CRITICISM AND TESTS OF
THE EDINBURGH POULTRY GROWTH MODEL

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DEDICATION

To thank my Dad and Step-mother,

Mr. and Mrs. Eleazar and Keziah Ezeukwu.

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ABSTRACT

The ability to predict responses caused by changes in production input factors is an important management strategy. When used for this purpose, response simulation models can have useful roles to play especially in the field of animal production. The Edinburgh Poultry Growth Model was developed with the objective of assisting the poultry nutritionist, breeder, adviser and poultry farmer in the making of management decisions in the areas of poultry growth, with special reference to broiler production processes, from the important variables of nutrition, genotype, temperature and husbandry.

An attempt has been made in this dissertation to test the Edinburgh Poultry Growth Model and to critically assess its theoretical features and performance. The model was found to possess great potential in fulfilling the stated objectives.

The responses from the majority of the variables were consistent with those found in the existing research literature. It was found to be highly flexible and stable in coping with all the variables. However, the model is at present too sensitive in its temperature aspects. The assumptions made to formulate the equations for the heat loss mechanism are not yet adequate for simulating the thermoregulatory activities of poultry. It is believed that the problem is due to an absence in the existing state of knowledge, of appropriate data which could incorporate the behavioural responses to temperature in animals under *ad libitum* feeding systems. If this aspect of the model could be improved upon, it would enhance its value as a computer program in the fields of poultry production, research and teaching.

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1. INTRODUCTION

Applied research and development in science and technology has become increasingly aimed towards meeting the practical needs of industry and large scale production systems. There are many illustrations of developments in Agriculture associated with the mechanisation and automation of production processes.

As the use and application of computers in Agriculture has increased, management aid programs and response prediction models have been developed to aid and improve the efficiency and ability of decision-makers in management. Response prediction models are a relatively new innovation which could have considerable relevance and potential in the field of Animal Production, assisting those concerned with agricultural management systems to predict the possible effects that may result from changes in production input factors involved in any specific system. The use of models, especially flexible ones, that can produce responses from economically important variables could be an effective way of bridging the gap between research and the farmer as well as a valuable asset to agricultural advisory services.

The development is a relatively new specialisation, involving the assembly of all necessary information from the existing state of knowledge and translation of the data into sets of equations (models) and numbers to produce a package which can mimic an animal or a biological system. If a system can be modelled correctly, the resulting model can be used as an alternative to experiments involving live animals, with consequent economies of experimental time and resources by advisers, consultants and researchers in the field of animal production.

The Edinburgh Poultry Growth Model is the result of many years development by Mr. G.C. Emmans, of the Animal Production and Advisory Department, The East of Scotland College of Agriculture; and was computerised in 1981/82 by Mr. S. Gibson of the same department. It is one of the few response simulation models at the present time that has been developed specifically for an agricultural application and is constructed around the theories of food intake and growth. It is designed to assist poultry nutritionists, breeders, advisers and poultry farmers to predict food intake, growth and body composition of *ad libitum* fed chickens, as functions of genotype, nutrition, temperature and management. If the model can perform these functions, it will undoubtedly make a considerable contribution towards the improvement of poultry, especially broiler production.

There can be problem areas inherent in any new developmental process including modelling, and these must be identified to encourage improvement or modification. There may be wrong concepts about the system being modelled, also, as response simulation models are constructed to mimic the responses of real life, miscalculations may be as dangerous to the production system as errors that might occur in the design and operation of a nuclear power station would affect the population. A high degree of efficiency is therefore required of such models to be useful in the field of production.

The objectives of this dissertation are to 1. criticise and 2. test the Edinburgh Poultry Growth Model. The emphasis will be placed on discovering whether there are weaknesses or defects in any parts of the model, and the evaluation will be based entirely on the information available in research literature on the subject of poultry growth and production. It is to be hoped that through the study, the potentialities, problems and methods of systems modelling in animal production will be explored.

It is intended now to review literature relating to concepts and current trends concerning models and especially the Edinburgh Poultry Growth Model; and critically review the theoretical aspects of the Edinburgh Poultry Growth Model. The model would be then subjected to a series of tests with results being discussed and evaluated. The findings will be presented with all necessary experimental details attached.

2. LITERATURE REVIEW

SECTION I: RESPONSE PREDICTION MODELS IN AGRICULTURE

Computer programs and models have been identified as playing useful roles in agricultural systems, including those of animal production. The rate of their introduction and use has increased in recent times, and like every innovation in science and technology which may have some practical significance, if not properly used or constructed, may affect the industry adversely. In this review, the principal ideas about response simulation models are surveyed as a framework to understanding the Edinburgh Poultry Growth Model.

The development

Modelling has been defined as an art of mimicry (Mihran, 1972). It inovlves the assemblage of the theories or ideas about a system being modelled into a manageable package to promote better appreciation of the system. It is one of the main attributes of the system's concept which was first proposed by Von Bertalanffy in the 1930's (Boulding, 1956; Von Bertalanffy, 1972). The involvement of the computer since the 1970's has enabled this approach to studying agricultural parameters to become more flexible but complex (Dent, 1975; Spedding, 1977, 1981).

Dillon (1976) has defined the system in this context to mean a functional or conceptual unit made up of interacting parts at various levels of organisation. This approach recognises the indivisibility of whole systems and the fact that they cannot be split without loss of their organisational identity (Rountree, 1977). It has been claimed by the proponents that the basic hypothesis in modelling is that a system, whether defined as a physiological entity or the economic system of a nation cannot be properly understood by some *ad hoc* set of studies (Wright, 1971; Dent and Blackie, 1979). In agriculture, the system is very complex and the variables highly interactive. Producers, too, have complex goals. However, it has been observed that research science tends to have simple goals which have been caused by the piecemeal solutions offered through different disciplines in the field; this, resulting in the apparent eclipse of the necessary spurs to produce comprehensive predictive models (Whittemore, 1981; Emmans, 1981).

Research has also been progressing with so rapid a speed that little time has been devoted to articulate the facts of existing knowledge into simple forms that would benefit the agricultural adviser or producer. For this purpose, considerable promise seems to be offered by models especially those that are flexible enough to incorporate routines to optimise decisions (Curll and Davidson, 1977). Models have also been found as useful assets in response prediction, and as an alternative to experimentation in situations where real-life study may be either impossible, inordinately costly or too disruptive to design the necessary multi-factorial experiment (Whittemore and Fawcett, 1974; Wathes, Gill, Charles and Back,. 1981). They may additionally serve to direct research into areas where gaps exist, and in providing objective assessment of effects of new inputs or comparing the efficacy of alternatives such as in the animal feed manufacturing industry (Wilson, 1977 and Dent *et al.*, 1979).

Types of models

The more flexible a model is, the more its capacity to handle complex situations and fulfil the previously mentioned roles. They range from simple forms of empirical regression at one extreme to a set of deductive mathematical descriptions of cellular biochemical reactions at the other extreme (Whittemore, 1981). Gaines (1927), for example, used an exponential equation to describe milk yield of dairy cows. Ostergaard (1979) used a linear model to study strategies for concentrate feeding in dairy cows too. Robertson (1908) was the first to describe animal growth, using the logistic equation. Flow-diagrams proved to be a more practical approach (Spedding, 1976) until the advent of different computer programs, including lately, deductive models. Empirical regressions tend to be static and inflexible hence deductive models are more useful, but owing to gaps in current knowledge, the latter can contain a high proportion of hypotheses and too few hard facts (Whittemore, 1981).

The first response prediction model of this kind was the Edinburgh Model Pig by Whittemore and Fawcett (1976). It marked an important advance in predicting animal growth in which nutrient intake, genetic potential and housing/environment of pigs were brought together numerically (Filmer, 1981), and it is based explicitly on existing knowledge (Wilson, 1977). At various centres in the world, work is going on to develop more models. In the U.K., a Poultry Growth Model (Emmans, 1981) and a simulation model of rumen fermentation (Black, Beever, Faichney, Howarth and Graham, 1981) have also been produced.

Modelling

Simulation modelling is not simply a matter of transcribing known formulae into a form suitable for computer analysis. It is rather an art which requires ingenuity, foresight, resourcefulness and integrity on the part of the model builder (Dent *et al.*, 1979). The complex nature of the system being modelled may force the builder to cross departmental boundaries before a meaningful package to simulate the system can emerge. It has been suggested that a true model must incorporate full knowledge of the metabolic processes which constitute the system in relation to the whole animal, and should reproduce all the phenomena observed (Wilson, 1977). However, it appears more relevant that the level of detail and structure should be related to the purpose of construction and in any case, the boundaries should be clearly defined (Spedding, 1981). Scheele, Janssen and Van Gils (1977) have proposed that the prime requirements for a growth model for instance, are that it should work in practice, be reliable and the relations should not be too complicated.

The problems and tests

Both the modeller and the model are constrained by various factors. Problems associated with the lack of suitable data, gaps in existing knowledge, inappropriate tests for the model and technical hitches that may be inherent in computers are the main ones (Booth, 1979; Butterworth, 1981; McDonald, 1981; Warren, 1981). Spedding (1977) expressed that data for modelling crop or livestock production are harder to find in developing countries where sociological factors seem to loom rather larger than elsewhere. In such situations, no progress may be made unless stochastic elements are to be introduced (Dent *et al.*, 1979).

The history of all models examined in connection with this work has shown that the initial teething problems or flaws are common. Critics point at possible faults that may be embodied in the concepts, data, equations or numbers that constitute the model. These indicate that a high degree of stability is expected of a prediction model (Beever, 1981) before it would merit practical application.

It has been proposed by Wood (1981) that models should be tested to destruction. A purist would insist that this should be so because of the prospective role they may play in the field, thereby necessitating that the industry should be protected. It is therefore the responsibility of the builder to verify, test or validate his model appropriately (Mihran, 1972; Dent *et al.*, 1972, 1979). Unfortunately, it has been claimed that the conventional statistical methods are deficient in scope for analysing the complex interacting variables that computer simulation models deal with (Whittemore, 1981; McDonald, 1981). Opinions vary about the best ways to test simulation models, but options available may include graphical comparisons of the simulated and observed responses, sensitivity tests on the numbers used, and criticisms of any assumptions.

SECTION IIA: EDINBURGH POULTRY GROWTH MODEL

This section contains a description of the model as detailed in Emmans (1981a,b), the model manuals and the program (unpublished). A theory about feed intake underpins the model and it purports to predict the feed intake, growth and body composition responses of poultry as functions of genotype, environment and feed composition.

The motivation to develop the model came as a result of a need for a theory about food intake in poultry. Such, it was hoped, should enable the prediction of intake in any specific case. Poultry nutritionists usually make decisions from nutrient requirements tables expressed as feed contents rather than response information. This was described as an unsatisfactory situation. There are many theories about the mechanisms that animals use in controlling their feed intake, at a given level, but there is none that can be used to predict what this level would be (Emmans, 1981b). In order to facilitate the formation of a model, therefore, a theory was postulated by Emmans (1981a) that: an animal has a potential rate of normal growth at a given time and it seeks to eat the amount of a given feed which will allow this to be achieved. Also, that its degree of success will depend on the feed offered and the environment within which it is kept. The model is a set of equations, numbers and logical tests. The main arguments and assumptions underlying it are discussed in Section IIB.

The boundary of the model

The reproductive phases in poultry are not dealt with by the model. It was also assumed that the combined effects of natural and artificial selection have led to all domestic animals being successful genotypes in achieving their purposes - in this case the potential normal growth. It therefore operates if given the genotype of the chicken. Its boundary of operation is outlined as follows:

1. Aim: to predict values for food intake, growth and body composition.
2. Species: avian (domestic fowl, particularly meat producing strains).
3. System: growth and development.
4. Age: from hatching to slaughter.
5. Management: intensive system of production.
6. Feeding system: *ad libitum* access to single feed.
7. The experimental variables:

   (i) Genotype and chick systems - the initial degree of maturity (U_o), rate of maturity (B), mature weight (A), minimum lipid : protein ratio (MINLIP), initial fat content (L_o).

   (ii) Feeding programme - number of feeds to be used, feed form (mash, crumbs, pellets), pattern of change, feed composition (DM, ME, CP, DCP, amino acids, crude fat, crude fat digestibility, crude fibre and ash).

   (iii) Temperature schedule - operates on an "effective temperature" schedule in degrees centigrade, type (constant, smooth and stepped change), number of temperatures, period(s) to change.

   (iv) Management system - stocking rate (birds/m^2) and husbandry level (efficiency score ranging from 0 to 10).

   (v) Slaughter system - i.e. whether to slaughter according to time (days) or weight.

   (vi) Additional costs in the production.

It has been assumed in the model that vitamins/minerals are not limiting in the feed as they would not be deliberately excluded, neither would toxins be so introduced. Lighting system is also left out because its effect on broiler growth was considered negligible and forms part of the husbandry.

Notes on the genotype and chick systems

The user of the model is required to describe the genotype of his birds by the parameters - rate of maturity, potential mature weight, minimum lipid : protein ratio. Where he is unable, the following approximate values have been suggested for use, for all strains of poultry:

Mature weight (A) = 4.55 - 7.5 kg
Rate of maturity (B) = 0.025 - 0.033/day
Minimum lipid : protein ratio (MINLIP) = 0.20

Users

The program was designed to serve three main user groups, namely:

(a) Poultry nutritionists, growers and breeders.

(b) Poultry production advisers in areas of nutrition, breeding, environment, marketing and management.

(c) Poultry meat processing, distribution and sales organisations.

It was hoped that the package would enable the users to predict biological and financial effects of changes in the experimental variables.

Available reports

The model issues a maximum of six different reports at the choice of the user. They are:

(A) The data summary: displays the input variables in the model for selection by the user.

(B) The biological events diary: shows the possible interrelationship between the variables on growth, fat deposition and feed intake. Altogether, 16 possible outcomes are predicted as shown in Table 1.

(C) The daily biological results: displays the daily predicted values on feed intake, growth and body composition.

(D) The biological results summary: shows values of the biological responses at the end of the experiment for food intake, food utilisation, growth, composition, carcass and meat parts.

