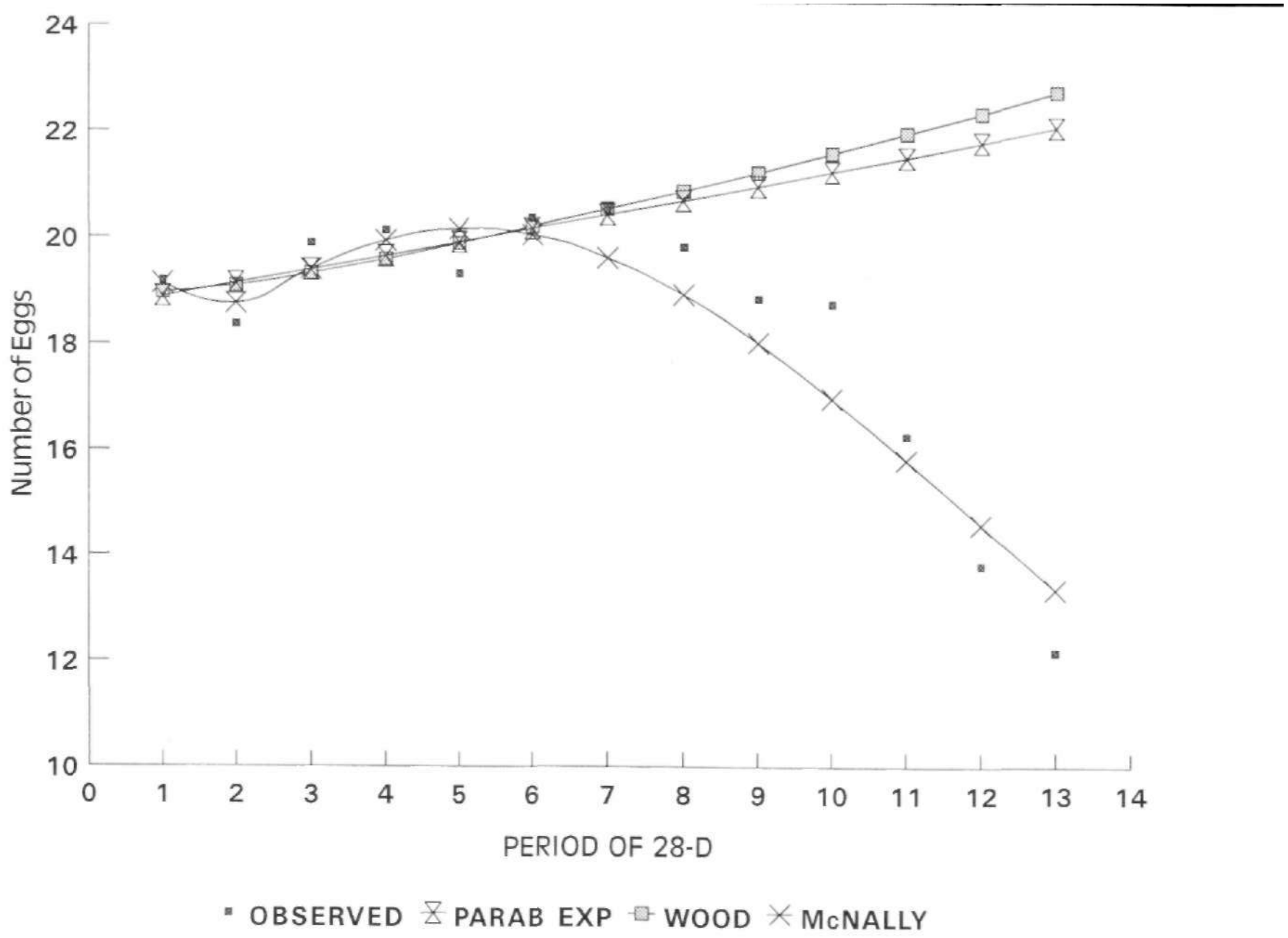


Fig.5 Points Predicted by best fitting models to Part-Record (24 wk) Data for Strain A

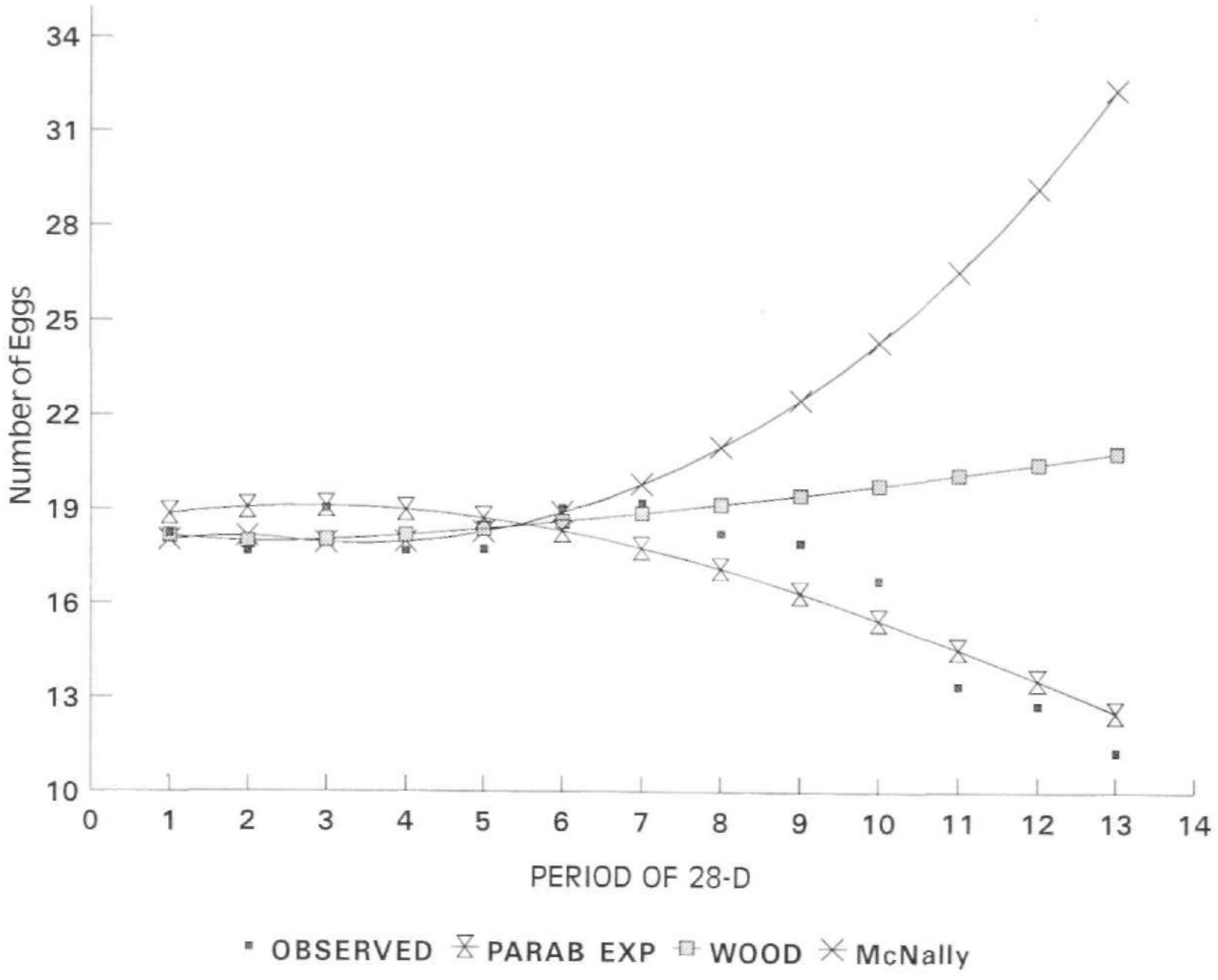


Fig.6 Points Predicted by best fitting models to Part-Record (24 wk) Data for Strain B

