AN ECONOMIC ANALYSIS OF
LEAST-COST LAYER RATIONS

A thesis presented in partial fulfilment
of the requirements for the degree of
Master of Agricultural Science in Farm
Management at Massey University.

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ABSTRACT

Fifteen treatments, replicated once, each containing eighty four birds of three strains of White Leghorn layers (White Base a, White Base b, M. Line) were fed rations *ad libitum* of five different metabolisable energy levels (2315, 2535, 2756, 2976, 3197 k. cal. M.E. per kg.) and three different protein levels (16, 17, 18 gms. per hen per day, based on an energy intake of 305 k. cals. per hen per day) to obtain quantitative estimates of the physical input/output relationships of layer production. Three other treatments, plus a control, were fed to obtain data on the response of laying hens to restricted energy intake and improved protein quality. All rations were formulated to least cost using Linear Programming.

Least Squares multiple regression was used to obtain linear response functions for feed intake, egg number, egg weight and liveweight gain (the variables included in a net revenue function for layers under New Zealand production conditions).

Feed intake was expressed in terms of dietary energy concentration and initial liveweight. Statistical problems encountered dictated that predicted nutrient intakes were used as the independent variables in the estimation of the egg number and liveweight gain functions. Predicted energy intake and methionine intake accounted for differences in egg number, particularly for White Base b layers. Predicted energy intake, methionine intake and isoleucine intake accounted for differences in liveweight gain. There were no significant differences between average egg weights.

There were significant strain differences in *ad libitum* feed consumption, egg number, average egg weight and liveweight gain.

A net revenue function was estimated in terms of the endogenous variables (dietary nutrient concentrations) which were included in the layer response functions. This was analysed in terms of the endogenous variables for the then current egg and feed prices.

CHAPTER ONE

INTRODUCTION

Feed is the major variable-cost item in an egg production enterprise. To reduce feed cost, linear programming has been used to solve the "least-cost feed-mix problem"; where ingredient levels in the ration are selected such that the cost per unit of ration is minimised subject to specified nutrient inclusion.

Nutrient recommendations for laying hens are expressed as a percentage of the diet (N.R.C., 1963) and as a daily hen requirement (Scott _et al_., 1969). Ration formulators in the past have been guided by dietary percentage recommendations. These are often related to a particular dietary energy concentration and the only criterion for their acceptance is that they support satisfactory layer performance. The need for these recommendations presupposes that variation in dietary nutrient content will affect a variation in animal performance. In the "least-cost feed-mix" formulation, no account is taken of the economic consequences of affecting an animal production response by means of a change in dietary nutrient content. This limitation was recognised by Brown and Arscott (1960) who noted that minimising feed cost was only part of the economic problem. They recognised that animal response must be included in the economic model and the determination of optimum nutrient levels was an economic problem.

Before animal response can be included in the economic analysis of layer rations it is necessary to quantify the physical input/output relationships of layer production. The relationships that are of direct interest are those that predict the responses that are included in the economic model. An economic model for egg production in New Zealand has been cited by Swan (1970). This model incorporates four layer performance measurements:-

(i) Feed consumption
(ii) Egg production
(iii) Grade distribution of eggs
(iv) Cull hen weight.

The dietary nutrient factors affecting these responses in laying hens have been the subject of extensive research. In Chapter Two of this dissertation these relationships are examined. This examination highlights that existing experimental data may not be sufficient to obtain quantitative estimates of the input/output relationships of economic significance. One reason for this is that the relationships we are interested in, have only recently been identified (Morris, 1967).

This study is viewed as part of a continuing investigation of the input/output relationship of layer production. To acquire the data suitable for an economic analysis it is necessary to obtain co-operation between production economists and animal nutritionists. For this study, indisciplinary co-operation was obtained and a specially designed experiment was conducted by the Massey University Poultry Research Centre. The objectives of this experiment (the details of which are presented in Chapter Three) were threefold.

(i) An attempt to quantify the relationship between dietary energy concentration and <u>ad libitum</u> feed consumption for three strains of laying hens under New Zealand production conditions.

(ii) An attempt to quantify the relationships between energy and protein intakes and layer performance where calcium and phosphorus intakes are sufficient to sustain maximum production.

(iii) Where differences in layer performance could not be satisfactorily explained in terms of different levels of energy and protein intakes then daily intakes of other nutrients, not specifically controlled in any way, would be analysed in an attempt to generate hypotheses about relationships that should be investigated in future studies.