(E) Daily financial results: show continuously the financial consequences of the varied inputs in the operation.

(F) The financial results summary: indicates the costs, benefits and margins at the end of the operation.

TABLE 1: The possible outcomes predicted by the Edinburgh Poultry Growth Model from interrelationship between temperature and nutrition.

	Bulk limiting		Bulk not limiting	
	Protein 1st limiting resource	Energy 1st limiting resource	Protein 1st limiting resource	Energy 1st limiting resource
Environment too hot				
Lipid stores[1]	growth reduced gain excess lipid	growth reduced lose lipid	growth reduced gain excess lipid	growth reduced lose lipid
No lipid stores	growth reduced gain excess lipid	growth reduced no excess lipid	growth reduced gain excess lipid	growth reduced no excess lipid
Environment not too hot				
Lipid stores	growth reduced gain excess lipid	growth reduced lose lipid	potential growth achieved gain excess lipid	potential growth achieved lose lipid
No lipid stores	growth reduced gain excess lipid	growth reduced no excess lipid	potential achieved gain excess lipid	potential achieved no excess lipid

[1] Stores = previously accumulated excess lipid.

SECTION IIB: THE THEORY UNDERLYING THE GROWTH MODEL

In the course of this study, it was noticed that the model has both conceptual and empirical characteristics. It was constructed around the theory of feed intake and growth. Substantial data from existing research literature was used, but the model cannot be specifically associated with particular experiment(s) as sole sources of data. Except for the main theory, the equations were derived or adopted from a variety of work and information on poultry and other animals. The main arguments are presented in this section in terms of the general growth equation.

Growth and feed intake

It has been suggested in the model that in the absence of constraints, an animal seeks to eat in order to achieve its potential normal growth. The general growth equation in Parks (1970) was applied and is given by:

$$\alpha \cdot \frac{dw}{dt} + f(W) - \frac{dF}{dt} = 0 \qquad (1)$$

where α = a number or a function

$\frac{dw}{dt}$ = growth rate

$f(W)$ = some function of weight, W

$\frac{dF}{dt}$ = rate of feed intake

The prediction of the amount of feed that the animal is seeking to eat - the desired feed intake $(\frac{dF}{dt})^*$ is given by a re-arrangement of *(1)*:

$$\left(\frac{dF}{dt}\right)^* = f(W) + \alpha\left(\frac{dw}{dt}\right)^* \qquad (2)$$

where $(\frac{dw}{dt})^*$ = potential growth rate

This situation is different for controlled and *ad libitum* free choice feeding systems. In relation to the feed offered, desired intake is given by:

$$\left(\frac{dF}{dt}\right)^* = \frac{R_1}{C_1} \tag{3}$$

where R_1 = requirement for first limiting resource

C_1 = food content of first limiting resource

The function α, (in the model) is given by:

$$\alpha = e.U^b \tag{4}$$

and

$$U = \frac{W}{A} \tag{5}$$

where e = the efficiency of utilisation of feed supply above maintenance (M) for growth.

U = degree of maturity

A = mature weight

By using the views and equations in Brody (1945) and Taylor and Young (1968) on maturity to substitute for M; and by incorporating the functions in *(3)* to *(5)*, equation *(2)* was modified to take account of more variables, and is given by:

$$\left(\frac{dF}{dt}\right)^* = \left[M_1^* . A^{-0{\cdot}27} . W + \frac{(dw/dt)^*}{e_1}\right] . \frac{1}{C_1} \tag{6}$$

where M^* = interspecies estimate of resources needed, per $A^{0{\cdot}73}$/day by a mature animal.

Equation *(6)* predicts the desired feed intake in terms of the decision variables C_1, the animal characters A, W and $\left(\frac{dw}{dt}\right)^*$, and the parameters M^* and e. It is proposed to apply to all feeds at thermo-neutrality, and where feed bulk and toxins are not constraints.

The equation raises some questions about the concepts as to what controls feed intake and how W and $(\frac{dw}{dt})^*$ can be predicted, for a given bird and at a given time.

Control of feed intake

It is suggested in the model that the mechanistic theory of food intake control is secondary to the theory that an animal desires to eat an amount of feed sufficient to attain potential growth (Emmans, 1981a). It is assumed that where the feed is deficient in any nutrient, the animal will try to eat more food in an attempt to obtain a sufficient quantity. Thus, equation *(3)* was constructed from this belief that desired intake is inversely related to food content of the first limiting resource for a given bird at a given time (Emmans, 1981b). This is a tacit implication of diet composition as playing a primary role in the control mechanism. The model, therefore, expresses that if for example, protein is the first limiting resource, then:

$$(\frac{dF}{dt})^* = \frac{MP + (^{dP}/dt)^*}{FPC} \tag{7}$$

where MP = protein for maintenance
P = protein value (= 0.8)
$(\frac{dP}{dt})^*$ = desired protein growth rate
FPC = food protein content

Also, if energy is limiting, then the desired intake,

$$(\frac{dF}{dt})^* = \frac{MEN + (^{dP}/dt)^* . e_{PG} + MINLIP\ (^{dP}/dt)^* . e_{LG}}{FEC} \tag{8}$$

where MEN = energy for maintenance
e_{PG} = efficiency of protein gain
MINLIP = minimum lipid growth
e_{LG} = efficiency of lipid gain
FEC = food energy content

In this way essential amino acids have been calculated and have been incorporated in the model.

Other factors suggested which influence the desired feed intake are temperature, feed bulk, the state of the animal and toxic substances. In the presence of these factors, desired intake is not achieved and the model attempts to predict the "actual" or "constrained" food intake.

(a) Temperature

This is thought to be subject to the metabolic energy relationships and the environmental heat demand. Several physical components of the environment do affect heat loss and all have been combined into a scale of effective temperature (T) of the bird. On *ad libitum* feeding, it is assumed that the environmental heat demand (EHD) can be represented by the equation:

$$EHD = MBW\,(a - bT) \qquad (9)$$

where MBW = metabolic body weight; while a and b are thought to be independent of environment and feed composition. They reflect the insulation value of an animal's coat and are therefore functions of the degree of maturity (U). The model is thence assuming that heat loss is independent on how the chicken has been fed; but only on the environmental heat and size of the bird.

(b) The state of the animal

The upper limit of lipid stores is proposed to be about 0.35 of total body weight in chicken (Emmans, 1981b). Above this, no more lipid can be stored, and all the excess energy eaten must then be lost as heat, or the feed intake reduced to prevent the excess. If a bird has previously accumulated lipid which can cause a reduction in feed intake, and if energy is now the first limiting resource, actual feed intake will then depend on genotype, current state (U and lipid stores), feed composition (energy relationships with first limiting nutrient, bulk and toxins), and environmental hotness.

(c) Toxins and nutrient excesses

These are thought to affect intake because of their deliterious effects and disorganisation of the chemical composition of the ideal mixture (feed).

(d) Feed bulk

It is also a constraint on intake despite the feed composition. Mraz, Boucher and McCartney (1957) gave evidence to this view.

The algorithmic interaction of all the above variables (excluding toxins, vitamins and minerals) as they relate to equation *(6)*, have been incorporated in the model for prediction of the actual feed intake.

Potential growth

It has been suggested that growth has two main aspects: i) the efficiencies of particular conversion processes, and ii) the rate at which these processes occur. The first is generally well-understood but the second, in growing animals, less so (Emmans, 1981a). Potential growth is also seen as being made up of two components:

i) normal growth - consists of all the protein, ash and water;

ii) fat growth - storage lipid which is all of the lipid above the minimum.

The two are seen as being independent of each other.

For the description of the potential normal growth in poultry, the Gompertz function of time was considered suitable because it had biological form about it, fitted data and had good mathematical properties. It has been compared with other equations from experiments (Wilson, 1977; Tzeng and Becker, 1981), and found suitable. It is given by:

$$W_t = A_{\exp} - \exp - B(t - t^*) \qquad (10)$$

where Wt = weight at time t
A = mature weight
B = rate of maturing
t = age; at hatching, t=0 (or U_0)

From the above were derived equations for potential protein growth and growth rate $\frac{dW}{dt}$; the latter is given by:

$$\frac{dW}{dt} = W.B.\mathrm{Loge}\left(\frac{A}{W}\right) \qquad (11)$$

and represents an attempt to express the entire journey of the bird from hatching to mature weight (W_0, U_0, B to A). With this, the values for W and the potential growth rate $(\frac{dW}{dt})^*$ from feed intake prediction equation *(6)* could be expressed as functions of U_0, B and A. That is, $(\frac{dF}{dt})^*$ expressed as function of these genotype parameters in addition to C_1, M^*, e and other variables already discussed.

Composition of potential growth

All the chemical and physical components of growth were treated as allometric functions of weight except reproductive tissues. The equation of Taylor (1980) which is similar to Huxley's (1932) was used and is given by:

$$y_1 = ay_2^b \qquad (12)$$

where y_1 = weight of component 1
y_2 = weight of component 2 (or whole body)
b = allometric coefficient
c = a constant

(i) Normal growth

This comprises protein, ash, water and MINLIP, and is related to protein growth as follows:

Normal gain =

$$Pr\ (0.16 + MINLIP + 2.96 - 0.3\ (\ln \frac{P_t}{P_{\hat{t}}}) + 1.0) \qquad (13)$$

where Pr = rate of protein growth
P_t = weight of protein at time t
$P_{\hat{t}}$ = weight of protein at time t = infinity
ln = Loge

(ii) Protein growth

The protein content of the body increases with degree of maturity - U. Therefore, it seems that protein requirement for growth will increase with U. The maximum protein growth rate is given by:

$$\frac{dP_t}{dt} = Pr^* = B.P_t.\ln \frac{(P_{\hat{t}})}{P_t} \qquad (14)$$

where Pr^* = maximum protein growth rate at a given value of P_t
B = rate of decline of relative growth rate
ln = Loge

The modeller assumed using the above equation that the potential rate of protein growth for a given genotype depends only on the value of P_t, i.e. that Pr^* at a given value of P_t is unaffected by the path that the animal took to get to P_t. This concept was found to agree with Whittemore (1976).

(iii) Water content

The model conforms with the opinions of Armsby and Moulton (1925) that there is an inverse relationship between protein weight and water content of body - i.e. animals become drier with age. Also

Hakansson, Eriksson and Svensson's (1978) data was adopted which shows that across genotypes of birds, this relationship applies with degree of protein maturity $P_t/\hat{P_t}$, with a slope b = 0.9077.

(iv) Ash

There is a close functional relationship between the growth of ash and protein. The data of Hakansson *et al*. (1978) for chickens which showed that Ash = 0.16 protein, and that this is unaffected during normal growth, with a coefficient b $\simeq$ 1, was adopted.

(v) Lipid growth

It is assumed in the model that every animal has a minimum amount of lipid which can be regarded to be of equal importance to protein, i.e. MINLIP. In chickens and turkeys this minimum lipid : protein ratio can be as low as 0.20. The model further suggests that the 'widespread' belief that modern chickens are inherently fat is a mistake, based on observations made on poorly balanced feeds. Also, that it is a mistake that broilers are fat at maturity. It preferred to recognise a wider ratio of energy : first limiting nutrient, rather than the popular view of energy : protein ratio in checking obesity; in the belief that the bird does not eat more food in order to grow fat but to make faster normal growth.

Genetic effect on fat deposition is thought to manifest where energy is the first limiting feed resource. In studies by Wilson and Emmans (unpublished) it was found that chicken and turkeys tend towards having about four per cent of their body weight as chemical lipid at least until females approach sexual maturity. This resembles the earlier findings in Fraps (1943) and Combs (1962). In an animal which does get fatter as it matures, such as a pig or a sheep, fat growth can be made allometric to protein as water is dealt with.

(vi) Efficiency of growth

The amounts of fat, carbohydrate and protein needed to form body fat is given in Table 2 (Emmans, 1981b). It is assumed that extra food resources are not needed for fat formation. It is also assumed that whereas carcass fat depends on feed intake, ash and water depositions depend only on protein growth.

TABLE 2: Quantities of substrates needed to form 1 kg of body fat.

Substrate	kg	MJME
starch	3.0	53
fat	1.1	44
protein	3.8	70

SECTION IIC: SUMMARY

The Edinburgh Poultry Growth Model is a multi-parameter deductive simulation model. It is constructed on the main assumption that the purpose of the animal is to attain potential normal growth. Also that the success depends on feed offered and the environment in which it is kept. The desired feed intake is inversely related to the food content of the first limiting resource, and this is also constrained by temperature, feed bulk, toxins and the lipid stores in the animal. It is further believed that the only reason why a fatty chicken is produced is because they are fed unbalanced diets.

As inputs in the model, practical broiler production can sufficiently be described by the variables - genotype (A, B, MINLIP), state of the bird (W, % fat), temperature, feeding programme and management. All these are completely interactive. In growing birds unlike reproducing stock and mammals, the performance of the individual is claimed to be very close to being equivalent to the average of the population.

It is also assumed that for a given chicken on a given feed, heat loss is constant. The potential rate of protein growth (Pr*) depends only on the weight of protein P_t, at time t; and is unaffected by the path the animal took to get to P_t. Whereas carcass fat depends on feed intake, ash and water content depend on protein deposition.

All the numbers for the parameters have been translated into a FORTRAN computer program to facilitate prediction of feed intake, growth and body composition of chicken on *ad libitum* access to single feeds.

3. CRITICAL REVIEW OF THE EDINBURGH POULTRY GROWTH MODEL

Genetic and environmental factors affect the performance, growth and composition of animals. In poultry and livestock, the factors include genotype, sex, age, nutrition, temperature and management. In the poultry growth model, these variables were recognised and all (see page 10) have been incorporated in an effort to produce a package that could simulate poultry responses during growth. This section is primarily a review of literature on some theoretical aspects of the model where there may be some incorrect assumptions.

The control of food intake

It is stated in the model that for a given state of an animal, the animal's desired food intake may be constrained by the feed composition, bulk and temperature (environmental hotness). Also, that intake will increase in response to deficiency of any (first limiting) nutrient in the diet. Predictive equations for the desired and actual food intake were therefore proposed (page 15). By implication, all essential nutrients are capable of chemostatic effects on the control of appetite. The impact of specific nutrients is reviewed next.