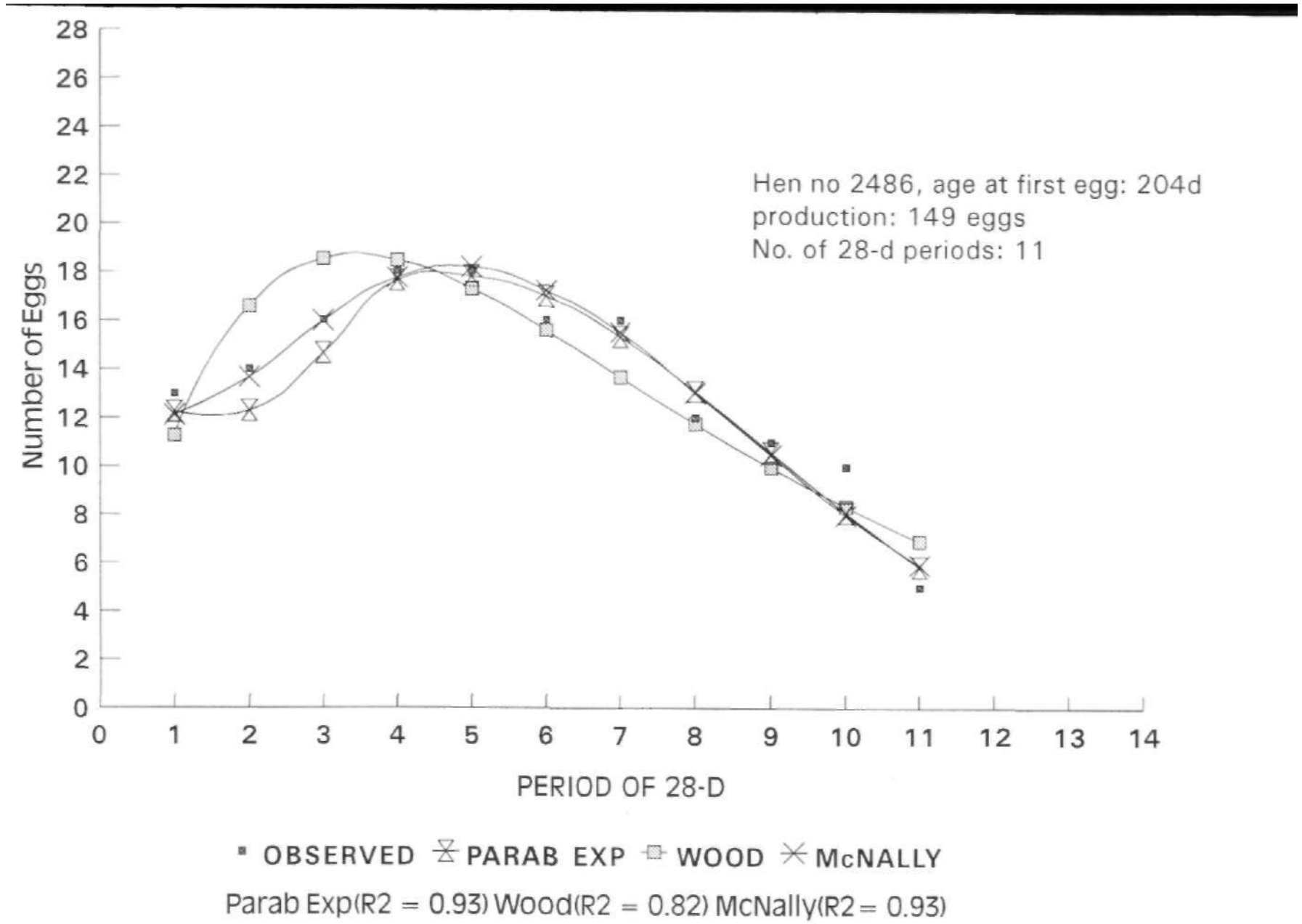


Fig.7 Fitted models for individual number 2486

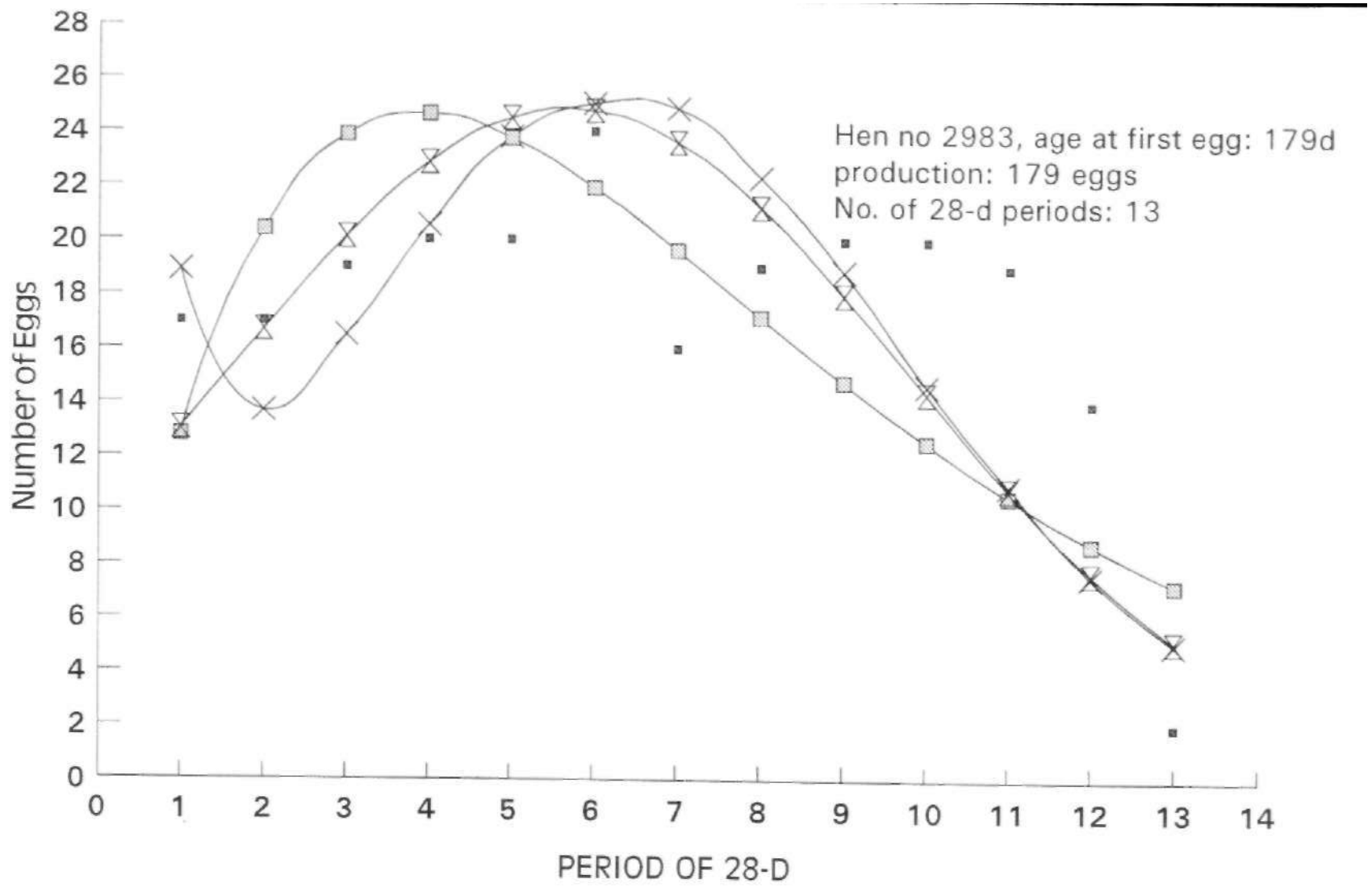


Fig.8 Fitted models for hen number 2983

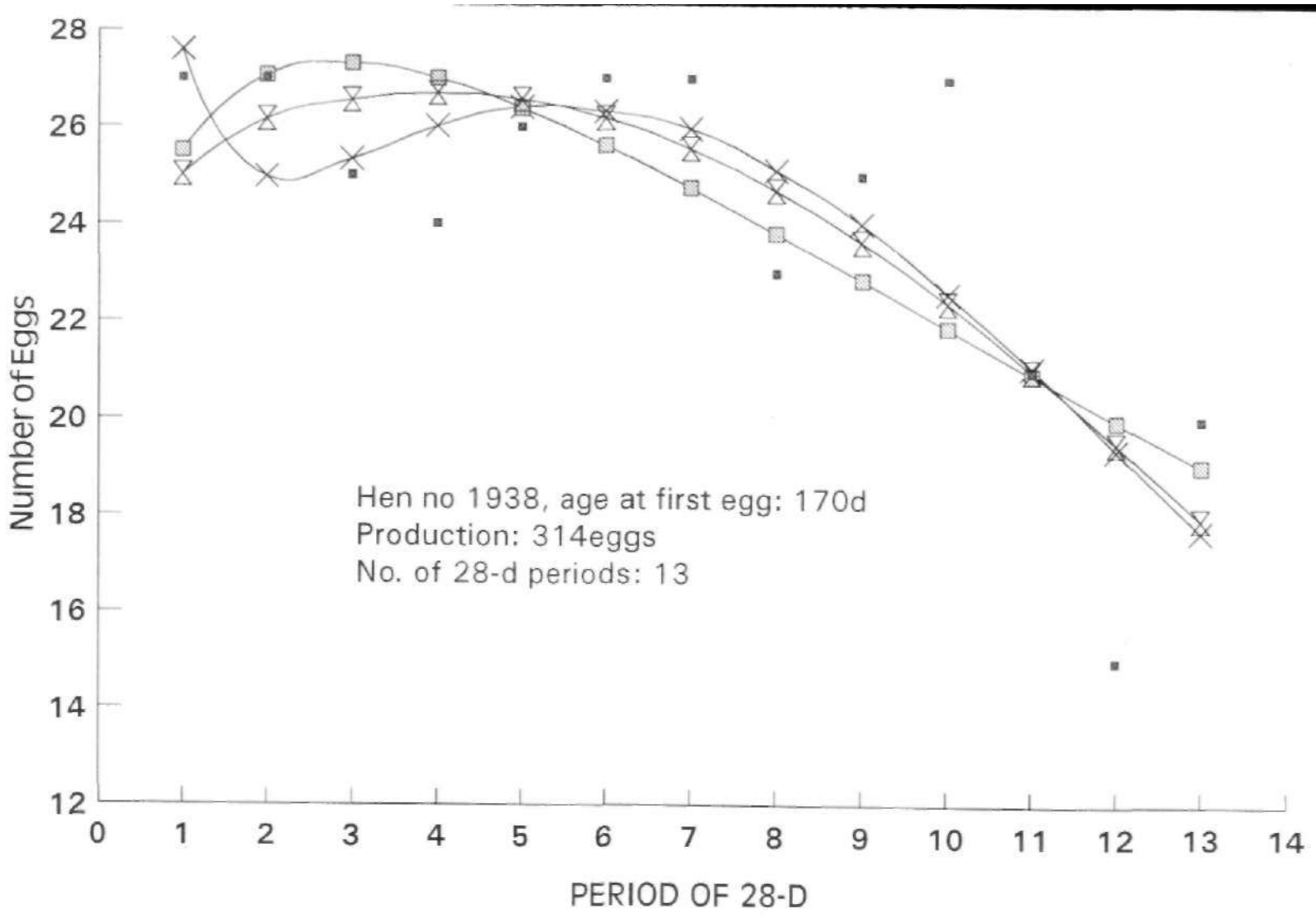


Fig. 9 Fitted models for hen number 1938

4.2. Prediction of Annual Egg Production from part-record productions

The three models were fitted to part-records for 16, 20 and 24 weeks of production on a hen-housed basis in both lines. Annual (or 52 week) egg numbers were predicted by the resulting egg production curves. The predicted and actual annual egg numbers and errors of predictions (i.e. Absolute values of the difference and the % difference between predicted and actual) are given in Tables 19 and 20.

In strain A, the McNally model consistently predicted less than the actual 52 week egg production, while the Wood and Parabolic exponential models tended to overestimate production. The latter two had similar accuracy in their predictions with a slight advantage to the Parabolic exponential especially with 20 week data. Similarly, for strain B, the McNally model had lower prediction values for fits to 16 and 20 weeks, but slightly over predicted for fit to 24 weeks data. The Parabolic exponential also gave similar pattern as observed for McNally, but resulted in a better fit than the McNally. However, for the Wood model, the predictions tended to overestimate and the numbers were higher than the actual values. The results suggest that both the McNally and Parabolic exponential models have fairly good abilities to predict. They yielded relatively smaller prediction errors than did the Wood model. Between the two, it is however, difficult to choose with respect to strain A or B, but the indication is that McNally may be more reliable for strain A.

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Table 19: Errors of predicted 52-week egg production based on fits to part records in strain A.

Model	Fit to wk	Abs. Errors	% Errors
Parabolic-Exponential	16	99.72	42.0
	20	1.52	0.64
	24	28.38	11.95
Wood	16	37.07	15.61
	20	23.85	10.04
	24	30.87	13.00
McNally	16	-29.40	(-)12.38
	20	-24.51	9.69
	24	-2.72	(-)1.15
Actual mean 52 week prod.(+S.D)		232.12+28.69	

Table 20: Errors of predicted 52-week egg production based on fits to part records in strain B.