The number and range of variables that can be studied in any one experiment is dependent upon the research resources available. When the response characteristics of interest are known it is desirable from an economic viewpoint that the range of inclusion of the independent variables is such that any maximum or minimum relationships (both physical and financial) are included. Research limitations for this study dictated that experimental precision (replication) had to be forfeited if a wide range of the independent variables were to be included. The analysis of experimental data in the absence of replication is discussed in Chapter Four.

Chapter Five contains an analysis of the physical input/output relationships of layer production. The economic analysis is presented in Chapter Six. In Chapter Seven some selected aspects of the experiment are examined.

CHAPTER TWO

NUTRITIONAL RELATIONSHIPS IN LAYER PRODUCTION

2.1 Introduction

This thesis is concerned only with the nutrition of the laying hen from 22 to 67 weeks of age.

Numerous studies have been made of the nutritional relationships of the laying hen. Factors responsible for this have been:

(a) the high cost structure of feed in extensive poultry enterprises
(b) the ease with which nutritional trials can be conducted
(c) the simple physiology of the laying hen in comparison with ruminants.

Recommendations have most commonly been made in terms of the nutrient density of the ration required for satisfactory layer performance. However, some variation in recommended nutrient densities is evident between researchers. Much of this variation can be explained in terms of differences in dietary energy conconcentration, and hence other nutrient intake levels of the different rations (Morris, 1967).

The recognition of the relationship between dietary energy concentration and feed consumption (Morris, 1967; DeGroote, 1972) has resulted in the presentation of recommended nutrient levels in terms of daily intake levels

(Scott *et al.*, 1969; Fisher and Morris, 1970). The recommended intake levels for nutrients are often those which support maximum production (Fisher and Morris, 1970; Bray, 1965; Tonkinson *et al.*, 1965). Maximum production levels are not necessarily economically optimal. Before it is possible to undertake an economic analysis of layer rations it is necessary to quantify the relationships between layer performance and nutrient intakes.

The following sections of this Chapter present a review of current knowledge of the nutritional relationships in layer production, relevant to this study.

2.2 Expression of the energy relationships in layer nutrition

Energy is required by laying hens for the growth of body tissues, egg production, maintenance of body temperature and for physical activity. Energy is stored in feedstuffs in the form of carbohydrates, fats and proteins. The daily intake of energy is related to the effects that blood glucose and other metabolites have upon the birds hypothalmus (Scott *et al.*, 1969). Any intake of energy that is excessive to daily requirements cannot be excreted and is stored in the body tissue as fat.

Energy exists in several forms. Potential energy of a feedstuff is a function of the carbohydrate, fat and protein that can be oxidised to carbon dioxide and water. The heat production from the burning of a feedstuff in the presence of oxygen, is the gross energy of that feedstuff. The amount of gross energy that can be digested will determine the ultimate efficiency of utilisation of a feedstuff. The relationship between gross energy and other energy values is shown in Figure 2.1 (after Scott *et al.*, 1969).

During digestion there is a loss of energy in the form of faeces and urine. When the digestible energy is corrected for faecal and urinary energy loss, the metabolisable energy value of the feedstuff is obtained. During energy metabolism there are heat losses. The net energy value of a feedstuff is corrected for this heat loss. Net energy is utilized by the laying hen for maintenance and production requirements as shown in Figure 2.1.