The generalisation in the model may be seen as a combination of the homeostatic theories that have been connected with voluntary food intake. These are: the thermostatic theory (Brobeck, 1947), lipostatic theory (Kennedy, 1952), glucostatic theory (Mayer, 1955) and the aminostatic theory (Mellinkoff, Frankland, Boyle and Greipel, 1956). Jacob and Scott (1957) proposed that food intake in mammals and birds are affected by a nutrient need, i.e. homeostasis, habit from experience, i.e. learning, and palatability. The cognitive set-point mechanism present in man, for example, to regulate weight or obesity is thought to be absent in animals (Booth, 1979; Thompson, 1980). Since these postulations were made, divergent opinions on the subject have emerged.

The views expressed in the model may be interpreted to mean that the bird/animal can recognise a state of deficiency. Studies about specific appetites for nutrients in poultry have been relatively few and with mixed results (Hughes, 1979). It would appear that the assumption in the model derives some support from some findings that have been reported in the research literature. For example, Cowan and Michie (1978) reported that broilers performed well and were able to select their nutrients in free choice situations. Evidences for specific appetites in layers have been found for calcium (Wood-Gush and Kare, 1966; Hughes, 1972; Mongin and Sauveur, 1974; Holocomb, Roland and Harms, 1975). In rats and poultry, zinc deficiency was reported to elicit some cyclical changes in food intake (Vohra and Heil, 1969; Williams and Mills, 1970; Hughes and Dewar, 1971). Phosphorus (Holocomb *et al.*, 1974), thiamine, and vitamin A (Ogunmodede, 1981) have also been suggested as affecting appetite and growth. With respect to the major constituents of food, levels of protein (Holocomb *et al.*, 1976) and essential amino acids (Carew and Hill, 1961) have been associated as affecting food consumption. Only methionine and lysine have so far been reported among amino acids, in this connection, by Combs (1962), Hughes and Wood-Gush (1971) and Bartov, Bornstein and Lipstein (1974, 1975). Most workers in the field agree that there is a relationship between energy intake and satiety. Emmans (1978), Wilson and Emmans (1979) and Booth (1979) reached conclusions that birds respond to both a deficiency and avoid excess nutrient intake.

On the other hand, some reports appear to be in opposition to the views in the model. Balnave (1974), McDonald, Edwards and Greenhalgh (1981) suggested that one of the ways of restricting food intake, hence weight gain and maintenance energy requirement of pullets is by feeding them low protein diets or diets deficient in one or more of the essential amino acids. This proposition is supported by the fact that chicks or broilers fed on diets deficient in amino acids were reported to have reduced their food consumption (Fisher, Griminger, Leveille and Shapiro, 1964; Khalil, Thomas and Combs, 1968; Sugahara, Baker and Scott, 1969; Lee, 1969; Velu, Scott and Baker, 1972).

The extent of deficiency of an essential nutrient may be important in determining its impact on the performance of the animal. Lipstein *et al*. (1975) observed that all the authors who reported an increase in food intake in response to a particular nutrient deficiency, were probably dealing with marginal deficiencies. The argument could also be supported by the findings of Thomas and Combs (1967) who reported that it is on a marginal deficiency of lysine that birds tend to overconsume.

Nutrients may also differ in their ability to exert control over food intake. It was found that chick diets that were formulated to be equally limiting in different amino acids were not equally limiting in terms of the ability to promote growth (Huston and Scott, 1968; Sugahara *et al*., 1969; Okumura and Mori, 1979). This may apply to food intake. Also, Booth (1972) proposed the theory that the absorbed nutrients generated satiety according to the speed of their use of energy. Therefore, it may be preferable to express amino acid requirement in terms of their "availability" to the chick as suggested by Freeman (1979), who ranked their order of importance as lysine, methionine, cystine, tryptophan, etc.

The above review has explored some of the controversy associated with influence of nutrient composition in food intake control. It is not yet clear whether the time is ripe to produce predictive equations for food intake based on the theory.

The temperature schedule

The model has been designed to react to the effective temperature of the environment; and operates on a daily basis. From the user's point of view, the effective temperature may be harder to define in some environments, thereby reducing the flexibility of the model. For example, in most tropical countries, diurnal variation in temperature is an important phenomenon in animal production. Siegel (1977) found that growth and the efficiency of food utilisation were decreased by daily temperature fluctuations of 11.1°C above and below the control, but were not significantly affected by 5°C variation. This agrees with the earlier findings in Siegel and Drurry (1970), Griffin and Vardaman (1970) and Harris, Dodgen and Nelson (1974). It is not clearly well understood how the effective temperature can be determined as a variable in the model for such situations.

Fat growth in chicken

The views expressed in the model with regards to fatness in chicken have been stated on page 21. Among others, it was stated that the domestic chicken, unlike the mammalian livestock, e.g. pig and sheep, does not get fatter as it matures if fed on well-balanced diets. This suggests that age does not affect the pattern of fat deposition in chicken. This view came from studies (Wilson and Emmans, unpublished) in which fat deposition was maintained at constant levels through adjustments in diet composition alone.

The degree of fatness in poultry has been proposed to be affected by both non-nutritional and nutritional factors (Bartov, Bornstein and Lipstein, 1974; Lin, Friars and Moran, 1980; Lin, 1981). These factors include breed, age, sex, temperature and nutrition (Kubena, Chen and Reece, 1974; Washburn, Guil and Edwards, 1975; Edwards and Denman, 1975; Van Middlekoop, Kuit and Zegward, 1977).

Age and sex appear to be the most important non-nutritional factors. The percentage of fat in the carcass of chicken has been found to increase with age (Combs, 1968; Edwards, 1971; Thomas and Twining, 1971; Kubena *et al.*, 1972). It has been further suggested by Edwards *et al*. (1973) that fast growing strains of poultry become considerably fatter when older. Also, the abdominal fat as percentage of carcass weight was reported by Tzeng and Becker (1981) to increase with age up to about 70 days in males, and at that age comprises approximately 4% of carcass weight.

Most workers in the field agree that nutrition may be playing the most important role in fat growth. Fraps (1943) was able to produce chickens with widely varying amounts of body fat by adjusting dietary constituents. It has also been proposed that changes in the total body composition of chicks can be produced by adjusting food composition, noteably the protein, fat or energy levels (Donaldson, Combs and Romoser, 1956; Spring and Wilkinson, 1957; Scott, Hill, Parssons, Bruckner and Dougherty, 1959; Combs, 1964; Thomas, 1966; Shank, Thomas and Combs, 1968; Yoshida and Morimoto, 1970; Hewit and Lewis, 1972; Velu, Baker and Scott, 1972a,b). Furthermore, Yoshida, Hoshii and Morimoto (1966) and Yoshida and Morimoto (1970) postulated that the effect of dietary protein concentration on carcass fat is direct and reversible. However, in all these and other data analysed where detailed results were presented, the per cent body fat increased with age up to an optimum and then declined.

[illegible]

Probably the only way to nullify the influence of age is by constant adjustment in diet composition. This may not be feasible in commercial broiler production. From most of the information examined, it would appear that the chicken does not differ with mammalian livestock in the pattern of fat growth.

4. TESTING THE EDINBURGH POULTRY GROWTH MODEL

In previous chapters, the principal points of response simulation models, the Edinburgh Poultry Growth Model (EPGM), and some critical reviews of some theoretical aspects of the latter have been presented. It was originally observed that workable computerised models can be useful as tools for decision making in agricultural management. The development of models that can simulate biological responses are still novel and could be affected by contraints, including gaps in the current knowledge of appropriate data for modelling. A model may contain some incorrect assumptions; the equations and numbers that form the framework can also be inappropriate. For these reasons, it is necessary to test any model that has been developed in order to assess its capacity and efficiency in playing the prospective roles.

The objectives of this test were three-fold:

1. To evaluate the simulation ability of the Edinburgh Poultry Growth Model (quantitative evaluation).
2. To evaluate the technical capacity of the model as a response simulation program.
3. To assess the biological responses (qualitative) that the model predicts.

In testing the simulation ability, the methods used in Whittemore and Fawcett (1974) are adopted. "Classical" experiments in research literature were selected and all details of the experimental input specifications were used to produce results by using the model. The simulation results are then compared with the observed results in the experiment. Graphical analysis of the predicted and observed responses should demonstrate whether the model can reproduce (simulate) experiments; consequently showing its value as an alternative to experimentation. Assessment of the biological responses predicted by the model involved performing several experiments that are similar to the ones found in research literature. The predicted responses are compared with findings in the literature. Testing for the general behaviour of the model dwelt mainly on the flexibility, stability and sensitivity of the EPGM to input variables, to conform with procedures mentioned in Beever (1981) and Black, Beever, Faichney, Howarth and Graham (1981).

Experiments I and II relate to the simulation (quantitative) potentials, while Experiments III and IV were hypothetical experiments to elucidate the model's prediction of responses from the variables used.

MATERIALS AND METHODS

A. Simulation experiments:

Materials comprise the computer model and the input specifications from experiments with real birds. The model operates with numbers and unless the right ones are supplied, no comparable results may be expected. Many experiments that have been published in research literature were examined with a view of selecting sufficiently detailed ones for the investigation. But after examining recent publications (1966-1982) of the major journals in the field of Poultry Science, it was found that most experiments were inadequately described. In most cases, the genotype and environmental factors were ill-defined. Nevertheless, two experiments were found and used in this work, where the input and results were described in reasonable details.

EXPERIMENT I

Experiments by the Department of Animal Husbandry of the College of Agriculture, Swedish University of Agricultural Science, edited by Hakansson, Eriksson and Svensson (1978) were used for the simulation experiment. In the experiments, the influence of feed energy level on feed consumption, growth and development of different organs of chicks were investigated. The experimental variables are as follows:

In genotype and chick systems: 1978 strain of Ross chicks were used. They weighed between 45 and 53 g at day old. In the simulation experiment, 46 g was used. Other required input variables for the

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Footnote: For experimental variables usable in EPGM and the suggested values in the genotype system, refer to page 11. The rate of maturity is derived from the Gompertz equation and it is expressed as the value/day.

simulation were not provided, but were chosen from the suggested values for experimenting with EPGM (see footnote). Thus, for the 1978 Ross strain, the following values were assigned: the potential mature weight (A) = 6.5 kg; the rate of maturity (B) = 0.025-0.028/day; the minimun lipid : protein ratio (MINLIP) = 0.20.

Management system: the birds were kept in individual cages thus, the stocking rate was calculated as being 5 birds/m^2. The experiment with the real birds was conducted under optimum husbandry levels judging from the descriptions and the consistency of the results obtained. A husbandry level score of 10 was therefore used.

In the temperature schedule: the chicks were started at 37°C and decreased by 0.5°C/day until 20°C - that is, a smooth change of temperature from 37° - 20°C.

The feeding programme: three feeds which differ only in their metabolisable energy content were used. They were High Energy (HE), Medium Energy (ME) and Low Energy (LE) diets. The feeds were in the form of mash and fed *ad libitum* throughout the duration of the experiment. For the simulation experiment, only the HE and LE diets were used. The feed composition is given in Table 3.

The slaughter system: liveweight was the criteria used for slaughter. They were killed at intervals of predetermined weights up to 4 kg.

TABLE 3: Composition of experimental diets used in Hakansson *et al*. (1978). The nutrients are expressed on fresh matter basis for the simulation experiment (Experiment I).

	High Energy diet (HE)	Low Energy diet (LE)
ME (MJ/kg)	13	10
Crude protein (%)	22.43	20.30
CP digestibility (%)	86.40	83.40
Amino acids (%):		
lysine	1.287	1.13
methionine	0.544	0.46
methionine + cystine	0.892	0.843
others	assumed not limiting	assumed not limiting
Crude fat (%)	6.04	5.044
Crude fat digestibility (%)	78.8	69.5
Crude fibre (%)	3.78	9.34
Ash (%)	5.87	5.87
Dry matter (%)	90.1	90.7

EXPERIMENT II

The influence of environmental temperature and diet composition on the performance of male broilers was investigated at the Centre for Tropical Veterinary Medicine, University of Edinburgh, by Mohamad (1981, M.Sc. Thesis). Eighteen 4-week old broilers of D.B. Marshall's strain were used. The experiment was designed as a factorial of three environmental temperatures x two diets x three blocks. Details as described in the thesis and used in the simulation experiment are as follows.

Genotype and chick system: the male broilers had been reared previously under commercial conditions until 4 weeks old when they weighed between 1.43 and 1.575 kg. A mode value of 1.5 kg was used for the simulation. The initial lipid content of the body, obtained by the analysis of five control birds was 6%. Other genotype numbers were chosen from the suggested values by the builder of the model for the users as follows: potential mature weight (A) = 6.5 kg; the rate of maturity (B) for the 1981 strain = 0.028/day, and the MINLIP = 0.20 (see footnote, page 32).

The management system: the birds were reared in individual cages, i.e. equivalent to 5 birds/m^2. The experimenter (Mohamad), however, noted that the cages were becoming too small for the birds towards the end of the experimental period. A husbandry level score of 8/10 was used for the simulation experiment because of the above reason and the fact that the birds were moved from their initial rearing position to the experimental unit which must have caused some lowering of their performance. Otherwise, other management procedures were accurate.

The temperature schedule: three temperatures were used - 16°, 24° and 32°C, against each feed and the temperatures were maintained constant throughout the duration of the experiments. (The simulation experiment used an additional temperature of 20°C for the LE/HP diet.)

The feeding programme: two diets were used. One consisted of low energy/high protein (LE/HP), and the other of high energy/low protein (HE/LP) proportions. They were in mash form and the birds were fed *ad libitum*. The diet composition is given in Table 4.

The slaugher schedule: the age of the birds was the criterion used. They were slaughtered when they were 45 days old and the carcass analysed. The experiment lasted for 17 days during which the feed intake and liveweights of the birds were periodically recorded.

TABLE 4: Composition of experimental diets in Mohamad (1981) for the simulation experiment (Experiment II).