Model	Fit to wk	Abs Errors	% Errors
Parabolic-Exponential	16	-52.28	(-)23.88
	20	-21.73	(-)9.92
	24	1.48	0.68
Wood	16	-18.86	8.61
	20	86.45	39.48
	24	29.12	13.30
McNally	16	-56.11	(-)25.63
	20	-32.58	(-)14.88
	24	-44.08	20.13
Actual mean 52 week prod.(+S.D)		218.39±29.56	

4.3 Estimates of Heritabilities, genetic and phenotypic Correlations

The estimated heritabiities for production traits and curve parameters are shown in Tables 21 - 24. The heritability estiamtes for production traits were moderate, while the values obtained for the curve parameters varied from low to moderate, although the estimates for some of the curve parameters especially for strain B were not available (Tables 21 & 22). The heritability estimates obtained from full-sib analyses for Strain A in groups of hens having not less than 13 periods were mostly higher (Tables 22) than the estimates obtained in groups of hens having not less than 9 periods (Table 21), especially for curve parameters. However for strain B, the heribatility estimates from full-sib analyses for production traits were higher for groups of hens having not less than 9 periods (Tables 21), while the estimates for curve parameters were higher in groups having not less than 13 periods (Table 22). On the other hand, the estimates obtained from the corresponding paternal half-sib analyses of the full model (Tables 21 and 22) and the one way model (Appendices 1 and 2) were in most casese consistently higher than values obtained from sire and dam families. The heritability estimates for monthly and cummulative monthly egg production are shown in Tables 23 and 24. The estimates obtained for the cummulative monthly production exceeded the estimates for the monthly production. The estimates of monthly and cummulative monthly production obtained for strain B were higher than the values for strain A. There was also a steady increase in heritability estimates in later months for cummulative monthly production. Again, the estimates obtained from sire families (i.e. paternal half-sib analyses of the full model (Tables 23 and 24) and one-way model (Appendices 3 and 4)) for the monthly and cummlative monthly production were higher than values obtained for the sire and dam families .

The heritability estimates for the part-production periods increased steadily from the first part-production period all through to the annual production record.

The estimates of genetic and phenotypic correlations are given in Tables 25 - 40. The genetic and phenotypic correlations are mostly similar in trends. However, the genetic correlations were consistently larger than the phenotypic correlations. Similarly, estimates of phenotypic correlations for curve parameters were low. The estimates of correlations of part-productions with 52-week total were fairly high.

Table 21: Heritability estimates for production traits and curve parameters in groups of hens having not less than nine 28-d periods*.

	Strain A			Strain B		
Traits	N	h^2_{s+d} ± S.E.	h^2_s ± S.E.	N	h^2_{s+d} ± S.E.	h^2_s ± S.E.
ASM	444	.299±.096	.326±.175	421	.490±.113	.271±.161
PP16	"	.192±.085	.333±.177	"	.212±.089	.259±.157
PP20	"	.209±.086	.319±.173	"	.248±.093	.234±.149
PP24	"	.213±.087	.288±.163	"	.252±.094	.233±.149
AP52	"	.242±.079	.191±.131	"	.351±.103	.106±.105
MA	"	.074±.070	.148±.117	"	.186±.086	NA
MB	"	.072±.070	.144±.115	"	.207±.089	NA
MC	"	.074±.070	.148±.116	"	.170±.085	NA
MD	"	.069±.069	.137±.113	"	.137±.080	NA
WA	"	.110±.074	.221±.139	"	.093±.077	.187±.136
WB	"	.125±.115	NA±	"	NA	NA
WC	"	.182±.083	NA±	"	NA	NA
PA	"	.077±.070	.154±.117	"	.140±.083	.134±.118
PB	"	.081±.071	.042±.078	"	NA	NA
PC	"	.095±.073	.012±.068	"	NA	NA

*ASM = age at sexual maturity; PP16, PP20 and PP24 = part-record productions for wks. 16, 20 and 24, respectively; AP52 = Total production for 52 wks; MA, MB, MC and MD = model parameters of McNally; WA,WB and WC = model parameters of Wood; PA, PB and PC = model parameters of parabolic as explained in the text.

Table 22: Heritability estimates for production traits and curve parameters in groups of hens having not less than thirteen 28-d periods*.

	Strain A			Strain B		
Traits	N	h^2_{s+d} ± S.E.	h^2_s ± S.E.	N	h^2_{s+d}±S.E.	h^2_s ± S.E.
ASM	356	.286±.108	.300±.185	292	.415±.132	.349±.219
PP16	"	.184±.097	.287±.181	"	.171±.109	.343±.217
PP20	"	.239±.103	.227±.161	"	.192±.112	.315±.208
PP24	"	.233±.103	.261±.172	"	.183±.111	.321±.210
AP52	"	.255±.105	.292±.182	"	.191±.111	.319±.210
MA	"	.157±.094	.078±.109	"	.242±.117	NA
MB	"	.159±.094	.058±.102	"	.216±.114	NA
MC	"	.167±.095	.071±.107	"	.224±.115	NA
MD	"	.228±.102	.038±.095	"	.315±.124	.035±.113
WA	"	.086±.083	.072±.139	"	.208±.117	.228±.185
WB	"	.084±.083	NA	"	NA	NA
WC	"	.128±.088	NA	"	NA	NA
PA	"	.073±.081	.146±.130	"	.053±.097	.165±.164
PB	"	.104±.085	.064±.102	"	NA	NA
PC	"	.129±.088	.036±.092	"	NA	NA

*ASM = age at sexual maturity; PP16, PP20 and PP24 = part-record productions for wks. 16, 20 and 24, respectively; AP52 = Total production for 52 wks; MA, MB, MC and MD = model parameters of McNally; WA,WB and WC = model parameters of Wood; PA, PB and PC = model parameters of parabolic as explained in the text.

Table 23: Heritabilty estimates for monthly egg production

	Strain (A)			Strain (B)		
Traits	N	h^2_{s+d}±S.E.	h^2_s±S.E.	N	h^2_{s+d}±S.E.	h^2_s ± S.E.
M1	369	.154±.091	.262±.169	281	.167±.112	.333±.219
M2	"	.149±.090	.298±.180	"	.156±.111	.255±.194
M3	"	NA	NA	"	.239±.120	.358±.226
M4	"	.169±.093	.035±.090	"	.034±.095	.068±.130
M5	"	.085±.082	.009±.080	"	.286±.125	.082±.135
M6	"	.139±.089	.241±.162	"	.099±.104	NA
M7	"	.082±.082	.055±.097	"	.007±.091	.014±.110
M8	"	.147±.090	.295±.179	"	.074±.100	.147±.158
M9	"	.073±.080	.034±.090	"	.146±.110	.226±.185
M10	"	.188±.095	.087±.109	"	.067±.099	NA
M11	"	.086±.082	.071±.103	"	.167±.112	.236±.185
M12	"	.113±.086	NA	"	.068±.100	.136±.154
M13	"	NA	NA	"	NA	NA

Table 24: Heritability estimates for cummulative monthly egg production.

	Strain (A)			Strain (B)		
Traits	N	h^2_{s+d}±S.E.	h^2_s±S.E.	N	h^2_{s+d}±S.E.	h^2_s±S.E.
CM1	369	.154±.091	.262±.169	281	.167±.112	.333±.219
CM2	"	.195±.096	.391±.209	"	.179±.114	.358±.226
CM3	"	.124±.087	.247±.164	"	.233±.119	.466±.258
CM4	"	.140±.089	.281±.175	"	.195±.115	.391±.236
CM5	"	.160±.092	.249±.165	"	.222±.118	.366±.229
CM6	"	.162±.092	.232±.159	"	.202±.116	.366±.229
CM7	"	.167±.091	.246±.164	"	.192±.115	.346±.223
CM8	"	.174±.093	.289±.178	"	.184±.114	.369±.229
CM9	"	.184±.094	.304±.182	"	.180±.114	.347±.223
CM10	"	.196±.096	.332±.191	"	.196±.115	.308±.211
CM11	"	.213±.098	.325±.189	"	.215±.118	.359±.227
CM12	"	.213±.098	.318±.187	"	.220±.118	.349±.223
CM13	"	.217±.098	.308±.184	"	.200±.116	.350±.224

The estimates of correlations for monthly production or part-production records that were close together in time were higher compared to estimates for records that were further apart. This pattern is much more apparent for the phenotypic correlations.

Considering the McNally model, the estimates of correlation between sexual maturity and curve parameters c and d were negative for Strain A (Tables 25 and 31) but positive for strain B (Tables 26 and 32). Similarly, the estimates of genetic correlation between part production periods, annual production and parameters c and d were positive in strain A, but negative in strain B. However, for phenotypic correlation, the estimates were negative in both strains. On the other hand, the correlation between curve parameters a and b with age at sexual matutity (ASM) was positive in strain A but negative in strain B. Also, just as observed with curve parameters c and d, the genetic correlations between part-production, annual production and the parameters a and b were negative for strain A but positive for strain B. The phenotypic correlations were however positive in both strains. Similarly, for the Wood and Parabolic models, there were some differences between the two strains in the genetic and phenotypic relationships for the curve parameters and production traits, although not as marked as observed for the McNally model. It should be noted that the estimates of genetic and phenotypic correlations between the curve parameter (a) and part-production or annual totals are positive and moderately high.

The estimates of correlation between part-production and the annual production were consistently higher than the estimates obtained for sexual maturity with annual production. Some patterns seem to emerge from the estimates of phenotypic correlations of part-month productions wuith the annual total; the highest estimates are for the last period and the lowest

for the first period.

It was observed that the absolute values obtained for estimates of correlations between the production traits differed slightly for runs for each of the models, although the trend is quite similar (Tables 25-36). This was as a result of data editing for each of the runs. Consequently, the number of records for each of the runs varied slightly.

The estimated genetic and phenotypic correlations between monthly productions and Annual production and sexual maturity are given in Tables 37 and 38. The results obtained are similar to what was observed for part-productions and annual totals. Thus, the highest estimates are for the middle months and the lowest for the first two months.

The comparable estimates for cummulative monthly production are shown in Tables 39 and 40. The estimated correlations between cummulative monthly production and total 13 month production increases rapidly (especially for the phenotypic correlations) until the 4th month and then more slowly until it is essentially unity (at about 10 months for genetic correlations).

Again, on a comparative basis, the estimated correlations obtained from sire components using the one-way model were in most cases larger than the estimates from the pooled sire and dam components.

Table 25: Estimates of genetic and phenotypic correlations for production traits and model parameters of McNally from sire and dam components of variance and covariance in groups of hens having not less than nine 28-d periods in Strain A*.