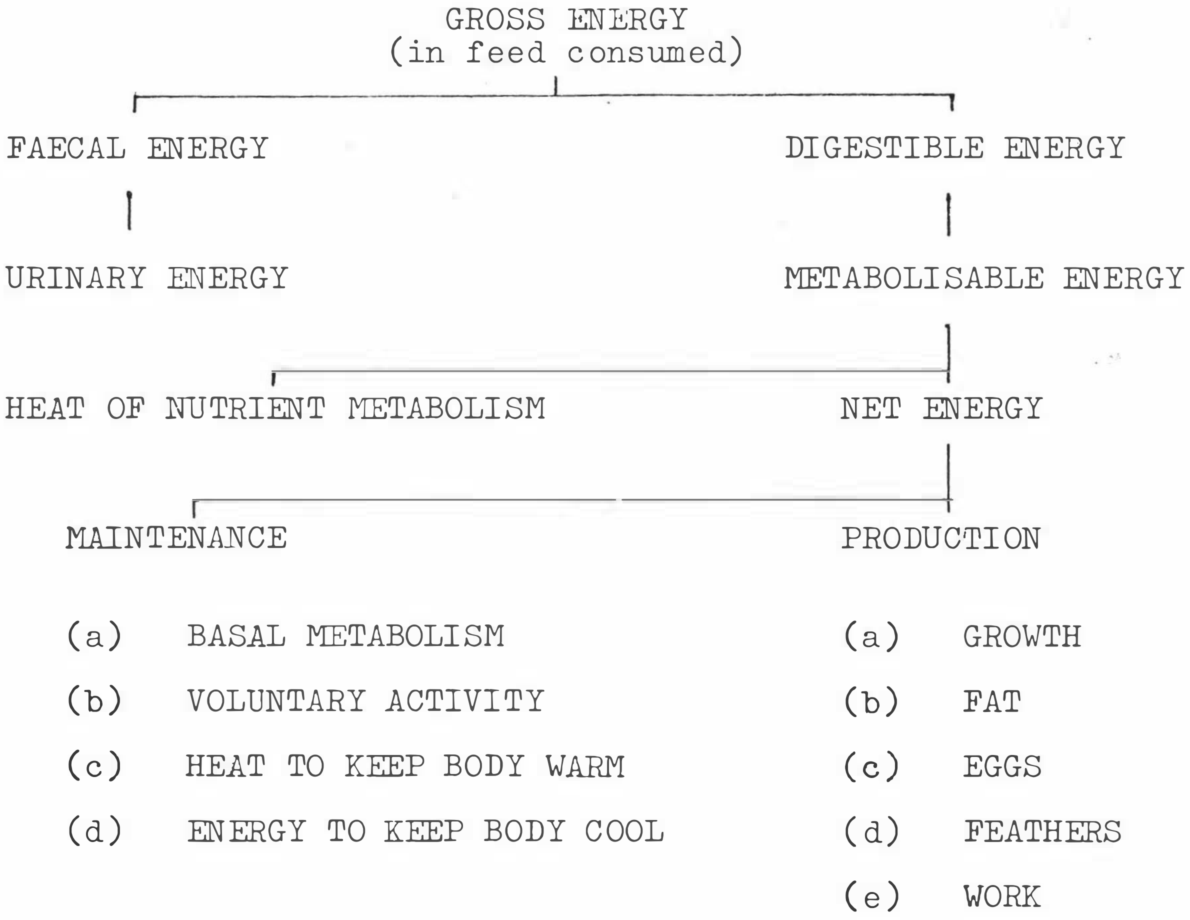
Brown (1964) concludes that although there is disagreement on the determination of energy values (laboratory techniques etc.) the use of metabolisable energy values for laying hens is the most appropriate. The definition used by Brown for metabolisable energy is:

> "The fraction of the total energy which is absorbed and utilized for heat production and energy storage, i.e. difference between calorific value of the feed and that of the visible excreta."

The use of metabolisable energy for measuring energy values is not corrected for nitrogen retention by the hen. Brown suggests that a concept of "corrected metabolisable energy" may be used in the future.

This study uses metabolisable energy, measured as k. cals M.E. per kg, as the energy value.

Figure 2.1: ENERGY RELATIONSHIPS IN LAYER NUTRITION



2.3 Energy utilization by laying hens and its relation to voluntary feed consumption

Scott *et al*. (1969) conclude that high producing white leghorn hens, in moderate temperatures, require between 300 and 320 k. cals. of metabolisable energy per day to meet the requirements of maintenance and production. They point out that hens will adjust their daily feed consumption to meet this energy requirement. For a dietary energy range of 2500-3300 k. cals. M.E. per kg., Scott *et al*. showed that a decrease of 110 k. cal M.E. per kg. will result in an increase in food consumption of about 3.5-4.0 per cent. This chemostatic control of feed intake occurs when the bulk of the ration does not affect a physiological limit to daily feed intake. The control of feed intake is not perfect and over consumption of energy occurs when dietary energy concentration is high.