	Low Energy/ High Protein (LE/HP) diet	High Energy/ Low Protein (HE/LP) diet
ME (MJ/kg)	9.3	11.6
Crude protein (%)	23.4	14.5
Crude protein digestibility (%)	86.0	86.0
Amino acids (%):		
lysine	1.47	0.75
methionine	0.36	0.24
methionine + cystine	0.75	0.52
others	assumed adequate	assumed adequate
Crude fat (%)	1.25	1.25
Crude fat digestibility (%)	85.0	85.0
Crude fibre (%)	7.5	2.5
Ash (%)	8.0	8.0
Dry matter (%)	84.0	88.0

B. Other response evaluation experiments

Some imaginary experiments were performed with the model to compare the predicted responses with the results of similar experiments that have been published in the research literature. Two of such experiments are briefly described below.

EXPERIMENT III

The responses predicted by the model from the effects of temperature and levels of dietary protein were assessed.

The main variables are in the temperature schedule and the feeding programme. The numbers for the genotype, management and slaughter schedules are used as described in Experiments I and II, with the following annotations.

In the genotype system: the initial age = 14 days; initial weight = 350 g; potential mature weight (A) = 6.5 kg; rate of maturity (B) = 0.028/day; the initial lipid content of the body = 6% and the lipid : protein ratio (MINLIP) = 0.20.

In the management system: the stocking rate = 5 birds/m^2, and the husbandry level = 10.

Temperature schedule: two temperature ranges were used. A smooth change in the temperature was allowed from the upper to the lower range. They were (a) 32/27°C, and (b) 28/23°C.

Feeding programme: isocaloric diets similar in all respects except protein was formulated. The experimental diets consisted of six levels of protein, i.e. 5%, 10%, 15%, 20%, 25% and 30%.

The experimental period was 14 days (i.e. from the age of 14 to 28 days). The experiment was therefore a factorial design of 2 temperatures x 6 diets.

EXPERIMENT IV

The effects of diluting diets with some levels of fibre, fat and ash at different temperatures were investigated using the growth model.

The descriptions of the variables are as in Experiments I, II and III. An imaginary male broiler strain was used with the following annotated values.

In the genotype system: initial age = 21 days; initial liveweight = 560 g; potential mature weight (A) = 6.5 kg; rate of maturity (B) = 0.030/day; MINLIP : protein ratio = 0.20; initial lipid = 6%.

Management schedule: stocking rate consisted of 5 birds/m^2 and husbandry level was optimum, i.e. 10.

Temperature schedule: three temperature ranges were used - (a) 32.5/30°C, i.e. high (HT); (b) 28.5/26°C, i.e. medium (MT); and (c) 24.5/22°C, i.e. low (LT) temperatures. A smooth change of temperature was allowed from the higher to the lower limit within each range.

Feeding programme: ten diets were used, all mash, and fed *ad libitum*. The basal diet was formulated and portions of it were then diluted. The diluents consisted of fibre (sawdust), fat (corn oil) and ash (sand). They were used at the inclusion levels of 4%, 8% and 12%.

The experiment was designed to last for a 14-day duration. It was a factorial design of 3 temperatures x 10 feeds. Some sections of the experiment were found to resemble others found in the research literature, including Mraz *et al*. (1956, 1957) and Deaton *et al*. (1981).

RESULTS

A large volume of data can be obtained from the Edinburgh Poultry Growth Model (EPGM) depending on the user's objectives. The available reports (see page 11) are displayed through the typewriter keyboard or a visual display unit of the computer. Only a few illustrative details of economic importance are presented with the attached tables and graphs. Throughout this report, the word "predicted" implies the responses predicted by the EPGM, while "observed" refers to the observed responses or data from experiments with real birds. Also, the model is referred to as if it is an entity.

A. THE SIMULATION EFFICIENCY

The ability of the model to simulate responses was determined by using two experiments based on similar studies found in the research literature.

Experiment I was by Hakansson *et al*. (1978) in which high energy (HE) and low energy (LE) diets were the main variables. Experiment II was by Mohamad (1981) where feed composition and temperature were the variables. In this (Experiment II), a low energy/high protein (LE/HP) and high energy/low protein (HE/LP) diets were used; while the experimental temperatures were 16°, 24° and 32°C. Experimental details have been presented on page 32.

1. Production of results: For the HE diet (Experiment I), the model produced results and simulated the observed results satisfactorily (Figures 1-3A). But it was a complete failure with respect to the LE diet where no data was produced because the model bird died in 25 days whereas the real bird lived for the duration of the experiment and functioned normally.

In Experiment II, the model produced results with the HE/LP diet. With the LE/HP diet, results could not be produced at the lowest temperature, i.e. 16°C, until the temperature was adjusted to 20°C. When comparisons were made between the simulated and observed results, it was seen that the results were dissimilar quantitatively, but the biological responses to the variables were alike in most respects (Figures 5 and 6). The inability of the model to produce results in the situations mentioned above was found to be related to its high sensitivity in some aspects of temperature (see 'C').

2. The growth curves produced by the model from the HE diet (Experiment I) were similar to the ones by the real birds (Figure 1). The predetermined slaughter weight of 4 kg was achieved at about the same age, 85-88 days, in both the predicted and the observed experiments. They also had a comparable growth rate (LWG). With the model, an optimum liveweight gain of 68 g/day was predicted to be achieved at the age of 64 days. The real birds achieved their optimum of 66 g/day in 69 days.

3. The curves of feed intake (Figure 2) illustrate a good alignment between the predicted and observed results. This shows that both the amount and rate of food consumption were very close for the model and the real bird. The total consumption of feed at the time of slaughter was 9586 g by the model bird, and 9566 g by the real bird. The curves also illustrate that the rate of feed intake (daily intake) tends towards a peak value as the animal/bird matures.

4. When Figure 1 was superimposed over Figure 2, it was seen that there is a correlation between live weight and cumulative feed intake. This appears to illustrate the theory on homeostasis of growth

as reported in Parks (1970), whereby it is possible to predict the live weight from the amount of food consumed with some reasonable accuracy.

5. On the analysis of results for composition of the body, it was found that the model simulated all tissues (in chemical terms) accurately except lipid as illustrated in Figure 3. The growth curves of protein, ash and water contents of the body in both the predicted and observed were similar. However, the model was less optimistic at simulating the lipid aspects.

6. Analysis of the results show some dichotomy in the data from observed and simulated experiments on fat deposition. This is illustrated by Figure 4 where, in the observed, the lipid : protein ratio and percentage abdominal fat had an initial increase, then peaked before declining. The model on the other hand, predicted that these parameters would fall, and tend towards a lipid : protein ratio of 0.20.

A further manipulation of the genotype system of the model showed that the aspects dealing with lipid is an independent variable in the model and it was possible to make the lipid growth close to the observed response. However, this dissertation finds the practice of choosing numbers in the genotype system by default before operating the model unsatisfactory.

B. TECHNICAL ASPECTS OF THE MODEL

Tests were performed to assess the general "behaviour" of the model as a computer response simulation program. It was found to be flexible, stable and sensitive in the way it dealt with input variables. However, it was found too sensitive in some aspects of temperature.

C. THE EFFECT OF TEMPERATURE ON THE MODEL

The model was found to be too sensitive in the way it dealt with heat loss mechanism.

1. With temperature as an input variable, the model bird was found to operate satisfactorily only within a too narrow range of temperatures than would be the case with the real bird.

2. Through the sensitivity tests performed to evaluate responses from this variable, it was found to be more highly susceptible to cold and heat stress than the real bird.

3. When bulky feeds or diets of low energy content were used as input variables, it was found to be unable to regulate its heat loss. The "mortality" cited in the two experiments above (I and II) with LE and LE/HP could be due to this weakness. In the former (LE) where the model bird died in 25 days, it was reported by the computer that as a result of the low energy content of the feed, the model bird tried to eat more food to maintain the energy balance as the brooding temperature was lowered from 37°C to 20°C. Consequently, the bird died. With the LE/HP diet at 16°C, a similar effect was reported. It was found that when the temperatures were increased towards an ideal for the model, results similar to the ones from the real birds were produced.

4. Despite the above findings, it was noticed that if suitable temperature schedules are used for a given class of bird and on a given feed, the simulated biological responses are close to resembling those found with real birds. The problem is in how to determine this ideal temperature; hence the exaggerated effects on some of the biological responses.

D. BIOLOGICAL RESPONSES

Food intake

From the tests performed, it was found that the model predicts that food intake is controlled by temperature, feed composition, and bulk of the food. It also potrayed that there are some interactions between these variables. This aspect makes it often difficult to understand what factors the model was responding to.

1. The effect of temperature on food intake is illustrated in Figures 5, 7A and 8. It predicts that intake is inversely related to ambient temperature.

2. The model predicts that the level of dietary protein affects food intake as illustrated in Figure 7. But that the magnitude of the response is also dependent on the ambient temperature.

3. The food intake response of the model to the energy content of the food has been reported in C.3.

4. The interaction between dietary energy/protein ratio and temperature on food intake shows similar responses between the predicted an observed results with respect to temperature. But they differ in their responses to the dietary energy : protein ratio (Figure 5). The model predicted an increase in intake as a response to low protein : energy ratio while the real bird responded to low energy : protein ratio of the diet by increasing food intake.

5. Tests were performed to observe the model's predictions of food intake responses as a result of varying the amino acid levels in the diet. Lysine was used and it showed an increasing intake as the

lysine level was lowered. However, this test was not conducted to the extent of evaluating the response that would have been produced if there were some dietary amino acid imbalance.

6. Increasing the crude fat content of the diet produced varied results with the model (Figure 8). The responses depend also on the ambient temperature.

7. The effect of bulk and density of feeds on food intake as predicted by the model was determined by diluting a "basal" diet with 4%, 8% and 10% levels of "sawdust" (crude fibre) and "sand" (ash), as detailed in Experiment IV. The results (Figure 8) illustrate that bulk and density of the feed affect food intake. It predicts that as the bulk of the mixture increases, feed intake increases to enable the bird obtain enough of the nutritionally important components of the mixture (especially eating for 'energy'). It also predicts that at low ambient temperature, the fibre content of the diet could limit feed intake - as reported in C.3., because the alimentary canal of the bird cannot cope with the excessive consumption for energy at the low ambient temperature.

Factors affecting growth and development

The model produced responses to predict how variables affect growth and body composition of poultry.

1. The effect of time (age) has been illustrated with the simulation experiments (Figures 1-3). The effect of sex has not been evaluated.

2. Nutritional effects are illustrated by Tables 6, 7 and 8. It predicts that there is a high degree of interaction between temperature and nutrient composition on growth and body composition.

With Mohamad's experiment, there was considerable similarity between the predicted and observed results (Table 6). On LE/HP diet, they showed that the temperature for optimum liveweight gain (LWG), protein and lipid gains was 24°C. They were also similar by reporting that an HE/LP diet would lead to higher gains of lipid than with the LE/HP diets. Also, that at ideal temperatures, an LE/HP diet should produce leaner carcass. But they differed in the temperature for optimum LWG using HE/LP diet.

The model's predictions on the effects of dietary protein levels are shown in Table 7 and Figure 7. It predicts that the lipid gain can be reversed by increasing the dietary protein levels; but the response also depends on the ambient temperature.

The effects of increasing the levels of dietary fat on body composition shows a considerable interaction with temperature with respect to LWG and protein retention; but the lipid content of the body is increased (Figure 9).

The model also predicts that although the level of crude fibre or ash may affect food intake, there is no recognisable effect of these components on LWG, protein and lipid retention (Table 8, Figure 9).

3. On the effect of temperature *per se*, the model predicts that LWG and protein retention are inversely related to temperature (Figure 7 and Table 8). It produced varied results from this variable on fat deposition.

Fat deposition

The effects of input variables on fat deposition showed inconsistent responses with the model.

1. In the simulation experiment, it was noted that the model failed to produce comparable results with the observed experiment - see A.6.

2. In respect of Mohamad's experiment using the LE/HP diet, similar responses were obtained from both the predicted and observed experiment (Table 6).

3. Inconsistent results were produced by the model on the effect of temperature on fat deposition. In Figure 7, it predicts that the bird would be fatter at a higher temperature, while the opposite is demonstrated in Figure 9. On further analysis of results, the responses due to increasing the dietary fat levels were found to be similar to the ones obtained by Deaton *et al.* (1981) - Figure 10.

With the inconsistent results, examples of which have been mentioned above, it is difficult to assess precisely the effects of variables on fat deposition as predicted by the model.

TABLE 5: A comparison of predicted and observed data on the effects of a high energy (HE) diet on feed intake, growth and composition of broilers (Experiment I).