	ASM	PP16	PP20	PP24	AP52	MA	MB	MC	MD
ASM		0.62	-0.59	-0.61	-0.55	0.60	0.95	-0.68	-0.57
PP16	-0.42		1.01	1.01	1.01	-0.57	-0.90	0.64	0.53
PP20	-0.42	0.97		0.99	0.98	-0.44	-0.75	0.51	0.41
PP24	-0.42	0.95	0.98		0.97	-0.67	-0.95	0.74	0.61
AP52	-0.44	0.75	0.76	0.78		-0.52	-0.77	0.60	0.45
MA	0.06	0.09	0.09	0.06	0.18		-0.12	-0.06	-0.25
MB	0.10	0.03	0.03	0.01	0.11	0.94		-0.02	0.21
MC	-0.07	-0.05	-0.05	-0.02	-0.15	-0.96	-0.95		0.36
MD	-0.04	-0.05	-0.04	-0.02	-0.19	-0.95	-0.92	0.95	

*ASM = age at sexual maturity; PP16, PP20 and PP24 = part-record productions for wks. 16, 20 and 24, respectively; AP52 = Total production for 52 wks; MA, MB, MC and MD = model parameters of McNally as explained in the text. Genetic correlations are above the diagonal and phenotypic corelations are below the diagonal.

Table 26: Estimates of genetic and phenotypic correlations for production traits and model parameters of McNally from sire and dam components of variance and covariance in groups of hens having not less than nine 28-dperiods in Strain B*.

	ASM	PP16	PP20	PP24	AP52	MA	MB	MC	MD
ASM		-0.42	-0.43	-0.42	-0.38	-0.64	-0.49	0.65	0.60
PP16	-0.38		1.01	0.99	1.11	1.19	1.02	-1.22	-1.19
PP20	-0.38	0.96		0.99	1.05	1.02	0.87	-1.04	-0.96
PP24	-0.35	0.93	0.98		1.04	0.88	0.73	-0.89	-0.84
AP52	-0.33	0.75	0.78	0.81		0.57	0.39	-0.55	-0.58
MA	-0.12	0.20	0.16	0.12	0.16		0.75	-0.74	-0.75
MB	-0.10	0.14	0.12	0.09	0.11	0.93		-0.73	-0.77
MC	0.11	-0.16	-0.12	-0.09	-0.13	-0.97	-0.93		0.73
MD	0.11	-0.13	-0.09	-0.05	-0.14	-0.94	-0.88	0.94	

*ASM = age at sexual maturity; PP16, PP20 and PP24 = part-record productions for wks. 16, 20 and 24, respectively; AP52 = Total production for 52 wks; MA, MB, MC and MD = model parameters of McNally as explained in the text. Genetic correlations are above the diagonal and phenotypic corelations are below the diagonal.

Table 27: Estimates of genetic and phenotypic correlations for production traits and curve parameters of Wood from sire and dam components of variance and covariance in groups of hens having not less than nine 28-d periods in Strain A*.

ASM	PP16		PP20	PP24	AP52	WA	WB	WC
ASM		-0.47	-0.40	-0.45	-0.50	-0.92	0.41	0.10
PP16	-0.29		1.01	1.02	0.99	1.03	0.03	0.29
PP20	-0.29	0.97		0.99	0.98	1.00	0.02	0.27
PP24	-0.30	0.94	0.98		0.98	1.07	0.04	0.32
AP52	-0.36	0.75	0.76	0.78		0.92	-0.04	0.18
WA	0.26	0.78	0.74	0.72	0.53		0.05	0.29
WB	0.10	-0.17	-0.10	-0.06	-0.25	-0.47		0.80
WC	0.05	0.03	0.08	0.10	-0.23	-0.17	0.92	

*ASM = age at sexual maturity; PP16, PP20 and PP24 = part-record productions for wk 16, 20 and 24, respectively; AP52 = Total production for 52wk; WA, WB, and WC = model parameters of Wood as explained in the text. Genetic correlations are above the diagonal and phenotypic corelations are below the diagonal.

Table 28: Estimates of genetic and phenotypic correlations for production traits and curve parameters of Wood from sire and dam components of variance and covariance in groups of hens having not less than nine 28-d periods in Strain B*.

	ASM	PP16	PP20	PP24	AP52	WA	WB	WC
ASM		-0.55	-0.58	-0.61	-0.49	-0.84	-	-
PP16	-0.32		1.01	0.99	1.12	1.63	-	-
PP20	-0.32	0.96		0.99	1.04	1.56	-	-
PP24	-0.29	0.93	0.98		1.04	1.42	-	-
AP52	-0.27	0.76	0.79	0.81		1.24	-	-
WA	-0.15	0.49	0.47	0.45	0.30		-	-
WB	-0.02	-0.04	0.03	0.07	-0.03	-0.30		-
WC	-0.04	0.03	0.08	0.10	-0.06	-0.07	0.87	

*ASM = age at sexual maturity; PP16, PP20 and PP24 = part-record productions for wk 16, 20 and 24, respectively; AP52 = Total production for 52wk; WA, WB, and WC = model parameters of Wood as explained in the text. Genetic correlations are above the diagonal and phenotypic corelations are below the diagonal.

Table 29: Estimates of genetic and phenotypic correlations for production traits and curve parameters of parabolic from sire and dam components of variance and covariance in groups of hens having not less than nine 28-d periods in Strain A*.

	ASM	PP16	PP20	PP24	AP52	PA	PB	PC
ASM		-0.43	-0.37	-0.42	-0.46	-0.69	0.33	-0.14
PP16	-0.28		1.01	1.02	1.01	0.65	0.10	-0.34
PP20	-0.28	0.97		0.99	1.00	0.69	0.01	-0.23
PP24	-0.29	0.94	0.98		1.00	0.71	0.05	-0.30
AP52	-0.36	0.75	0.76	0.78		0.57	0.16	-0.36
PA	0.23	0.69	0.65	0.62	0.56		-0.54	0.38
PB	0.12	-0.31	-0.24	-0.20	-0.31	-0.85		0.97
PC	-0.09	0.16	0.10	0.07	0.32	0.71	-0.96	

*ASM = age at sexual maturity; PP16, PP20 and PP24 = part-record productions for wk 16, 20 and 24, respectively; AP52 = Total production for 52wk; PA, PB, and PC = model parameters of parabolic as explained in the text. Genetic correlations are above the diagonal and phenotypic corelations are below the diagonal.

Table 30: Estimates of genetic and phenotypic correlations for production traits and curve parameters of parabolic from sire and dam components of variance and covariance in groups of hens having not less than nine 28-d periods in Strain B*

	ASM	PP16	PP20	PP24	AP52	PA	PB	PC
ASM		-0.55	-0.58	-0.61	-0.49	-0.84	-	-
PP16	-0.32		1.01	0.99	1.12	1.69	-	-
PP20	-0.32	0.96		0.99	1.04	1.59	-	-
PP24	-0.29	0.93	0.98		1.04	0.28	-	-
AP52	-0.27	0.76	0.79	0.81		1.17	-	-
PA	-0.13	0.45	0.40	0.37	0.30		-	-
PB	-0.03	-0.15	-0.08	-0.03	-0.08	-0.79		-
PC	-0.01	0.09	0.03	-0.01	0.11	-0.67	-0.93	

*ASM = age at sexual maturity; PP16, PP20 and PP24 = part-record productions for wk 16, 20 and 24, respectively; AP52 = Total production for 52wk; PA, PB, and PC = model parameters of parabolic as explained in the text. Genetic correlations are above the diagonal and phenotypic corelations are below the diagonal.

Table 31: Estimates of genetic and phenotypic correlations for production traits and model parameters of McNally from sire and dam components of variance and covariance in group of hen having not less than thirteen 28-d periods in Strain A*.

	ASM	PP16	PP20	PP24	AP52	MA	MB	MC	MD
ASM		-0.70	-0.64	-0.71	-0.58	0.28	0.48	-0.31	-0.21
PP16	-0.40		1.02	1.02	0.95	-0.71	-0.87	0.69	0.51
PP20	-0.41	0.96		0.99	0.89	-0.55	-0.71	0.56	0.41
PP24	-0.41	0.93	0.98		0.90	-0.72	-0.84	0.71	0.50
AP52	-0.40	0.77	0.80	0.83		-0.42	-0.51	0.42	0.27
MA	0.06	0.06	0.06	0.05	0.13		0.97	-1.01	-0.95
MB	0.09	-0.01	0.13	0.01	0.07	0.97		-0.98	-0.93
MC	-0.07	-0.01	-0.02	-0.01	-0.10	-0.99	-0.98		0.94
MD	-0.04	-0.02	-0.03	-0.02	-0.14	-0.96	-0.93	0.96	

*ASM = age at sexual maturity; PP16, PP20 and PP24 = part-record productions for wk 16, 20 and 24, respectively; AP52 = Total production for 52wk; MA, MB, MC, and MD = model parameters of McNally as explained in the text. Genetic correlations are above the diagonal and phenotypic corelations are below the diagonal.

Table 32: Estimates of genetic and phenotypic correlations for production traits and model parameters of McNally from sire and dam components of variance and covariance in groups of hens having not less than thirteen 28-d periods in Strain B*.

	ASM	PP16	PP20	PP24	AP52	MA	MB	MC	MD
ASM		-0.63	-0.63	-0.58	-0.46	-0.63	-0.60	0.62	0.36
PP16	-0.38		0.91	0.84	1.03	0.63	0.68	-0.62	-0.30
PP20	-0.40	0.96		0.98	1.11	0.52	0.58	-0.51	-0.18
PP24	-0.35	0.92	0.98		1.10	0.44	0.49	-0.43	-0.15
AP52	-0.29	0.79	0.84	0.87		-0.03	0.04	0.05	0.15
MA	-0.16	0.23	0.21	0.17	0.15		0.82	-0.82	-0.86
MB	-0.12	0.17	0.17	0.14	0.11	0.95		-0.81	-0.93
MC	0.14	-0.18	-0.16	-0.13	-0.11	0.98	-0.96		0.89
MD	0.13	-0.13	-0.11	-0.07	-0.09	-0.92	-0.87	0.92	

*ASM = age at sexual maturity; PP16, PP20 and PP24 = part-record productions for wk 16, 20 and 24, respectively; AP52 = Total production for 52wk; MA, MB, MC, and MD = model parameters of McNally as explained in the text. Genetic correlations are above the diagonal and phenotypic corelations are below the diagonal.

Table 33: Estimates of genetic and phenotypic correlations for production traits and curve parameters of Wood from sire and dam components of variance and covariance in groups of hens having not less than thirteen 28-d periods in Strain A*

	ASM	PP16	PP20	PP24	AP52	WA	WB	WC	
ASM		0.17	0.19	0.07	-0.07	-0.36	0.06	-0.10	
PP16	-0.21		0.84	0.82	0.78	0.47	0.20	0.27	
PP20	-0.22	0.95		0.98	0.88	0.65	0.14	0.25	
PP24	-0.22	0.93	0.98		0.88	0.78	0.18	0.33	
AP52	-0.28	0.78	0.82	0.84		0.49	0.14	0.14	
WA	-0.19	0.73	0.71	0.68	0.52		-0.02	0.20	
WB	0.07	-0.12	-0.06	-0.03	-0.18	-0.48		0.77	
WC	0.05	0.06	0.11	0.13	-0.15	-0.17	0.92		

*ASM = age at sexual maturity; PP16, PP20 and PP24 = part-record productions for wk 16, 20 and 24, respectively; AP52 = Total production for 52wk; WA, WB, and WC = model parameters of Wood as explained in the text. Genetic correlations are above the diagonal and phenotypic corelations are below the diagonal.