Morris (1967) reviewed experiments that related daily metabolisable energy intake to dietary metabolisable energy concentration. He recognised that variation existed in the determination of energy values of individual feedstuffs and these values were standardised in his study. Morris concluded that birds which had an inherently large daily metabolisable energy intake, adjusted their intake on high energy rations less effectively than birds whose daily metabolisable intake was lower. A 'characteristic calorie intake" was obtained for birds, on each treatment, being fed a ration of 2,700 k. cal. M.E. per kg. An equation was fitted which predicted the daily energy intake for various dietary energy levels. Not only did each strain of bird have different "characteristic calorie intakes", but their adjustment of feed intake to varying dietary energy concentration differed. Birds whose "characteristic daily calorie intake" is around 320 k. cal. M.E. will "overconsume" energy by 2 to 3 per cent for each 10 percent increase in the dietary energy level. Birds whose daily "characteristic calorie intake" is greater than 320 k. cal. M.E. will overconsume energy by a greater amount.

Morris's equation is:

$$y = y_{2700} + (0.0005465\ y_{2700} - 0.1466)(x - 2700)$$

y = energy intake (k. cal. M.E. per bird day)

x = dietary energy concentration (k. cal. M.E. per kg.)

y_{2700} = "characteristic calorie intake" of each strain on a diet of 2700 k. cal. M.E. per kg.

De Groote (1972) working with White Leghorn hens of "characteristic calorie intake" of 317 to 320 k. cal. per hen for a ration of 2700 k. cal. M.E. per kg. showed that there was an increase in daily calorie intake of 3.14 ± 0.59 k. cal. for each 100 k. cal. per kg. increase in dietary metabolisable energy.

$$y = (3.14 \pm 0.59)\ x + 236.53$$

$$r = + 0.858\ (p < 0.01)$$

y = M.E. intake (k. cal. per hen per day)

x = dietary energy concentration (k. cal. M.E. per kg.)

The slight differences between De Groote's figures and those of Morris were suspected to be due to differences in environment and diet.

Hill *et al*. (1965) had earlier concluded that White Leghorn hens adjusted their food intake to obtain a constant daily energy intake when rations varying in energy concentration were fed *ad libitum*. Hill (1962) in discussing these results overlooked the reduced calorie intake when hens were fed a low energy diet of 2314 k. cal. M.E. per kg. His conclusions were based on the analysis of results from a higher, but narrow, energy range.

2.4 The relationship between energy intake and production responses

Production responses have been noted to changes in dietary energy concentration. Santana and Quisenberry (1967) showed that an increase in dietary energy from 947 to 1003 k. cal. P.E. per kg. resulted in an increase in egg size and body weight gain when methionine, lysine and tryptophan were included to N.R.C. recommendations. De Groote (1970, 1972) quantified these relationships using White Leghorn hens and feeding rations with a dietary energy range from 2500 to 3200 k. cal. M.E. per kg. for a forty week period (starting when the hens were 27 weeks old). These relationships are presented

$$y_1 = (0.213 \pm 0.04)\,x + 53.86 \qquad r = 0.859\ (p < 0.01)$$

$$y_2 = (38.85 \pm 10.7)\,x - 840.13 \qquad r = 0.903\ (p < 0.01)$$

Where y_1 = egg weight (grams per egg)

y_2 = body weight gain (grams per hen per 40 weeks)

x = dietary energy concentration (k. cals. M.E. per kg).

De Groote noted that part of the response to egg size could be attributed to increased linoleic acid consumption, (Combs, 1961; Shutz and Jensen, 1963; Edwards and Morris, 1966; Bray, 1967).

Earlier work by Heywang (1939) had shown that there was a positive response in egg number to an increase in dietary energy concentration but no response in egg size or body weight gain. Lillie and Denton (1964) found no production response to variation in dietary energy concentration. The level of response is no doubt related to other nutrient factors not analysed by Lillie and Denton. Tonkinson et al. (1965) analysed the response to energy intake in conjunction with protein intake (see 2.6).

It has been shown (2.3) that hens will "overconsume" energy when fed high energy concentration feeds. Should the intake of energy be above the requirement for maintenance and production the effect on production will be dependent upon the intake of other nutrients, notably protein and amino acids. To ensure maximum production at any time a balanced energy/protein ratio must be maintained. Combs (1962) and Sibbald (1964) state that this ratio must be modified to take account of protein quality, level of egg production and egg size. As protein quality is a function of amino acid levels and balance, the energy/protein ratio must be modified to account for variation in the amino acid content of the protein. The effect of protein and amino acid on layer performance are now discussed.

2.5 Protein utilization by laying hens and its relation to voluntary feed consumption

Much has been written by nutritionists on the protein requirements of laying hens. Nutritionists define a "requirement" for a nutrient, at a time in the laying cycle, as the intake of that nutrient which will support maximum production, given that other nutrients are not limiting. Nutritional research has resulted in tables of recommendations for the protein "requirements" of layers. These are expressed in several ways:

(a) grams per hen per day
(b) grams per 1000 k. cal. M.E.
(c) percentage of the diet.