Predicted values (by Edinburgh Growth Model)

Age (days)	LWT (g)	LWG (g/d)	Feed intake (g/d)	Cum. feed intake (g)	Total protein (g)	Total lipid (g)	Abdominal fat (%)
1	46						
8	113	12	18	94	18	10	1.2
22	412	30	52	581	70	36	1.2
36	981	51	100	1665	181	71	0.8
50	1807	64	140	3386	349	125	0.6
64	2681	68	182	5552	551	107	0
78	3610	64	195	8210	757	148	0
85	4041	60	198	9586	854	168	0

Observed data (from Hakansson et al., 1978)

Age (days)	LWT (g)	LWG (g/d)	Feed intake (g/d)	Cum. feed intake (g)	Total protein (g)	Fat (g)	Abdominal fat (g)
1	46						
8	152	15	20	139	22		
21	512	35	48	681	88	50	1.0
32	966	47	87	1542	180	98	1.2
38	1379	54	119	2322	267	168	2.0
52	2026	52	142	3967	398	256	2.0
69	3076	66	179	6623	619	361	2.0
86	3930	60	194	9566	813	400	1.4

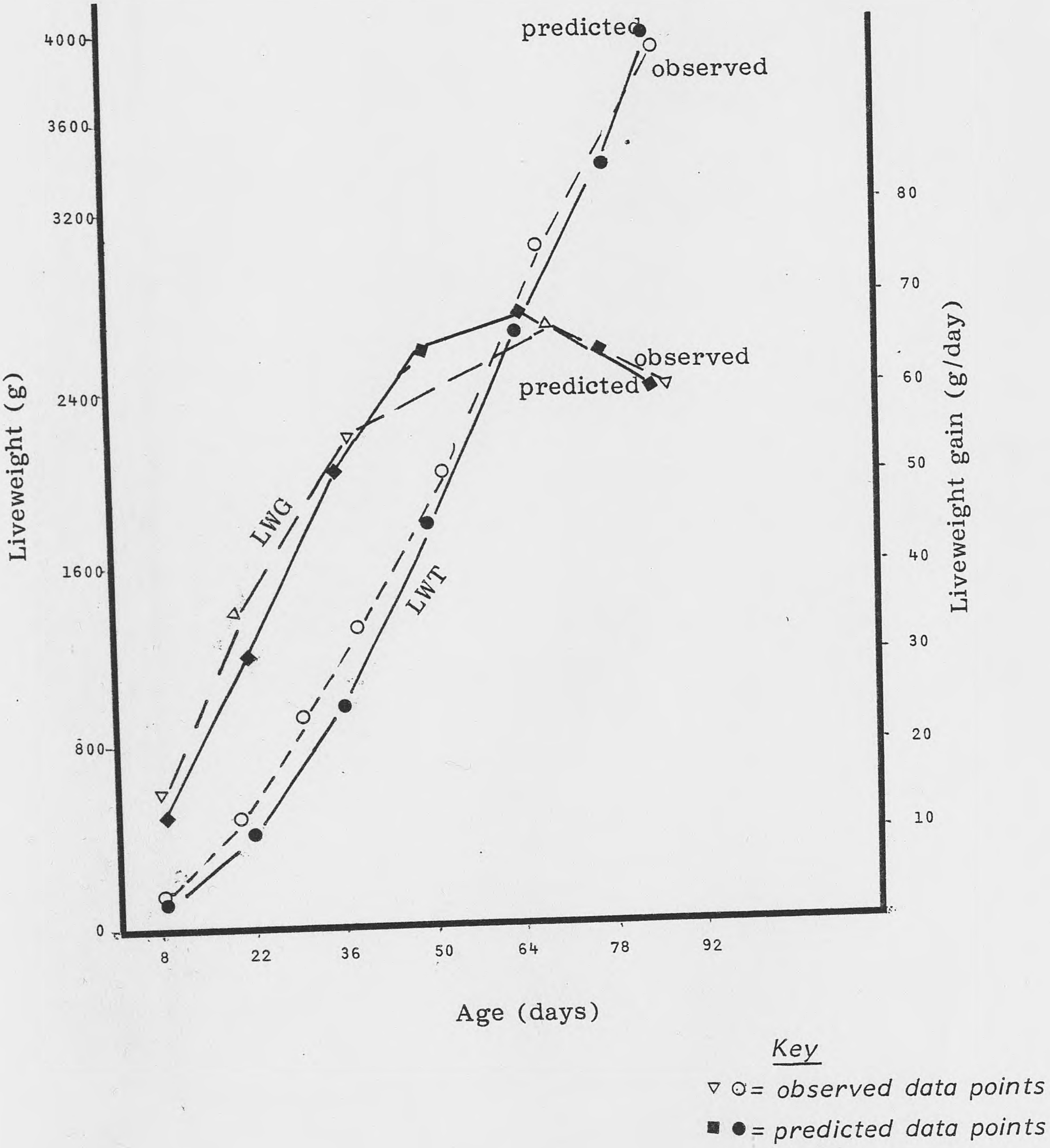

FIGURE 1: A comparison of observed and predicted growth data (liveweight (LWT) and liveweight gain (LWG)) of broilers reared on a high energy diet, to test the simulation ability of the Edinburgh Poultry Growth Model (predicted). The observed data relate to values of Hakansson *et al*. (1978).

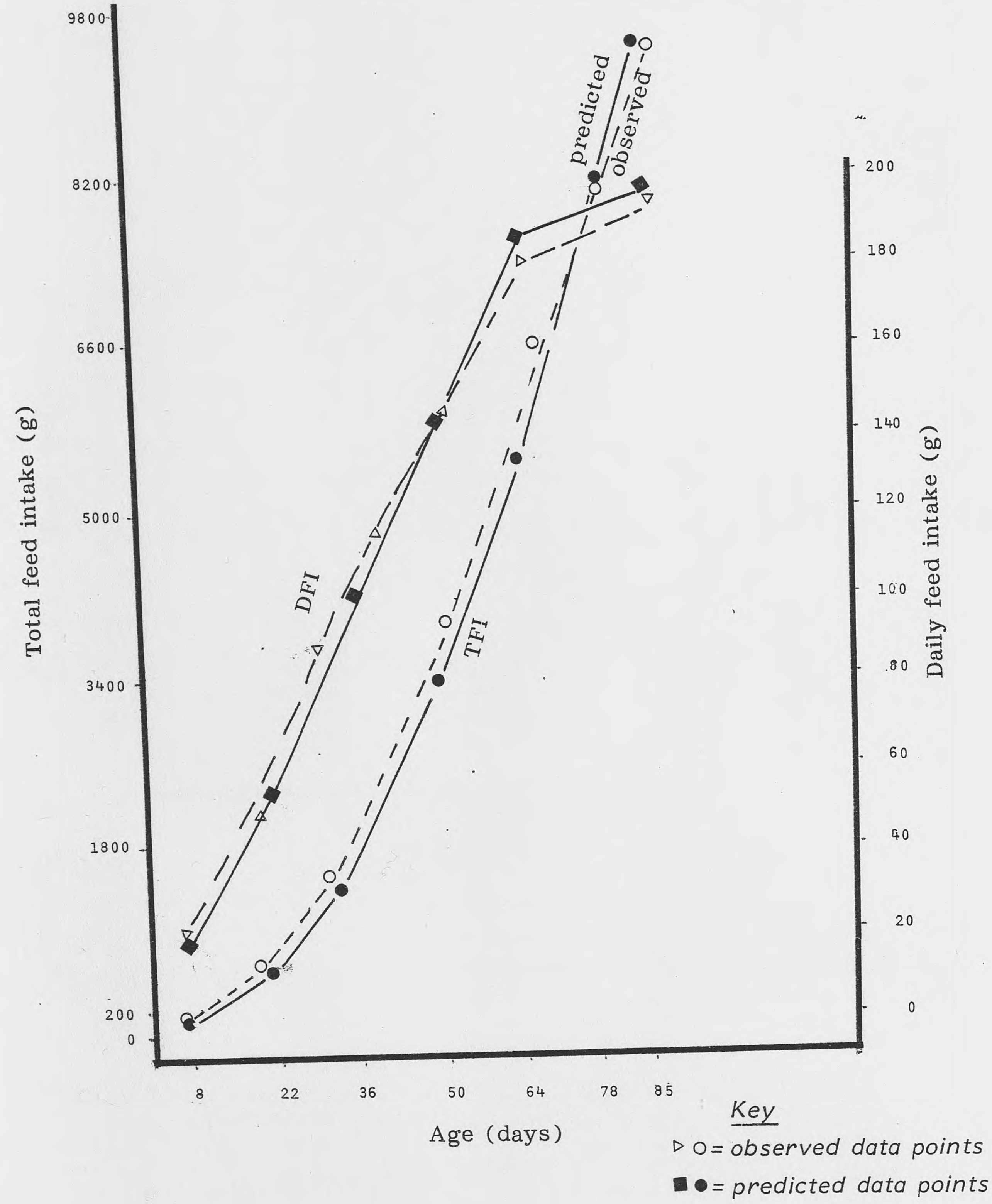

FIGURE 2: Comparison of observed and predicted feed intake (total intake (TFI) and daily intake (DFI)) of broilers reared on a high energy diet, to test the simulation ability of the Edinburgh Poultry Growth Model (predicted). The observed data relate to values of Hakansson *et al*. (1978).

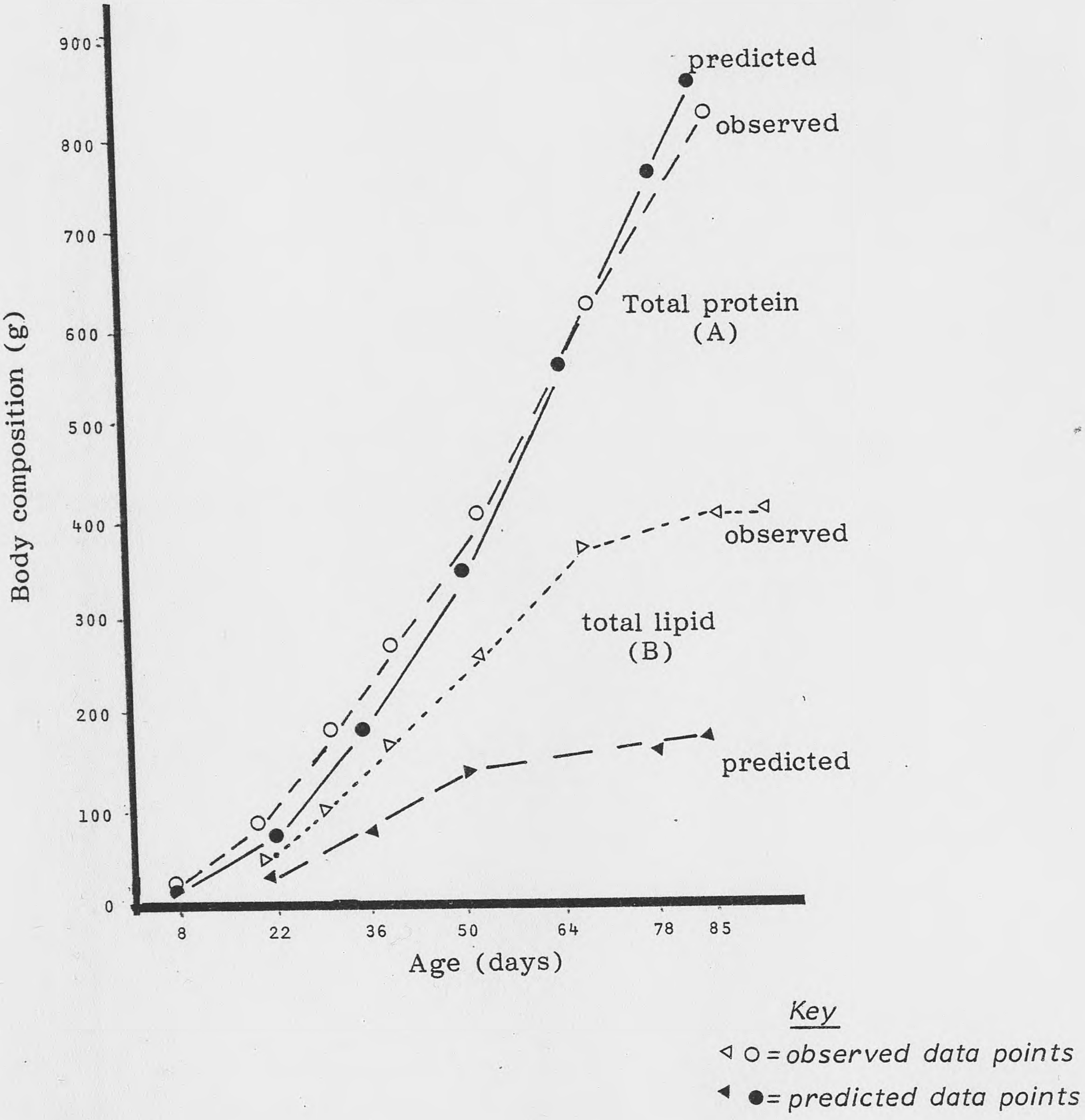

FIGURE 3: A comparison of observed and predicted values of the chemical composition of the body, to test the simulation ability of Edinburgh Poultry Growth Model. The observed data relate to values of Hakansson *et al.* (1978). The broilers were fed on a high energy diet.

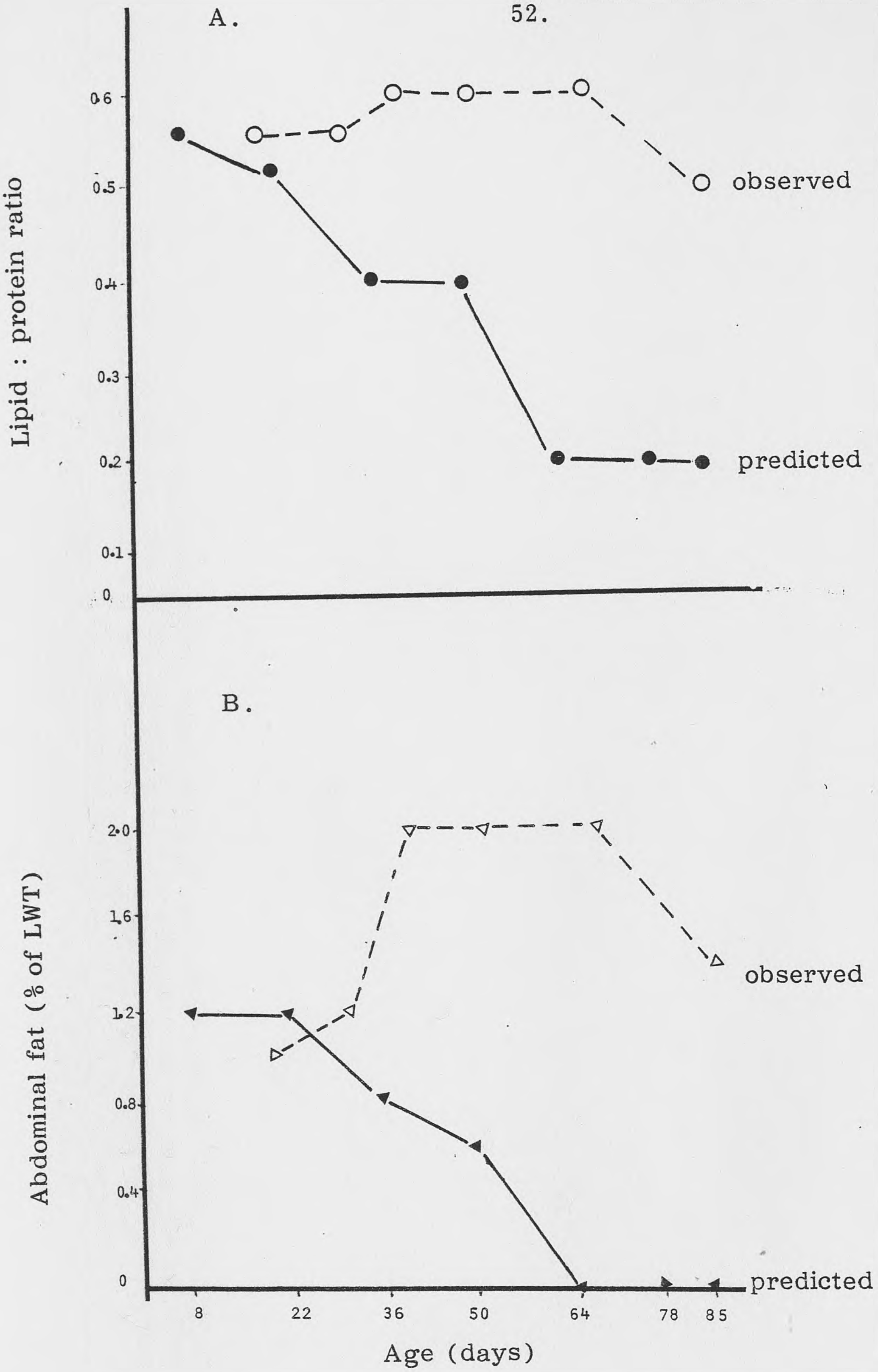

FIGURE 4: A comparison of observed and predicted relative growth of fat in broilers reared on high energy diet, to test the simulation ability of Edinburgh Poultry Growth Model. The observed data points relate to values of Hakansson *et al.* (1978).