Table 34: Estimates of genetic and phenotypic correlations for production traits and curve parameters of Wood from sire and dam components of variance and covariance in groups of hens having not less than thirteen 28-d periods in Strain B*

	ASM	PP16	PP20	PP24	AP52	WA	WB	WC
ASM		-0.71	-0.71	-0.70	-0.59	-0.76	-	-
PP16	-0.36		0.88	0.82	0.98	1.45	-	-
PP20	-0.38	0.95		0.99	1.08	1.43	-	-
PP24	-0.33	0.92	0.98		1.09	1.32	-	-
AP52	-0.27	0.79	0.84	0.88		1.12	-	-
WA	-0.19	0.51	0.50	0.48	0.41		-	-
WB	0.01	-0.04	0.03	0.07	-0.03	-0.32		-
WC	-0.03	0.04	0.09	0.12	-0.03	-0.09	0.89	

*ASM = age at sexual maturity; PP16, PP20 and PP24 = part-record productions for wk 16, 20 and 24, respectively; AP52 = Total production for 52wk; WA, WB, and WC = model parameters of Wood as explained in the text. Genetic correlations are above the diagonal and phenotypic corelations are below the diagonal.

Table 35: Estimates of genetic and phenotypic correlations for production traits and curve parameters of parabolic from sire and dam components of variance and covariance in groups of hens having not less than thirteen 28-d periods in Strain A*.

	ASM	PP16	PP20	PP24	AP52	PA	PB	PC
ASM		0.04	0.08	0.01	-0.13	0.13	-0.37	0.40
PP16	-0.22		0.94	0.94	0.87	0.16	0.42	-0.48
PP20	-0.22	0.96		0.99	0.88	0.35	0.25	-0.33
PP24	-0.23	0.94	0.98		0.89	0.40	0.28	-0.39
AP52	-0.29	0.78	0.82	0.84		0.25	0.29	-0.27
PA	-0.17	0.65	0.63	0.60	0.51		-0.63	0.52
PB	0.08	-0.25	-0.21	-0.17	-0.21	-0.84		-0.96
PC	-0.07	0.10	0.07	0.04	0.19	0.70	-0.96	

*ASM = age at sexual maturity; PP16, PP20 and PP24 = part-record productions for wk 16, 20 and 24, respectively; AP52 = Total production for 52wk; PA, PB, and PC = model parameters of parabolic as explained in the text. Genetic correlations are above the diagonal and phenotypic corelations are below the diagonal.

Table 36: Estimates of genetic and phenotypic correlations for production traits and curve parameters of parabolic from sire and dam components of variance and covariance in groups of hens having not less than thirteen 28-d periods in Strain B*.

	ASM	PP16	PP20	PP24	AP52	PA	PB	PC
ASM		-0.61	-0.55	-0.56	-0.48	-0.52	0.47	-
PP16	-0.30		0.88	0.82	0.98	1.43	-1.48	-
PP20	-0.30	0.95		0.99	1.08	1.37	-1.28	-
PP24	-0.26	0.92	0.98		1.09	1.26	-1.10	-
AP52	-0.22	0.79	0.84	0.88		0.90	-0.21	-
PA	-0.10	0.45	0.44	0.41	0.36		-1.04	-
PB	0.02	-0.16	-0.10	-0.05	-0.06	-0.78		-
PC	-0.01	0.09	0.04	-0.01	0.07	0.66	-0.94	

*ASM = age at sexual maturity; PP16, PP20 and PP24 = part-record productions for wk 16, 20 and 24, respectively; AP52 = Total production for 52wk; PA, PB, and PC = model parameters of parabolic as explained in the text. Genetic correlations are above the diagonal and phenotypic corelations are below the diagonal.

Table 37. Estimates of genetic and phenotypic correlations from sire and dam components of variance of monthly and 52 week egg production, and age at sexual maturity in strain A*.

Month	1	2	3	4	5	6	7	8	9	10	11	12	13	AP52	ASM
1		0.97	-	0.17	0.92	0.72	0.13	0.63	1.00	0.60	0.35	-0.44	-	0.50	-0.87
2	0.46		-	0.13	1.07	0.12	0.90	0.35	0.56	0.12	0.46	-0.16	-	0.52	0.81
3	0.33	0.37		-	-	-	-	-	-	-	-	-	-		
4	0.33	0.23	0.27		1.01	0.45	0.59	0.59	1.28	0.42	1.42	0.71	-	0.92	-0.30
5	0.31	0.39	0.25	0.40		0.40	0.65	0.35	-0.30	-0.07	0.85	0.97	-	1.01	-0.26
6	0.19	0.32	0.20	0.27	0.33		0.65	1.19	0.63	0.13	0.01	-0.62	-	0.56	-0.32
7	0.30	0.27	0.25	0.28	0.27	0.23		0.62	0.82	0.20	0.55	-0.36	-	0.66	-0.44
8	0.29	0.29	0.25	0.28	0.26	0.28	0.32		0.37	0.98	1.04	0.72	-	0.79	-0.47
9	0.12	0.17	0.19	0.22	0.21	0.20	0.31	0.44		1.75	2.64	1.35	-	1.41	0.42
10	0.11	0.17	0.14	0.20	0.11	0.21	0.21	0.33	0.37		1.19	1.11	-	0.85	-0.31
11	0.24	0.22	0.16	0.31	0.20	0.15	0.21	0.33	0.33	0.15		0.84	-	1.12	0.03
12	0.05	0.12	0.16	0.05	0.07	0.13	0.08	0.14	0.22	0.34	0.39		-	0.57	-0.16
13	0.08	0.08	0.02	0.15	0.10	0.05	0.08	0.18	0.19	0.28	0.35	0.47		-	-
AP52	0.56	0.59	0.51	0.57	0.57	0.48	0.51	0.59	0.52	0.55	0.64	0.47	0.47		-0.39
ASM	-0.19	-0.15	-0.08	-0.17	-0.15	-0.13	-0.19	-0.27	-0.14	-0.13	-0.26	-0.04	-0.12	-0.28	

*The genetic correlations are above the diagonal and phenotypic correlations are below the diagonal

Table 38: Estimates of genetic and phenotypic correlations from sire and dam components of variance of monthly and 52 week egg production, and age at Sexual maturity in strain B*.

Month	1	2	3	4	5	6	7	8	9	10	11	12	13	AP52	ASM
1		0.41	0.70	0.18	0.89	0.12	-	0.72	0.31	0.48	-0.15	0.65	-	0.45	-0.63
2	0.45		0.51	-0.20	0.31	-0.86	-	0.09	0.47	1.33	0.88	1.14	-	0.48	-0.78
3	0.37	0.35		1.41	0.41	-0.26	-	0.53	0.52	1.51	1.05	0.05	-	0.96	-0.85
4	0.29	0.34	0.38		1.58	1.60	-	-0.60	0.57	0.71	1.21	1.21	-	1.55	-0.70
5	0.40	0.36	0.32	0.47		0.98	-	0.27	0.32	0.64	0.50	0.44	-	0.96	-0.48
6	0.16	0.18	0.22	0.23	0.43		-	0.63	0.36	1.20	0.47	-0.49	-	0.70	-0.50
7	0.19	0.26	0.32	0.34	0.35	0.39		-	-	-	-	-	-	-	0.44
8	0.24	0.27	0.23	0.19	0.31	0.31	0.31		0.74	0.41	-0.19	1.14	-	0.60	-0.29
9	0.21	0.19	0.22	0.14	0.23	0.32	0.36	0.38		1.65	0.13	0.53	-	0.50	0.15
10	0.27	0.25	0.25	0.21	0.38	0.25	0.32	0.37	0.47		0.90	0.89	-	1.15	0.34
11	0.33	0.26	0.27	0.22	0.24	0.15	0.18	0.26	0.26	0.40		1.12	-	0.91	-0.21
12	0.08	0.16	0.14	0.07	0.14	0.17	0.14	0.19	0.23	0.22	0.22		-	0.60	-0.20
13	0.11	0.10	0.14	0.02	0.08	0.14	0.06	0.12	0.21	0.29	0.31	0.35		-	-
AP52	0.57	0.58	0.57	0.56	0.67	0.54	0.56	0.55	0.56	0.64	0.58	0.43	0.41		-0.58
ASM	-0.29	-0.24	-0.25	-0.26	-0.29	-0.05	-0.02	-0.12	-0.06	-0.21	-0.35	0.11	-0.04	-0.26	

*The genetic correlations are above the diagonal and phenotypic correlations are below the diagonal

Table 39: Estimates of genetic and phenotypic correlations from sire and dam components of variance and of covariance of cummulative monthly egg production and, age at sexual maturity in strain A*.

Cumm. Month	Cummulative Month 1	2	3	4	5	6	7	8	9	10	11	12	13	ASM
1		1.02	0.98	0.82	0.84	0.89	0.84	0.83	0.85	0.87	0.79	0.71	0.60	-0.16
2	0.85		0.94	0.78	0.83	0.83	0.83	0.81	0.81	0.80	0.74	0.67	0.63	0.14
3	0.78	0.92		0.76	0.90	0.89	0.86	0.85	0.88	0.84	0.81	0.72	0.68	0.30
4	0.76	0.87	0.94		0.91	0.91	0.90	0.90	0.94	0.91	0.90	0.86	0.86	0.12
5	0.72	0.84	0.90	0.96		0.99	0.97	0.95	0.96	0.91	0.91	0.87	0.89	0.15
6	0.69	0.82	0.88	0.93	0.98		1.00	0.99	1.00	0.95	0.92	0.88	0.89	-0.07
7	0.68	0.81	0.87	0.92	0.97	0.99		1.00	1.01	0.96	0.93	0.88	0.89	-0.04
8	0.67	0.80	0.85	0.91	0.96	0.98	0.99		1.00	0.97	0.95	0.91	0.90	-0.11
9	0.65	0.77	0.83	0.89	0.94	0.96	0.97	0.99		0.99	0.98	0.96	0.95	-0.02
10	0.62	0.75	0.81	0.87	0.91	0.93	0.95	0.97	0.99		1.00	0.99	1.00	-0.07
11	0.61	0.73	0.78	0.85	0.88	0.90	0.92	0.95	0.97	0.99		1.00	0.99	-0.06
12	0.58	0.70	0.76	0.82	0.86	0.88	0.90	0.92	0.94	0.97	0.99		1.01	-0.11
13	0.56	0.67	0.72	0.78	0.82	0.84	0.86	0.88	0.90	0.94	0.96	0.98		-0.09
ASM	-0.19	-0.20	-0.19	-0.21	-0.22	-0.22	-0.24	-0.26	-0.27	-0.27	-0.29	-0.28	-0.28	

*The genetic correlations are above the diagonal and phenotypic correlations are below the diagonal

Table 40: Estimates of genetic and phenotypic correlations from sire and dam components of variance and of covariance of cummulative monthly egg production and, age at sexual maturity in strain B*.