TABLE 6: Comparison of predicted and observed data produced, on the influence of temperature and diet composition on performance of male broilers, using Low energy/high protein (LE/HP) and high energy/low protein (HE/LP) diets (Experiment II).

	PREDICTED					OBSERVED				
	FI	LWG	PRG	LIPG	% carcass fat	FI	LWG	PRG	LIPG	% carcass fat
A. *On LE/HP:*										
32°C	1137	99	27	-24	4.5	1642	273	43	2	13
24°C	3009	926	206	10	4.4	2362	633	107	14	12
16/20°C	3074	267	63	-17	4.5	2478	315	80	-2	11
B. *On HE/LP:*										
32°C	933	143	37	-22	4.5	2047	407	56	71	19
24°C	3367	1125	183	304	13	2245	457	79	55	17
16°C	3740	1014	205	99	7	2425	612	68	34	15

<u>Key</u>:

FI = Total feed intake (g)
LWG = Liveweight gain (g/day)
PRG = Protein gain
LIPG = Lipid gain

Observed = results from Mohamad (1981)
Predicted = results obtained from Edinburgh Poultry Growth Model

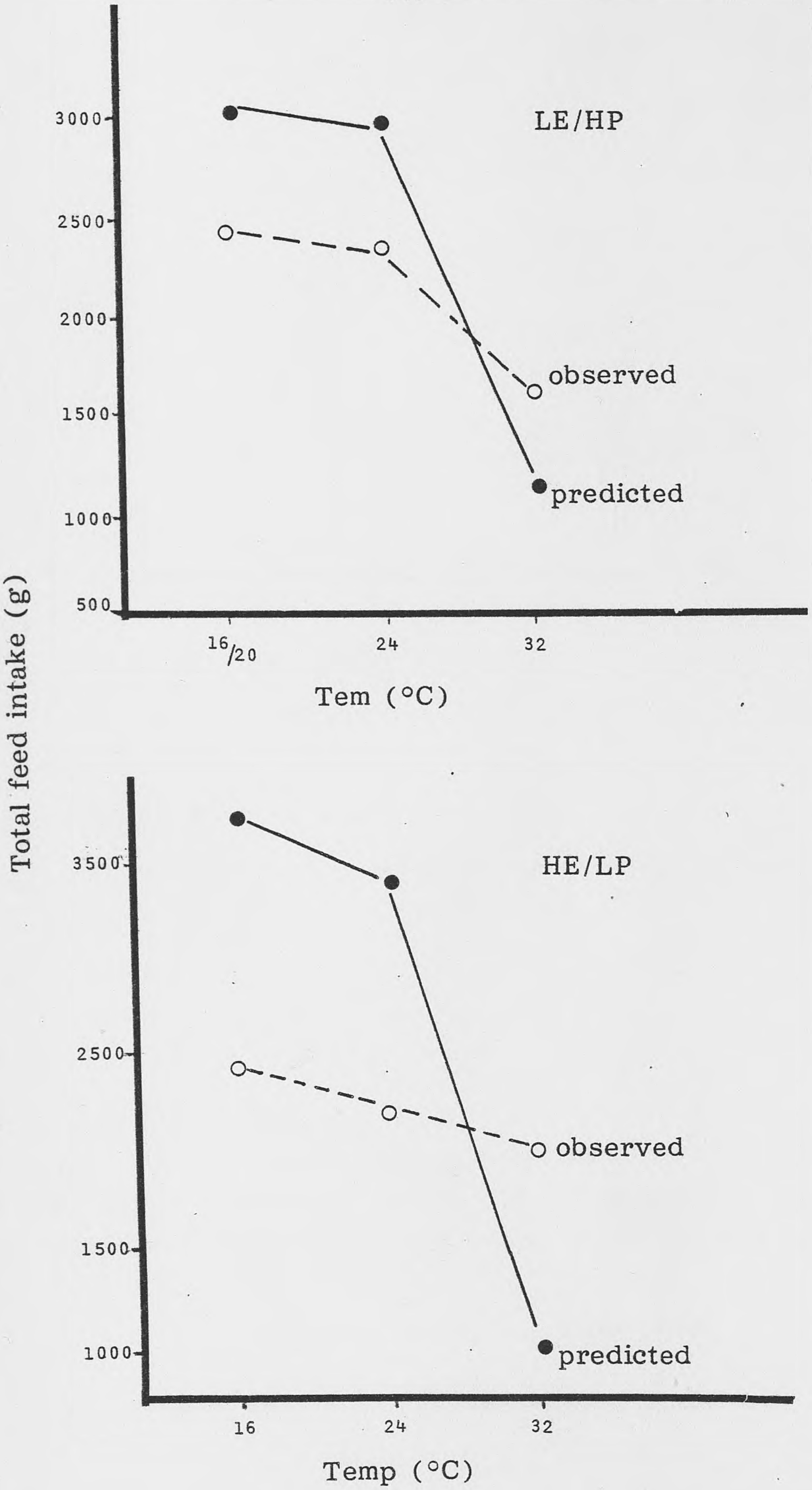

FIGURE 5: Effect of temperature and diet composition on food intake in broilers, to test the simulation ability of the Edinburgh Poultry Growth Model. The observed data relate to Mohamad (1981) using low energy/high protein (LE/HP) and HE/LP diets.

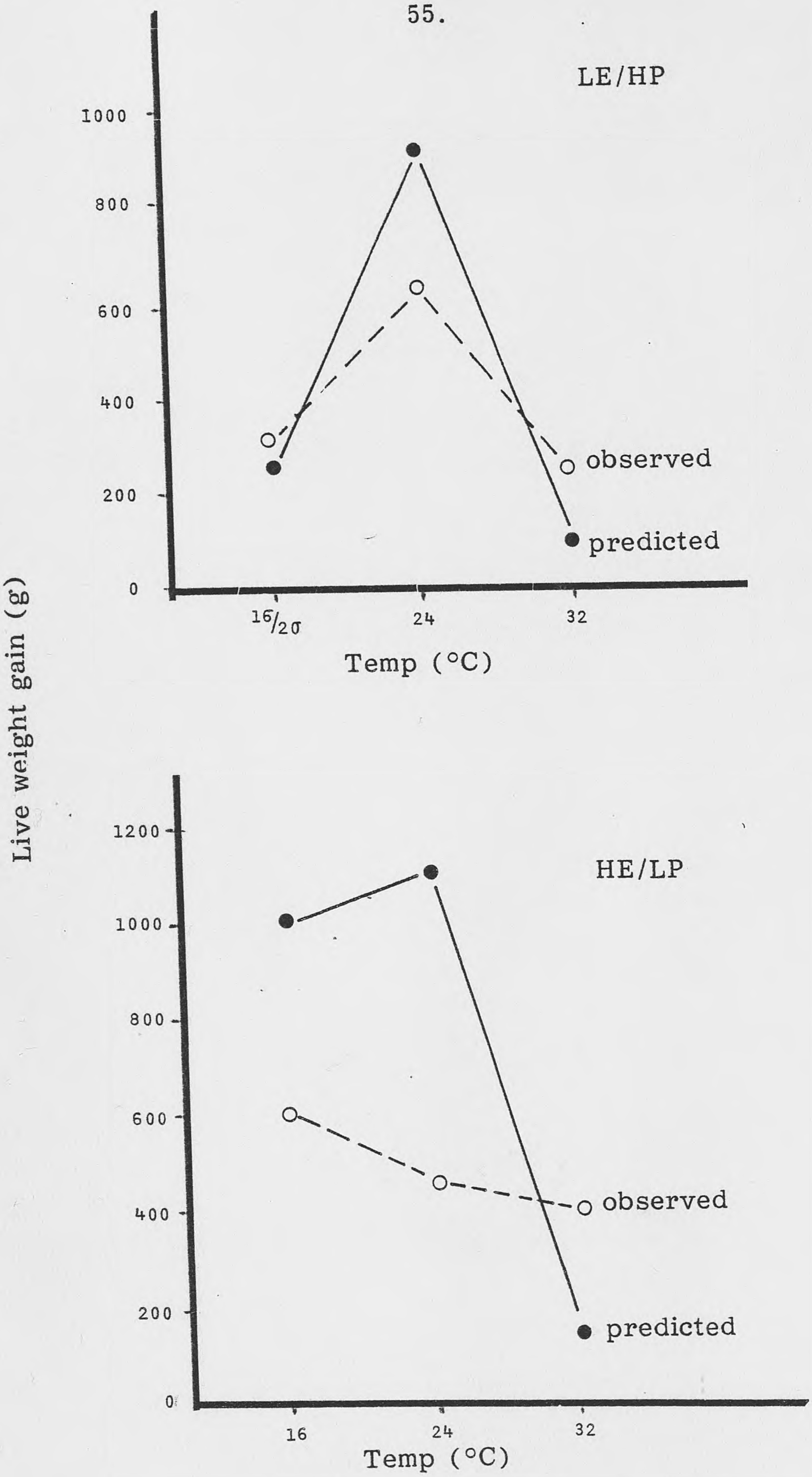

FIGURE 6: Comparison of predicted and observed data on the effects of temperature and diet composition on liveweight gain, to test the simulation ability of the Edinburgh Poultry Growth Model. The observed data relate to values of Mohamad (1981) using low energy/high protein (LE/HP) and HE/LP diets.

TABLE 7: Predicted effects of different temperatures and level of dietary protein on broiler performance by the Edinburgh Poultry Growth Model (Duration: 14-28-day old broilers) (Experiment III).

Temperature	Dietary protein (%)	Feed intake (g)	Protein gain (g)	Lipid gain (g)
32/27°C	30	776	96	10
	25	872	100	37
	20	970	89	77
	15	1078	73	123
	10	1091	48	147
	5	1023	20	150
28/23°C	30	1094	119	15
	25	1072	119	14
	20	1278	119	73
	15	1265	87	99
	10	1141	50	94
	5	1024	21	89

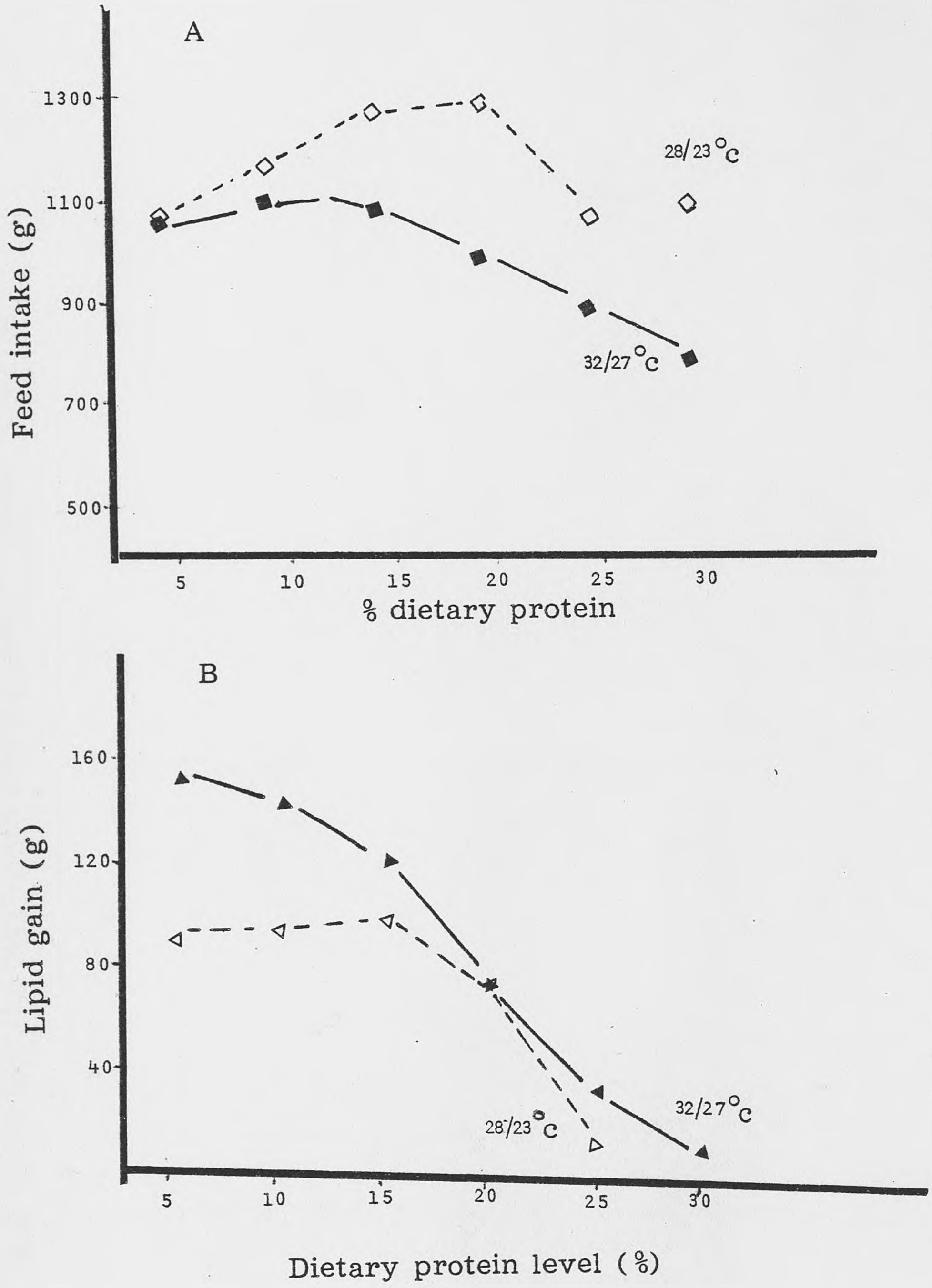

FIGURE 7: Predicted effects (on feed intake A and lipid gain B) of levels of dietary protein and temperature, by the Edinburgh Poultry Growth Model (age of the broilers = 14-28 days).