Cumm. Month	Cummulative Month 1	2	3	4	5	6	7	8	9	10	11	12	13	ASM
1		0.76	0.79	0.69	0.84	0.80	0.84	0.87	0.86	0.79	0.67	0.69	0.70	-0.63
2	0.84		0.84	0.70	0.76	0.65	0.63	0.64	0.67	0.67	0.65	0.69	0.72	-0.63
3	0.79	0.92		0.85	0.86	0.75	0.80	0.80	0.82	0.84	0.84	0.84	0.87	-0.76
4	0.72	0.84	0.92		0.88	0.82	0.87	0.85	0.87	0.87	0.91	0.93	0.98	-0.71
5	0.70	0.81	0.88	0.95		0.99	1.03	1.00	1.01	0.99	1.00	1.01	1.08	-0.70
6	0.66	0.77	0.84	0.92	0.98		1.00	0.99	1.00	0.99	1.00	1.00	1.09	-0.69
7	0.63	0.75	0.82	0.90	0.96	0.99		0.98	1.01	1.01	1.02	1.04	1.13	-0.64
8	0.62	0.74	0.81	0.88	0.94	0.97	0.99		0.97	0.97	0.98	0.98	1.05	-0.67
9	0.61	0.72	0.79	0.86	0.92	0.96	0.97	0.99		1.00	1.00	0.99	1.06	-0.61
10	0.60	0.71	0.78	0.84	0.90	0.94	0.96	0.97	0.99		0.99	0.99	1.03	-0.50
11	0.61	0.71	0.78	0.83	0.89	0.92	0.94	0.96	0.98	0.99		1.00	1.04	-0.56
12	0.59	0.69	0.76	0.81	0.87	0.90	0.92	0.94	0.96	0.98	0.99		1.02	-0.54
13	0.57	0.67	0.74	0.79	0.84	0.88	0.89	0.91	0.93	0.95	0.97	0.99		-0.58
ASM	-0.29	-0.31	-0.33	-0.36	-0.37	-0.32	-0.29	-0.29	-0.26	-0.27	-0.31	-0.27	-0.26	

*The genetic correlations are above the diagonal and phenotypic correlations are below the diagonal

5.0 DISCUSSION

5.1. Comparison of goodness of fit

Some reports dealing with mathematical models of group egg production expressed egg production on the basis of the birds' chronological age (McNally, 1981; Yang, et al., 1989). Under such circumstances, the increasing slope of the egg production curve depends on the actual rate of increase in egg production of the individual hens, as well as on the variation in age at sexual maturity within the group (Gavora, et al., 1982). In the present study, individual egg production was expresed in 28-d periods from the day the birds laid the first egg. Consequently, summation of such records resulted in group egg production data free of the influence of sexual maturity.

The results of this study confirmed earlier observations by other authors that the McNally, Parabolic exponential and Wood models indicate relative adequacy to fit group egg production data (McNally, 1971; McMillan, et al., 1986; Johari, et al., 1987). However, contrary to report of Johari et al. (1987), in which the Wood model gave better fits than Parabolic exponential, the latter was found to perform better than the former in this study (Tables 1 and 2). For production records that peaked more gradually, the difference between McNally and Parabolic exponential was negligible (Fig. 7). Similarly, figures 3 and 4 show that the three models fitted data points very

closely and could generate well the two most critical periods, i.e. the initial slowly increasing slope and the abrupt change from a positive to negative slope near the peak. Although the Parabolic exponental model had high R^2, in the initial period of lay it could not accurately describe the changes. However, in the middle and latter periods of lay, the model gave a good decription of actual changes in egg production. This probably suggests that if data for the first 1 or 2 weeks were excluded from the model fitting, the goodness of fit of the model might probably be improved with respect to the R^2 and estimated peak values. Similar observations have been made by Cason and Britton (1988) and Yang, et al., (1989) who reported that early egg production data are important in determining the goodness of fit of different models. So, arbitratily starting flock production records at 5 or 10% production may influence the ability to predict future egg laying behaviour by mathematical analysis of those records.

Both the Linear and Exponential models gave a poor fit to the data (Table 1 and 2) when compared with the other models. The main reason for the inferior fit obtained for the linear regression to mean group egg production data seems to be the fact that even the 'Synrochronized' data have a short increasing slope before reaching peak production which cannot be expressed by the Linear regression. With increasing cycle length, this deficiency of the linear regression seems to become less important.

The average R^2 obtained from fitting the three models to the individual production records was 0.59, 0.63 and 0.51 for Parabolic, McNally and Wood models,

respectively in strain A ; and 0.52, 0.56 and 0.47, respectively for strain B. Individual records varied from 0.02 to 0.94 for Parabolic, 0.03 to 0.95 of McNally and 0 to 0.93 for Wood in strain A; and 0 to 0.96 for Parabolic, 0.01 to 0.99 of McNally and 0 to 0.88 for Wood in strain B, indicating the possible existence of patterns not fitted by either of these models (Fig. 8). The pattern suggest that some birds may have undergone a partial moult and started new egg production cycles. The arbitary criteria used to distinguish between the first and subsequent egg production cycles within the hen's record as described earlier, were apparently too crude to detect multiple production cycles separated by smaller production decreases and may require refinement (Gavora et al., 1982). This probably explains the sudden decrease in R^2 value observed for the production cycle length of 12 periods compared with other periods. Ibe and Hill (1988) also reported that egg production traits, particulerly those based on early records, exhibit markedly non-normal distributions. They observed that age at first egg, a measure of sexual maturity, is usually positively skewed, whereas survivor, hen-housed and hen-day egg productions are negatively skewed. The outliers which cause skewness in data may be simply aberrant or may be true values inherent in the underlying distribution. The mean parameter values calculated from fitting the models to individual records and the parameters obtained from fitting the models to the group mean often differed (not shown). Similarly, the R^2 values for the individual curves and mean curve values were substantially different (Tables 3 and 4). Detailed examination of fitting the models

to individual records revealed that, for some records, the parameters have either large negative or positive values. Also, some of the records typically reached their peak in the first 28-d period (Fig. 9). Consequently, such records contributed to the differences between "individual curve" and "mean curve" values of the parameters (Gavora, et al., 1982). Thus, records starting at the peak and then decreasing could be expected to be fitted as well (or better) by a Linear regression than by any of the other models. This is because the exponential models tend to approach a straight line over the actual time interval considered in these cases. From this point of view, it would appear that for an optimum fit to individual egg production records it may be necessary to decide, on the basis of a preliminary examination of each record, which model is suited for the pattern and only then proceed with the fit itself. It should be noted that the data in Fig. 9 seem to be fitted quite well by the models. This suggests that, for hens maintaining high egg production throughout the period considered, such as in Fig. 9, the R^2 value may be a misleading measure of goodness of fit relative to hens with different egg production patterns (such as in Fig. 7). Again, it should be noted that the observed data in this study did not follow the expected pattern of egg production at the initial stage. This was because the onset of egg production (sexual-maturity) for the population coincided with the period of high environmental temperature. Thus, rather than the expected steady increase in production from the first to the 2nd month, the production actually dropped and later rose again. Furthermore, irregular feed supply or unavailaability at this period

is also a likely reason for the unusual pattern.

Judging from the several criteria of goodness of fit presented in Tables 17 and 18, the Wood model was the least preferable in this study with respect to its goodness of fit, especially for the greatly delayed estimated peak, which confirms the results of Congleton, et al., (1981).

The effect of strain on the functions of egg production curve showed (Tables 14-16) that the constant, a (i.e potential maximum egg production per period), was significantly ($P<0.05$) higher for strain B (female line) than for strain A (male line). This is not surprising since selection to improve number of eggs is concentrated on the female line, while the emphasis on the male line is to improve bodyweight and egg weight. Similarly, production cycle lengths shorter than 13 periods show a fast rise to peak yield (b) but have a much quicker rate of decline from the peak (c) resulting in a lower persistency (S) as shown in Table 16. The general the level of production (a) is also low in these short cycle lengths. It would appear that hens with short production cycle lengths also suffer from a low level of production so that the net effect on Annual egg production is a reduction due to a combination of both factors. Thus, it is quite possible to use data from the early part of laying year to determine the constants in the models and then to predict the whole year performance.

5.2 Comparision of abilities to predict annual egg production

The choice of model is often difficult, especially when the purposes it serves are not clearly defined. McMillan, et al., (1986) considered the importance of another criterion in judging different models, that is, the predictive ability. Thus, one of the objectives in establishing a mathematical model of egg production is to predict whole record production from part-record.

Prediction of egg production (and egg size) is necessary for economic projections for laying hens. Mathematical models provide one means of prediction, but they are sometimes inadequate due to poor extrapolative properties or large deviations from expectations. Therefore, in this study, the predictive aspect of the models was to be an important consideration for ranking the utilities of the three chosen models. The predictions play important roles in early selection, production planning and economical decision making (Yang, et al., 1989).

On this basis, the Wood model is less suitable than the Parabolic exponential or the McNally models. Between the later two, it is difficult to choose with respect to strain A or B. This is similar to the result obtained by McMillan, et al., (1986) in which they examined the predictive ability of three equations and reported that the Compartmental model performed quite well in its predictive capacity compared to the Linear model, while the Wood model did not. Yang, et al., (1989) also reported that for the two lines studied, the Wood models consistently had the greatest errors in prediction compared to the other two models namely, the modified Compartmental and the Compartmental. This probably suggests that all models do not fit all data equally well. This agrees with the results of McMillan et al (1986) who found that all the models they examined predicted whole-record egg production of two selected strains better than that of an unselected control strain, and the rank of the two best predictive models changed with strain.

As the Wood model was identical to the McNally model except for an extra term in the later, it appeared that mathematical properties of this term was important in differentiating between the two models. Congleton, et al., (1981) observed that there is no inflection point

in the initial period for the Wood model which causes problems in this part of the curve and that leads to greater systematic errors in model fitting.

Based on the comparisons presented here, the McNally model appears to be superior to the Wood model in terms of goodness of fit or predictive ability for egg production. Also, on a R^2 basis, the McNally model came slightly ahead of the Parabolic exponential.

5.3 Genetic estimates for production traits and curve parameters

Hays (1924), observed that four determinants of egg production are important in monthly production records. These determinants are sexual maturity (Classically measured as age at first egg or ASM), intensity of production (length of runs of consecutive days on each of which an egg is produced), persistency of production (length of period until production ceases and the bird begins to moult) and occurence of pauses (periods of consecutive days, usually more than four, during which no eggs are laid). Mortality also affects these production records since a bird is counted as having laid zero eggs after death. Intensity of production certainly enters into all monthly records, and is probably the primary influence on production after the first part-year production until difference in persistency and viability begin to have major effect, which increases in importance with time.

The low to moderate heribatility estimates for production traits and curve parameters indicate that intensity of production is low. After the first part-year production, the heritability estimates rose slightly due to increasing variability of persistency and viability during the later months. This result is in agreement with the findings of VanVleck and DooLittle, (1964), who also observed that after the sixth month, heritability estimates from dam families

rise while those from sire families remain low. In comparison with estimates from other investigations (Kinney, 1969; Kolstad, 1972a,b), the heritabilities for sexual maturity and egg number were in good agreement with normal values. The heritability estimates obtained for the different production periods are varied. This supports the claim that different periods within the production record may have dissimilar genetic parameters (Flock, 1977; Muir, 1990). Consequently, all parts of the production period should not have equal weights when selection is based on partial record. Differences in sexual maturity influence the measures of egg production in the first and to a lesser extent in later months, as evident by the progessive decline in correlation estimates between ASM and part-production (or monthly production) and annual production (Tables 25-40). However, the low correlation of early monthly production with annual production, and medium to high correlations of direct measurement of sexual maturity with annual production, suggest that the separate measurement of sexual maturity may be useful in supplementing selection from part-records. Maternal effects appear important in describing differences in reaching complete sexual maturity and in persistency of production (VanVleck and DooLittle, 1964).

The differences observed in the signs of the relationship between ASM, egg production and curve parameters in the two strains probably indicate strain difference, and are apparently characteristic of the production curve for each strain. Low estimates of heribatility are likely to be associated with widely fluctuating estimates of genetic correlations. The heritability estimates obtained for the curve estimates appeared quite low. However, since there are high correlations between the curve parameter '**a**' and production traits, coupled with the ability of the models to predict full production from partial records, the models will be useful as added

tool in selection programme for poultry.

The phenotypic correlations between the part-year production and annual total increases progessively from the first period or after the second month. Accordingly, after the third month of production essentially the same effects apparently contribute to monthly (or part-record) as to annual egg production.

The pooled sire and dam component estimates of genetic correlations of part-record or monthly production with annual production increased rapidly from low values in the first months and approached unity in the 4th and 5th months. This suggests that genetic differences in persistency and viability are more important determinants of variation in total annual production than are differences in intensity. Generally, the genetic correlations are also consistently larger than the phenotypic correlations. These results agree with the report of other workers who have also made similar observations (VanVleck and DooLittle, 1964; Lerner and Cruden, 1948). It should be noted that the estimates from sire components of variance were mostly larger than the estimates from the pooled estimates of sire and dam components. Usually, h^2_{s+d} estimates are larger than h^2_s, since h^2_s is expected to be less biased than h^2_{s+d} because of the confounding of maternal effects or dominance variance in the hierachical mating structure. However, there are frequent exceptions and probably indicate the influence of sex-linked genes on the traits concerned.

The relative genetic gain to be obtained by selection on the basis of part-record can now be discussed. The common objective of commercial breeders of laying stock is to increase the number of eggs produced per unit of time. The use of early partial egg records as a selection criterion for improving annual egg production has often been cited as a procedure for obtaining

this objective in the shortest time (Bohren, 1970). It has been shown (Lerner and Cruden, 1948) that because of the high genetic correlation between part year production and total annual production, selection for the latter based on the former would not diminish genetic progress as compared to selection based on complete records. The generation interval resulting from selection on part-record will probably more than offset the loss in efficiency if records are taken for about half of the full laying year. Thus the value of using part of the annual egg production for the early selection of superior sire and dam lines in chickens has been widely accepted. This was confirmed by the results obtained by VanVleck and DooLittle, (1964). They reported that if cummulative records of not more than five to six months are used in conjuction with a supplemental measure of ASM, the relative efficiency of selection on part records increases rapidly. This finding agrees with the results obtained by Lerner and Dempter (1956) who concluded that pullet breeding is a practical and desirable procedure in programs of combined family and individual selection for egg production.

6.0 CONCLUSION

The choice of model is often difficult, especially when the purposes it serves are not clearly defined. In this study, the predictive aspect of the models was to be the main concern for ranking the utilities of the three chosen models.

Based on the comparisons presented in this study, it can be concluded that the McNally model has theoretical advantages over the Parabolic exponential and Wood models in respect to its goodness of fit to the data and its ability to predict. However, one model may not necessarily be best in all circumstances or with all data. The properties of the model and the data should be examined, and the appropriate model chosen.

It appears from these results that selection for total annual production or 52-wk production from a single month will not be satisfactory unless the month chosen is one in the latter part of the laying year (i.e. from the 7th month onward). If, however, cummulative records are used, the decreased interval resulting from selection on the part record will probably more than offset the loss in efficiency if records are taken for about half of the full laying year.

Furthermore, selection on functions of the parameters, such as part-record or total egg production, seem more reliable than using the individual parameters judging from the h^2 estimates. However, in theoretical and breeding applications, mathematical models of egg production could be used to improve the accuracy of prediction of whole-record egg production for selection purposes or to explore breeding strategies, such as optimum length of the part-record used for selection.

Application of a mathematical model to egg production records of laying hens in a tropical environment seems practicable. However, its use for individual hen records in selection experiments or programme requires further and more extensive research.

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Appendix A

Formulas used in calculation of estimates of heritability and genetic, phenotypic and environmental correlations using the Mixed Model Least-Squares and Maximum likelihood computer programme (Harvey, 1990).

Heritability

MODEL1:

σ^2_s is the crossclassified or nested "family" variance component estimate; σ^2_e is the within family variance component estimate; NRI is the decimal percentage of additively genetic variance in σ^2_s and NW is the decimal percentage of additively genetic variance in σ^2_e (in random mating populations NRI = .25 and NW = .75). Note: BETWEEN = NRI and WITHIN = NW.

$$g^2 = \frac{\frac{1}{\text{NR1}}\sigma^2_s}{\frac{\text{1-NW}}{\text{NR1}}\sigma^2_s + \sigma^2_e}$$

MODEL 4:

With animal breeding data the "family" variance components under these models will usually be for sires, σ^2_s and dams within sires, σ^2_{ds} and the full-sib variance component will be σ^2_e

In this case, NRI3 is the decimal percentage of genetic variance in σ^2_s, NRI4 is the decimal percentage of genetic variance in σ^2_{ds} and NW is the decimal percentage of genetic variance among full sibs, i.e in σ^2_e (in random mating populations $NR1_3 = NR1_4 = .25$

and NW = .50). Note: BETWEEN = $NR1_3$, BETWEEN2 = $NR1_4$ and WITHIN = NW.

Full-Sibs

$$g^2 = \frac{\frac{1}{\frac{}{NR1_3+NR1_4}}(\sigma^2_s + \sigma^2_{d:s})}{\frac{1\text{-}NW}{\frac{}{NR1_3+NR1_4}}(\sigma^2_s + \sigma^2_{d:s}) + \sigma^2_e}$$

Paternal Half-Sibs

$$g^2 = \frac{\frac{1}{\frac{}{NR1_3}}\sigma^2_s}{\frac{1\text{-}NW\text{-}NR1_4}{\frac{}{NR1_3}}(\sigma^2_s + \sigma^2_{d:s}) + \sigma^2_e}$$

Maternal Half-Sibs

$$g^2 = \frac{\frac{1}{\frac{}{NR1_4}}\sigma^2_{d:s}}{\frac{1\text{-}NW\text{-}NR1_4}{\frac{}{NR1_4}}(\sigma^2_d + \sigma^2_{d:s}) + \sigma^2_e}$$

Correlations

Genetic Correlations are computed in each case by simply dividing the "family" covariance component estimate for the two traits by the geometric mean of the two "family" variance component estimates.

Phenotypic and Environmental Correlations

In paternal half-Sibs there is no interection of sires with fixed effects (MODEL 1).

$$r_{p(hh')} = \frac{\sigma_{e(hh')} + \frac{1\text{-}NW}{NR1}\sigma_{s(hh')}}{\sqrt{(\sigma^2_{e(h)} + \frac{1\text{-}NW}{NR1}\sigma^2_{s(h)})(\sigma^2_{e(h')} + \frac{1\text{-}NW}{NR1}\sigma^2_{s(h')})}}$$

Full-Sib Analyses Model 4:

Full-Sibs

$$r_{p(hh')} = \frac{\sigma_{e(hh')} + \frac{1\text{-}NW}{NR1_3+NR1_4}(\sigma_{s(hh')} + \sigma^2_{d:s(hh')})}{\sqrt{(\sigma^2_{e(h)} + \frac{1\text{-}NW}{NR1_3+NR1_4}(\sigma^2_{s(h)}+\sigma^2_{d:s(h)}))\,((\sigma^2_{e(h')} + \frac{NW}{NR1_3+NR1_4}(\sigma^2_{s(h')}+\sigma^2_{d:s(h')}))}}$$

Parernal Half-Sibs

$$r_{(w:hh')} = \frac{\sigma_{e(hh')} + \sigma_{d:s(hh')} + \frac{\text{1-NW-NR1}_4}{\text{NR1}_3}\,\sigma_{s(hh')}}{\left(\sigma^2_{e(h)} + \sigma^2_{d:s(h)} + \frac{\text{1-NW-NR1}_4}{\text{NR1}_3}\,\sigma^2_{s(h)}\right)\left(\sigma^2_{e(h')} + \sigma^2 d{:}s(h') + \frac{\text{1-NW-NR1}_4}{\text{NR1}_3}\,\sigma^2_{s(h')}\right)}$$

APPENDIX

Appendix 1: Heritability estimates from sire components of variance for production traits and curve parameters in groups of hens having not less than nine 28-d periods.

	Strain (A)			Strain (B)		
Traits	N	h^2	± S.E	N	h^2	± S.E
ASM	479	0.335	0.151	459	0.322	0.151
PP16	"	0.343	0.154	"	0.289	0.142
PP20	"	0.335	0.151	"	0.297	0.144
PP24	"	0.312	0.145	"	0.290	0.142
AP52	"	0.206	0.116	"	0.219	0.122
MA	"	0.159	0.102	"	N.A	
MB	"	0.145	0.098	"	N.A	
MC	"	0.156	0.101	"	N.A	
MD	"	0.149	0.099	"	N.A	
WA	"	0.249	0.128	"	0.196	0.115
WB	"	0.033	0.063	"	N.A	
WC	"	0.017	0.058	"	N.A	
PA	"	0.193	0.112	"	0.169	0.107
PB	"	0.100	0.084	"	0.006	0.55
PC	"	0.073	0.076	"	N.A	

Appendix 2: Heritability estimates from sire components of variance for production traits and curve parameters in groups of hens having not less than thirteen 28-d periods.