TABLE 8: Response predictions for feed intake (FI), weight gain (LWG), protein (PR) and lipid retention (LR) as affected by temperature and diet dilution with 4%, 8% and 12% levels of sawdust (fibre), corn oil (fat) and sand (ash), by the Edinburgh Poultry Growth Model (Experiment IV).

Name of diluent		Level (%)	24.5/22°C (LT)				28.5/26°C (MT)				32.5/30°C (HT)			
			FI	PR	LR	LWG	FI	PR	LR	LWG	FI	PR	LR	LWG
Basal		0	1448	163	20	785	1102	136	16	654	647	71	2	338
Fibre	(T2)	4	1508	163	20	785	1148	136	16	654	674	71	2	338
	(T3)	8	1356	94	6	451	1198	136	16	654	704	71	2	338
	(T4)	12	*Dead (Day 4)*				1233	134	31	661	736	71	2	338
Fat	(T5)	4	1366	163	43	809	1197	142	68	736	600	67	3	321
	(T6)	8	1426	163	70	837	1212	137	101	750	659	72	31	373
	(T7)	12	1491	163	124	892	1228	133	135	764	669	69	50	381
Ash	(T8)	4	1508	163	20	785	1148	136	16	654	674	71	2	338
	(T9)	8	1574	163	20	785	1198	136	16	654	704	71	2	338
	(T10)	12	1645	163	20	785	1252	136	16	654	736	71	2	338

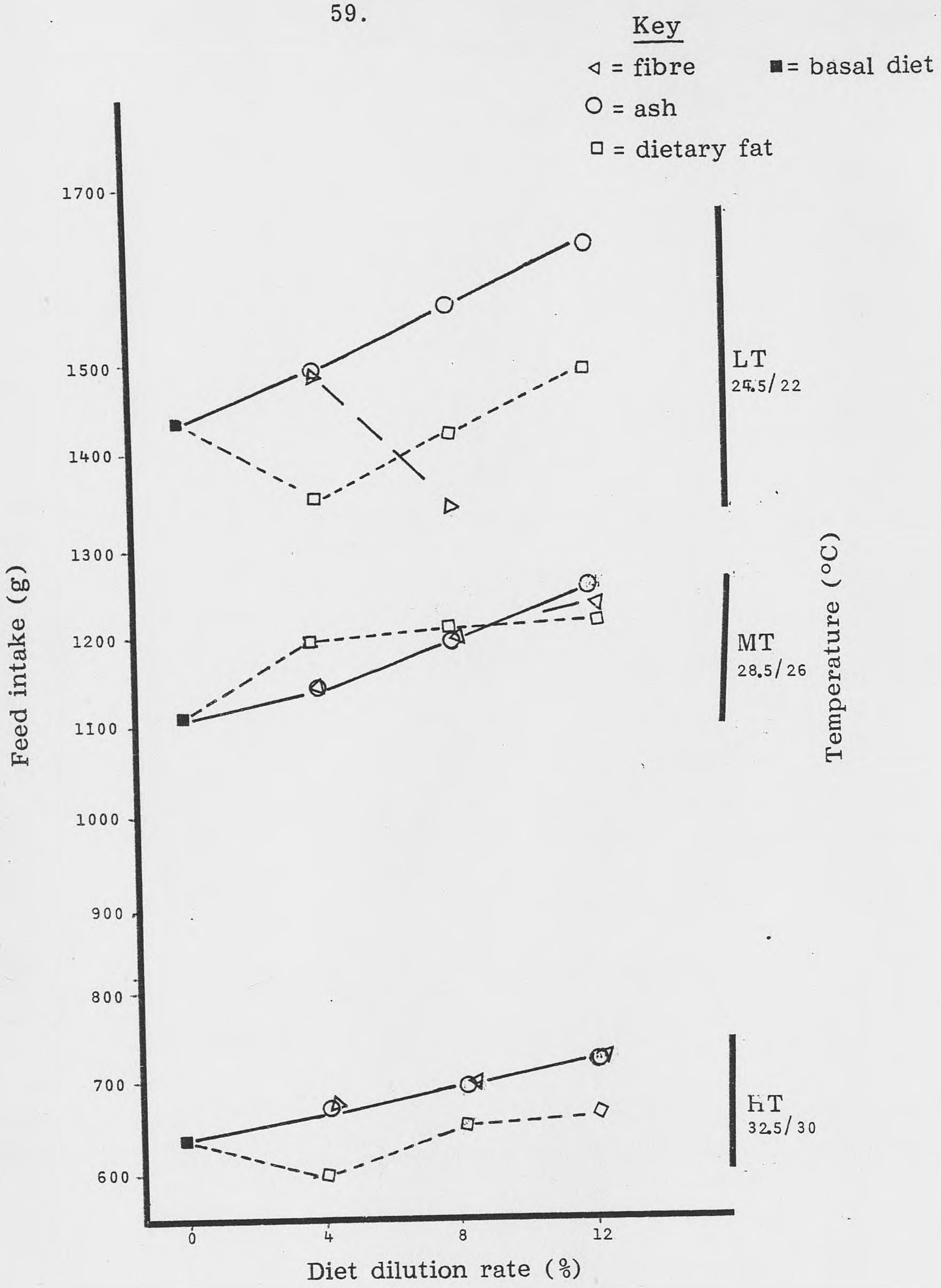

FIGURE 8: Predicted effects (on feed intake) of diluting diets with different levels of fibre, ash and dietary fat; and their interaction with temperature, by the Edinburgh Poultry Growth Model.

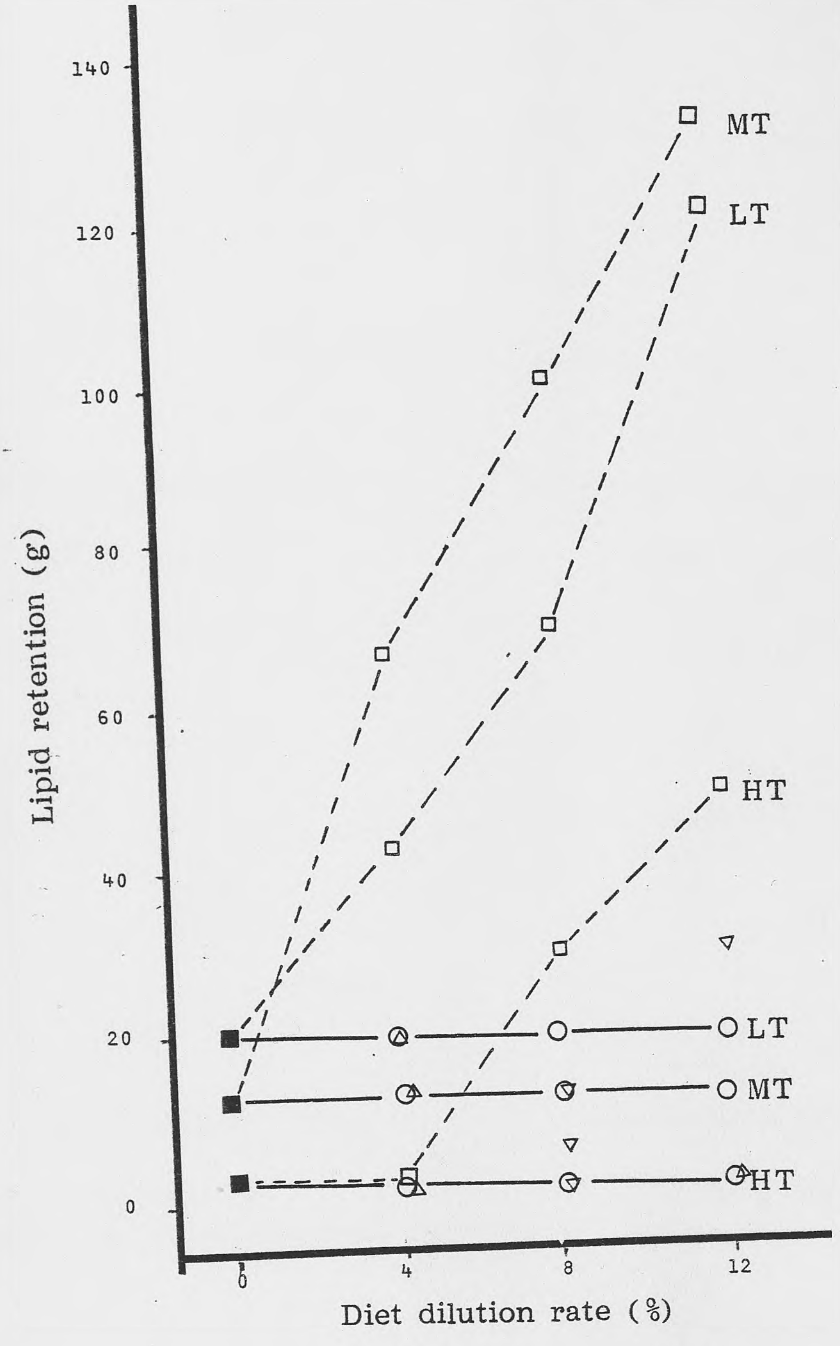

FIGURE 9: Predicted effects (on lipid retention) of diluting diets with different levels of fibre, ash and dietary fat; and their interaction with temperature, by the Edinburgh Poultry Growth Model.

Key

○ = ash

■ = basal diet

▽ = fibre

□ = crude fat

LT = low temp (22/24.5°C)

MT = medium temp (26/28.5°C)

HT = high temp (30/32.5°C)

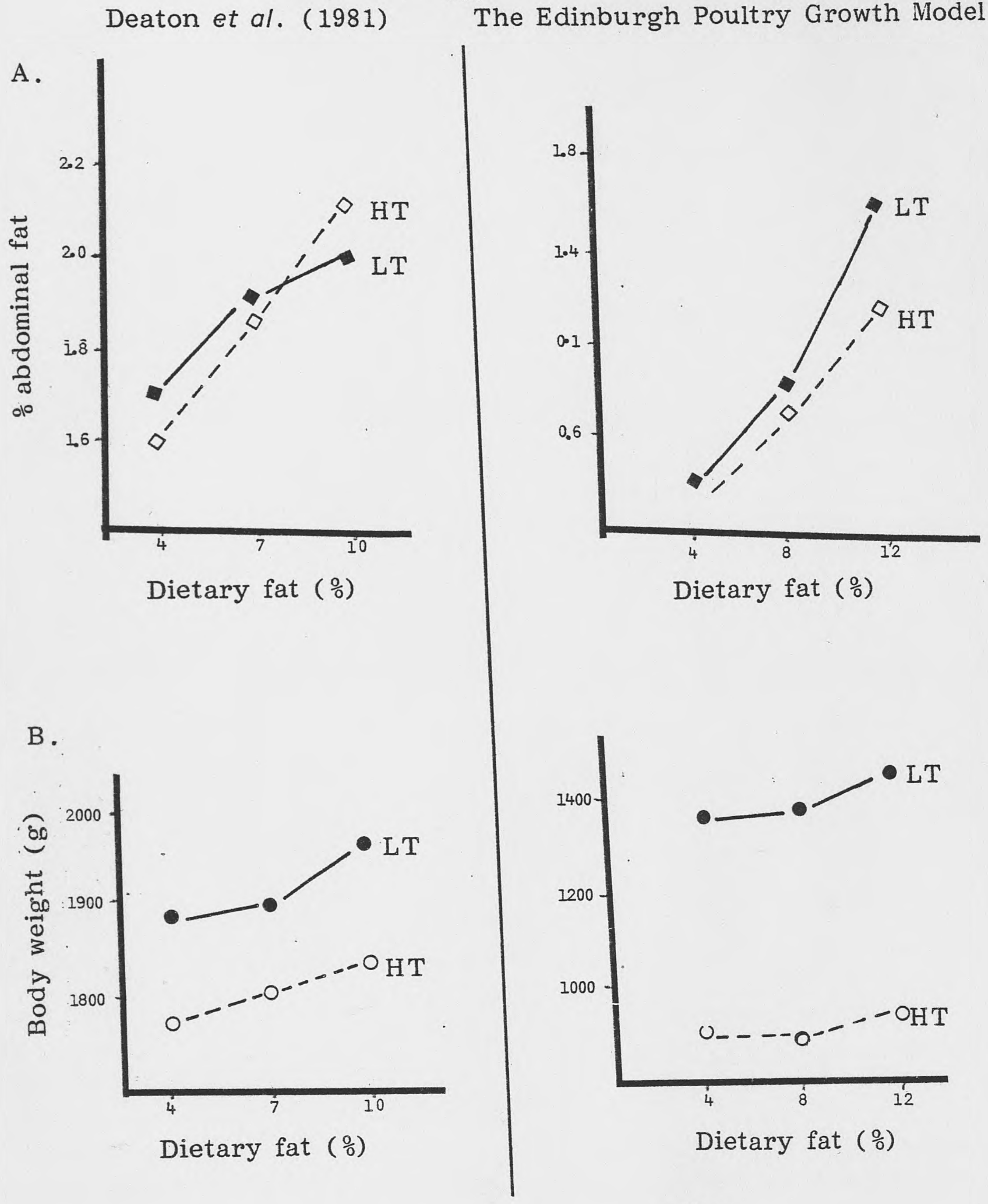

FIGURE 10: Effects of dietary fat levels and temperature on broilers (A. % abdominal fat, and B. body weight); to compare the predicted response by the Edinburgh Poultry Growth Model with observed effects from Deaton *et al.* (1981).

Key

HT = high temperature (29°C in observed and 30/32°C in predicted experiments)

LT = lower temperature (21°C in observed and 22/24°C in predicted experiments)

Note: This is not a simulation experiment because the experimental details were different. The predicted results were derived from Experiment IV - see text.

5. DISCUSSION

Response prediction models have an important role to play in the study of agricultural systems. The Edinburgh Poultry Growth Model (EPGM) has shown how information from the existing research findings referred to in the literature on EPGM as detailed on page 14, can be used to construct a program which could be useful in teaching, research and in the field of poultry production. It also indicated through some assumptions that were made to facilitate its construction that there are gaps in areas of existing knowledge.

The technical aspects are good. It is very flexible. Through tests performed, it produced responses to all variables, levels of input including possible interactions that occur in poultry growth, namely: genotype, nutrition, temperature and management. It has amply demonstrated the potentials of computer response simulation models in dealing with many factors simultaneously (Curll *et al.*, 1977; Spedding, 1977; Whittemore, 1981). It also displayed impressive time savings while investigating the effects of inputs on poultry. For example, one of the tests (Experiment IV) which is a multi-factorial design of thirty experiments was completed in two hours using the computer.

The model is also stable. There is no ambiguous data when experiments are repeated. Stochastic elements are also not present as pointed out by Dent *et al.* (1979). It reflects a view that similar experiments should produce similar results (Emmans, 1981).

Based on the sensitivity tests, as mentioned in Beever (1981), it was found to be sensitive to input factors, including the limits of the prevailing expectation, that the real bird would survive. The model was subjected to various levels of stimuli, and like the real bird, it reacted to undue stresses. Situations were found where it had high, medium or low sensitivity, depending on the physiological merit and the level of the input. However, the limits of tolerance to temperature are rather narrow and unrealistic.

The ability of the model to simulate responses quantitatively is not yet satisfactory. This is largely due to problems that may be associated with the temperature schedule. However, the efficiency with which it simulated responses in one of the experiments (Figures 1-3) holds some hope that this function could be perfected. Despite the problem on its dealings with temperature, most of the other biological responses were in qualitative terms, found to conform with some responses reported in other research studies.

Some of the assumptions which are present in the model could be seen as being capable of weakening its scope for practical application, because this runs counter to the suggestion by most proponents that models should be constructed explicitly from the existing knowledge (Wilson, 1977; Whittemore, 1981). It is possible, however, that certain assumptions are inevitable if they are designed to fill a gap and if they are sound and can be tested. In this research it was identified that some assumptions were made to support the main theory of growth in poultry. They are in the subject areas of feed intake control, heat loss mechanism, tissue relationships in growth and fattening. The discussion on the controversy associated with the relative importance of nutrient composition in feed intake control has been elucidated in a critical review of some theoretical aspects of EPGM (page 24). Judging from the conflicting reports about the food intake responses of poultry to a deficiency of essential nutrients, it is not clear whether the time is ripe for a predictive model on food intake to be based on this framework. The shortcomings discovered while testing the model have indicated a possible weakness in the assumptions about temperature.

Temperature aspects

It has been assumed in the model that heat loss of a given chicken on a given feed is constant. For this purpose, heat loss was related to a temperature coefficient (TCOEFF) and the environmental heat demand (EHD) as follows:

$$\mathrm{TCOEFF} = 0.001\,(28.5 - (\mathrm{Log}\,(\frac{\mathrm{Protein}}{\mathrm{MPMASS}})) \times 19.2)$$

and

$$\mathrm{EHD} = \mathrm{MBWT}\,(\mathrm{TCOEFF}\,(40 - \mathrm{Temp}))$$

where MPMASS = mature protein mass
MBWT = metabolic body weight
Temp = the effective temperature of the day

The equations describe the rate of heat loss as a linear function of the difference between environmental temperature and 40°C. It is a finding of this study that the scale of the temperature coefficient may have contributed to the inflexibility of the model, thereby making it operate within a too narrow limit and causing it to be sensitive outside the range. It may have also incapacitated the model's ability to vary its heat loss in conjunction with the energy content of the diet.

Unlike the model, the real birds vary their heat loss through behavioural means. If the environmental temperature is colder than ideal, among the population, birds would huddle in groups and pack more closely together as the condition becomes more unfavourable (Osbaldiston, 1966). The individual bird also has options to reduce the heat loss. It may sit down to prevent losses from the unfeathered areas (Deighton and Hutchinson, 1940; Deshazer, 1967), it could tuck its head under its wing (Deighton *et al.*, 1940), or hunch up to minimise heat loss (Hutchinson, 1945). Under heat stress, insensible heat loss is increased (Ota, Graver and Ashby, 1953) and the bird may pant (Randall, 1943; Richards, 1971), or splash water on combs and wattle (Wilson, 1949). The population would also disperse within the available space with some, spreading out of their wings in a fanning movement.

Through the above behavioural means, the real bird is able to vary its heat loss irrespective of how the feeding may influence the metabolic heat production. The absence in the model of suitable descriptions to simulate these aspects is seen by this study as a handicap. It only operates within a narrow range of thermoneutral zone and is unable to vary heat loss in association with the energy content of the feed, especially in relation to bulky feeds.

From the above review and results of tests performed, it is thought that the model adopts an over-simplistic approach in dealing with the heat loss. Also the numbers in this schedule could be wrong hence the high sensitivity to temperature as a variable.

There is a need to improve upon this aspect of the model with suitable sets of formulae or numbers that would incorporate the behavioural effects on the effective temperature scale. The builder of the model had expressed some scepticism about the reaction of the model to this input. Unfortunately, alternative equations have not yet been found in the existing literature that deal with the behavioural responses to temperature in *ad libitum* fed animals.

Biological responses

Food intake:

The model maintained a realistic relationship in attempts to predict food intake. It shows that whereas cumulative feed intake increases with age, the rate of intake increases with a diminishing return towards optimum values. When Figures 1 and 2 were superimposed over each other, it showed that birds consume the same amounts of food against time, to grow along the same curve of liveweight against time. These findings are in agreement with the findings of Parks (1970). Thus, an indication that the model could be acurate in predicting responses associated with feeding. The production of similar responses in Figure 2 also demonstrates its potentials in evaluating factors that affect food intake. The overall impression from analysis of results shows that the model's feed intake is a function of nutrient composition, temperature, the state of the bird and the bulkiness of the food. These results are consistent with the results in literature.

Most of its results show that food intake is inversely related to temperature, in agreement with expressed views in the literature (Byerly, Kessler, Thomas and Gons, 1978). Variable results were produced when there is temperature-nutrient interaction. It responds to low dietary protein level by increasing food intake. However, its preferential increase in food intake in response to HE/LP rather than LE/HP diet (Figure 5) casts some doubt about its ability to control its energy intake, as proposed for birds by Hill (1962). It appears to have reduced energy need to be of secondary importance to protein in this condition. The observed experiment showed that energy content seems to be the major controller of food intake when an energy : protein ratio is established. This statement is in agreement with the findings by Scott, Neshein and Young (1969), who claimed that chickens eat food to satisfy their energy needs. Further studies may be undertaken in this area to determine where a balance is maintained. The food intake responses to bulk or density of the feed has been found to be consistent with the observations by Mraz *et al*. (1956, 1957) who found that with the increasing dilution of diets with fibre, chicks compensated for the low energy content of the diets by increasing feed consumption.

Interaction between variables

The general picture presented by the study of the model's behaviour is that there is a high degree of interaction between variables in the system. It also suggests that it is not possible to make a general statement regarding the effect of a particular factor on food intake, growth and body composition, without a consideration of how its levels and those of the other prevailing variables in the system may relate. Table 1 shows the model's prediction of possible interactions between environment and nutrition. Most test results follow the same tendency. This study also investigated the subjects of the limits of expected interactions in the system as reported in research findings, and then compared the outcome with the model's predictions.

The majority opinion is in support of the above view. The type of temperature-nutrient interaction the model has demonstrated has been found to be similar to those reported in Harris, Waldroup, Seay and Nelson (1974), Emmans (1974), Fisher and Wilson (1974), Cowan and Michie (1978), Mohamad (1981 thesis). Tests on the model also demonstrated some interaction between the effects of strain, stocking rate and husbandry levels on the values. The results are comparable with observations of Rinehart, Green and Williamson (1975), Evans, Goodwin and Andrews (1976), Tarrago and Puchal (1977).

Growth and body composition

The model's ability at simulating growth curves is commendable. The quantitative simulation of the growth curves of poultry in experiments by Hakansson *et al.* (1978) has proved that indeed, the Gompertz function is fit and suitable for describing poultry growth (Wilson, 1977; Tzeng *et al.*, 1981).

Fattening

The model produced varied responses to fat deposition which may be consistent with the belief that the variable fat can be manipulated especially nutritionally. This dissertation is reluctant to give a final conclusion on the potentials of the model in dealing with lipid until further investigations have been carried out.

It has been shown in Figures 3B and 4 that the model was unable to simulate the observed values. The reasons could be three-fold:

1. that the assumption in the model about fattening in poultry is wrong;
2. that the input variables used in the simulation are unsuitable whereby the right numbers should produce the right response; and
3. it is also possible that some non-protein nutrient was missing in the real feed used.

The model has been built with the belief that chickens differ with the mammalian livestock in the relationship between fat deposition and age. But this study takes a differing view which is based upon the information assembled in this dissertation as detailed on page 27. In fiarness, the model only operates with the input numbers. The minimum lipid : protein ratio is an independent variable in the model and in many situations, the numbers used have been chosen by default because the experiments being simulated could not supply the appropriate values for the trial. If this is the case, then there is the need for the refinement of the genotype system in the model to reduce elements of subjectivity in the choice of numbers. The need to assign numbers to the genetic parameters A, B and MINLIP in order to use the model (see notes on genotype system, page 11); also stresses the urgent need to have good descriptions of the potential growth and inherent fattening characteristics of different chicken genotypes.

6. CONCLUSIONS

In animal production, the development of programs or models can be valuable tools to aid the advisory service, by facilitating the prediction of responses from changes in the production strategy. However, the development of models have been constantly affected by constraints. These range from lack of suitable information in the existing research literature, to inappropriate equations to describe the complex biological relationships involved. As a result of the gaps in knowledge, some further theoretical components which can be tested, may be inevitable before a comprehensive response simulation program can be built.

The construction of the Edinburgh Poultry Growth Model has been identified as the boldest effort aimed at simulating biological responses of food intake, growth and body composition in poultry; from the important variables of genotype, nutrition, temperature and management. The objectives have considerable relevance to poultry production, especially in the area of broiler production, in that it could influence objective decisions in the system.

It has potentials for quantitative simulation of responses. A deductive simulation model, however, is supposed to obey an "all or none rule" within practical limits. For this reason, the weakness found in its dealing with heat loss is a handicap to performing that function. The high sensitivity of the model to temperature is also a proof that the assumption used in the construction of that section is inappropriate. The model would therefore appear worthy of some amendment in this respect. Although the simulation efficiency is affected in general terms, the biological responses that are predicted by the model are consistent with findings in most research literature.

The nutrition aspects are adequate. The responses to food intake are consistent with some findings in the field of research. Consequently, the main theory that underpins the model, which relates to food intake control has not yet been proved wrong. The growth curves are consistent and it has contributed in proving that the Gompertz function of time is suitable for describing poultry growth.

This dissertation has not highlighted most of the potentialities of the Edinburgh Poultry Growth Model because of the nature of the topic. Nevertheless, it is the suggestion in this conclusion that the findings should help to improve rather than denigrate the package.

7. OBSERVATIONS

An awareness of current research and development is essential in all fields of study. In Agriculture and Animal production, most research findings have probably been under-utilised because they cannot be easily applied in production processes. Consequently, apart from publication in scientific and academic journals, there are few incentives to encourage researchers to produce more reports. Systems modelling might be a stimulating and useful outlet for demonstrating objective findings which could be a way of encouraging further research work.

Response simulation modelling demands detailed attention before good deductive relationships can be derived. Co-operation and understanding of the aims and objectives of all specialist skills must be the responsibility of all concerned with the integration of agricultural research and modelling. With an increasing interest in, and demand for models, there is now a need for the disciplines in agricultural research to produce precise and objective data.

It has been observed in the course of this study that most of the published research work reviewed, suffers from the defect of insufficient detail. Responsibility for this could be blamed on the editors of scientific journals who place a high premium on the space available for the materials being contributed for publication. This situation sometimes results in essential experimental detail being omitted. It is a suggestion of this dissertation that more allowance be made for authors of research articles to include all necessary experimental details to be published. This could increase the scope for the correct data to be identified and used in models.

This study also identified a gap in the understanding of the appropriate mathematical relationships that represent the behavioural responses to heat loss in animals under *ad libitum* feeding systems. A further investigation might involve the quantitative evaluation of heat loss due to physiological and behavioural activities. The data obtained could be useful in modelling temperature parameters. An additional area in which further research could be of interest is the determination of whether an optimum practical diet can be formulated to eliminate the effect of age on fat deposition in poultry.

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