	Strain (A)			Strain (B)	
Traits	N	$h^2_s \pm$ S.E.		N	$h^2_s \pm$ S.E.
ASM	405	0.301	0.153	338	0.360 0.179
PP16	"	0.297	0.150	"	0.298 0.162
PP20	"	0.272	0.143	"	0.296 0.162
PP24	"	0.271	0.143	"	0.284 0.158
AP52	"	0.317	0.155	"	0.326 0.170
MA	"	0.115	0.098	"	N.A
MB	"	0.103	0.095	"	N.A
MC	"	0.116	0.095	"	N.A
MD	"	0.102	0.094	"	0.007 0.076
WA	"	0.201	0.123	"	0.246 0.148
WB	"	0.008	0.065	"	N.A
WC	"	N.A		"	N.A
PA	"	0.160	0.111	"	0.186 0.130
PB	"	0.086	0.089	"	N.A
PC	"	0.069	0.084	"	N.A

Appendix 3: Heritability estimates from sire components of variance for monthly egg production.

		Strain (A)			Strain (B)	
Traits	N	h^2_s	± S.E	N	h^2_s	± S.E
M1	405	0.253	0.138	338	0.249	0.148
M2	"	0.299	0.151	"	0.223	0.141
M3	"	N.A		"	0.343	0.174
M4	"	0.095	0.091	"	0.119	0.111
M5	"	0.082	0.087	"	0.192	0.132
M6	"	0.283	0.147	"	N.A	
M7	"	0.078	0.086	"	0.004	0.074
M8	"	0.298	0.151	"	0.162	0.123
M9	"	0.068	0.083	"	0.313	0.166
M10	"	0.133	0.103	"	0.033	0.084
M11	"	0.094	0.091	"	0.244	0.147
M12	"	N.A		"	0.075	0.097
M13	"	0.330	0.160	"	N.A	

Appendix 4: Heritability estimates from sire components of variance for cummulative monthly egg production.

		Strain (A)			Strain (B)	
Traits	N	h^2_s	± S.E	N	h^2_s	± S.E
CM1	405	0.253	0.138	338	0.249	0.148
CM2	"	0.370	0.171	"	0.278	0.157
CM3	"	0.246	0.136	"	0.410	0.192
CM4	"	0.295	0.150	"	0.391	0.187
CM5	"	0.279	0.146	"	0.393	0.187
CM6	"	0.278	0.146	"	0.374	0.182
CM7	"	0.288	0.148	"	0.353	0.177
CM8	"	0.329	0.160	"	0.370	0.181
CM9	"	0.340	0.163	"	0.357	0.178
CM10	"	0.356	0.167	"	0.338	0.173
CM11	"	0.354	0.167	"	0.384	0.185
CM12	"	0.348	0.165	"	0.378	0.183
CM13	"	0.330	0.160	"	0.390	0.187

Appendix 5: Estimates of genetic and phenotypic correlations for production traits and model parameters of McNally from sire components of variance and covariance in groups of hens having not less than nine 28-d periods in Strain A*

	ASM	PP16	PP20	PP24	AP52	MA	MB	MC	MD
ASM	-0.37	-0.42	-0.49	-0.53	0.27	0.34	-0.29	-0.15	
PP16			1.00	0.99	1.03	-0.05	-0.28	0.12	0.15
PP20	-0.30	0.97		0.99	1.04	-0.02	-0.25	0.08	0.12
PP24	-0.30	0.94	0.98		1.05	-0.08	-0.30	0.14	0.17
AP52	-0.36	0.75	0.77	0.78		0.03	-0.14	0.04	0.09
MA	0.01	0.08	0.07	0.05	0.17		0.97	-0.99	-0.99
MB	0.03	0.01	0.01	-0.01	0.09	0.97		-0.99	-0.98
MC	-0.02	-0.03	-0.03	-0.01	-0.14	-0.99	-0.98		0.99
MD	0.01	-0.03	-0.03	-0.01	-0.18	-0.97	-0.94	0.97	

*ASM = age at sexual maturity; PP16, PP20 and PP24 = part-record productions for wks. 16, 20 and 24, respectively; AP52 = Total production for 52 wks; MA, MB, MC and MD = model parameters of McNally as explained in the text. Genetic correlations are above the diagonal and phenotypic corelations are below the diagonal.

Appendix 6: Estimates of genetic and phenotypic correlations for production traits and model parameters of McNally from sire components of variance and covariance in groups of hens having not less than nine 28-d periods in Strain B*.

	ASM	PP16	PP20	PP24	AP52	MA	MB	MC	MD
ASM	-0.45	-0.56	-0.56	-0.42	-	-	-	-	
PP16	-0.37		1.00	0.01	0.95	-	-	-	-
PP20	-0.37	0.96		1.00	0.96	-	-	-	-
PP24	-0.34	0.93	0.98		0.96	-	-	-	-
AP52	-0.33	0.75	0.79	0.81		-	-	-	-
MA	-0.13	0.23	0.19	0.15	0.19		-	-	-
MB	-0.11	0.17	0.14	0.12	0.13	0.95		-	-
MC	0.10	-0.19	-0.15	-0.12	-0.16	-0.99	-0.94		-
MD	0.05	-0.17	-0.12	-0.09	-0.16	-0.89	-0.83	0.92	

*ASM = age at sexual maturity; PP16, PP20 and PP24 = part-record productions for wks. 16, 20 and 24, respectively; AP52 = Total production for 52 wks; MA, MB, MC and MD = model parameters of McNally as explained in the text. Genetic correlations are above the diagonal and phenotypic corelations are below the diagonal.

Appendix 7: Estimates of genetic and phenotypic correlations for production traits and model parameters of Wood from sire components of variance and covariance in group of hens having not less than nine 28-d periods in Strain A*

	ASM	PP16	PP20	PP24	AP52	WA	WB	WC
ASM		-0.35	-0.40	-0 47	-0.52	-0.58	0.20	-0.34
PP16	-0.30		1.00	0 99	1.03	1.01	-0.88	-0.16
PP20	-0.30	0.97		0 99	1.04	1.00	-0.88	-0.20
PP24	-0.30	0.95	0.98		1.06	1.01	-0.78	-0.04
AP52	-0.37	0.76	0.77	0 78		0.99	-0.52	0.31
WA	-0.27	0.79	0.75	0 73	0.54		-0.74	0.09
WB	0.11	-0.16	-0.09	-0 06	-0.24	-0.46		0.57
WC	0.07	0.03	0.08	0 11	-0.22	-0.16	0.93	

*ASM = age at sexual maturity; PP16, PP20 and PP24 = part-record productions for wks. 16, 20 and 24, respectively; AP52 = Total production for 52 wks; WA, WB and WC = model parameters of Wood as explained in the text. Genetic correlations are above the diagonal and phenotypic corelations are below the diagonal.

Appendix 8: Estimates of genetic and phenotypic correlations for production traits and model parameters of Wood from sire components of variance and covariance in groups of hens having not less than nine 28-d periods in Strain B*

	ASM	PP16	PP20	PP24	AP52	WA	WB	WC
ASM		-0.73	-0.79	-0 80	-0.61	-0.88	-	-
PP16	-0.33		1.00	1 00	0.99	1.21	-	-
PP20	-0.32	0.96		1 01	0.98	1.21	-	-
PP24	-0.29	0.93	0.98		0.98	1.18	-	-
AP52	-0.28	0.75	0.79	0 81		1.17	-	-
WA	-0.16	0.49	0.47	0 44	0.31		-	-
WB	0.01	-0.08	-0.01	0 03	-0.05	-0.40		-
WC	-0.02	-0.01	0.04	0 08	-0.09	-0.16	0.94	

*ASM = age at sexual maturity; PP16, PP20 and PP24 = part-record productions for wks. 16, 20 and 24, respectively; AP52 = Total production for 52 wks; WA, WB and WC = model parameters of Wood as explained in the text. Genetic correlations are above the diagonal and phenotypic corelations are below the diagonal.

Appendix 15: Estimates of genetic and phenotypic correlations for production traits and model parameters of parabolic from sire components of variance and covariance in groups of hens having not less than thirteen 28-d periods in Strain A*

	ASM	PP16	PP20	PP24	AP52	PA	PB	PC
ASM		-0.25	-0.32	-0 45	-0.47	-0.46	0.15	-0.07
PP16	-0.23		1.00	0 98	1.03	0.87	-0.40	0.20
PP20	-0.23	0.95		0 98	1.03	0.93	-0.48	0.29
PP24	-0.24	0.93	0.98		1.04	0.90	-0.39	0.18
AP52	-0.29	0.68	0.73	0 76		0.82	-0.20	-0.09
PA	-0.19	0.62	0.56	0 53	0.43		-0.77	0.63
PB	0.09	-0.23	-0.15	-0 12	-0.19	-0.86		-1.00
PC	-0.08	0.08	0.02	0 00	0.23	0.71	-0.96	

*ASM = age at sexual maturity; PP16, PP20 and PP24 = part-record productions for wks. 16, 20 and 24, respectively; AP52 = Total production for 52 wks; PA, PB and PC = model parameters of parabolic as explained in the text. Genetic correlations are above the diagonal and phenotypic corelations are below the diagonal.

Appendix 16: Estimates of genetic and phenotypic correlations for production traits and model parameters of parabolic from sire components of variance and covariance in groups of hens having not less than thirteen 28-d periods in Strain B*

	ASM	PP16	PP20	PP24	AP52	PA	PB	PC
ASM		-0.96	-0.93	-0 94	-0.81	-1.11	-	-
PP16	-0.31		0.99	1 01	1.06	1.13	-	-
PP20	-0.30	0.96		1 01	1.01	1.24	-	-
PP24	-0.26	0.92	0.98		0.99	1.26	-	-
AP52	-0.23	0.78	0.84	0 87		1.12	-	-
PA	-0.12	0.44	0.40	0 38	0.32		-	-
PB	0.04	-0.16	-0.09	-0 05	-0.05	-0.80		-
PC	-0.03	0.09	0.03	-0 01	0.06	0.67	-0.95	

*ASM = age at sexual maturity; PP16, PP20 and PP24 = part-record productions for wks. 16, 20 and 24, respectively; AP52 = Total production for 52 wks; PA, PB and PC = model parameters of parabolic as explained in the text. Genetic correlations are above the diagonal and phenotypic corelations are below the diagonal.