The need for these recommendations recognises that there is a relationship between protein consumption and production responses.

Early work on the protein recommendation for laying hens did not recognise the relationship between feed intake and dietary energy concentration. Recommendations for protein were expressed as a percentage of the diet, independent of the dietary energy concentration. This resulted in a confusing variation in the nutrient recommendations of various researchers. These variations were recognised by Childs (1963):

> "The problem of protein requirements for layers is both a confusing and controversial one. Reports in the literature from various

> experimentations list a range of 12-18 percent as the minimal requirement. Some of the reasons for this variability are: geographic location, strain of birds used, caloric content of the diet and whether or not the basal ration is supplemented with any amino acids."

Protein is required by laying hens for maintenance and production. The maintenance requirement is a function of the breed and size of the hen, together with environmental factors which may affect the hens metabolic rate. Under normal conditions, White Leghorn hens require some three grams of protein daily for the maintenance of body tissues. Excess to maintenance, the level of protein intake will affect both egg size and rate of lay. During maximum egg production the daily output of egg protein is approximately six grams. In addition there will be a minimal requirement for feather growth. Results of experiments on the utilization of protein from corn and soya-bean diets(1) suggests that 17.5 to 18.5 grams of protein per hen per day is required for overall maximum production. This suggests that the efficiency of utilization of protein at the point of maximum egg output is only around 55 percent.

There is evidence (Sharpe and Morris, 1964; Santana and Quisenberry, 1967) that layers will adjust their daily

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(1) Rations with corn and soya-bean meal as the major ingredients are common in U.S. layer production and have been used extensively in U.S. layer production research.

feed intake to increase protein consumption when dietary protein concentration was as low as 10.5 and 12.0 percent respectively. However, Thornton et al. (1957), Dewan and Gleaves (1969) and Swan (1970) do not support this on the evidence from feeding 11.0, 13.0 and 11.8 percent protein rations respectively.

2.6 The relationship between protein intake and production responses

Thornton et al. (1957) studied the response to increasing dietary protein levels of 11, 13, 15 and 17 percent. Egg production and body weight gain were not significantly different. A reduced egg weight for the hens fed the 11 percent protein ration led the authors to the conclusion that 13 percent dietary protein was required for maximum performance. Quisenberry et al. (1962) confirmed these results although they excluded the 11 percent protein ration. They also noted that the feeding of a 17 percent protein diet reduced the number of undersize eggs early in the production period.

Sharpe and Morris (1964) found that a comparison of 10.5, 12.5, 14.5 and 16.5 percent protein diets (2765 k. cals. M.E. per kg.) showed that for a light strain of bird, all production aspects were the same. However, they found a reduction in egg size when a 10.5 percent protein diet was fed to a heavy strain of layer. These authors concluded that a diet which is too low in protein to support peak egg production will also fail to support normal egg production at a later stage in the laying cycle. Santana and

Quisenberry (1967) showed that there was an increase in egg number and egg size when dietary protein concentration was increased from 12 to 14 percent.

Lillie and Denton (1967) found that for daily intakes of 14.4 and 16.2 grams of protein per hen there was no difference in egg number, however 16.2 grams of protein per day was required for the maintenance of body weight. This experiment compared oats, corn, wheat and barley as the sole grain at various protein levels. Regardless of the protein level there was a grain effect on egg number. This suggests that there was a response to the difference amino acid content of the grains.

Swan (1970) at the Massey University Poultry Research Centre found no response in egg production when isocaloric (2425 k. cals. M.E. per kg.) diets were fed with protein variation from 11.8 to 16.7 percent of the ration. There was no response in feed intake and daily protein consumption increased as a function of the dietary protein concentration. Daily protein consumption ranged from 15.1 to 21.6 grams per hen.

Quantitative estimates of the relationships between egg production responses and protein consumption have been limited. Least squares regression was used by Tonkinson _et_ _al_. (1965) to obtain production responses to energy and protein consumption for laying hens from 22 to 54 weeks of age.

The form of the model was:

$$y = \beta + \sum_i b_i X_i + \sum_{ij} X_i X_j + e$$

$$i = 1,2.$$

$$j = 1,2.$$

where y = production response

y_1 = body weight gain

y_2 = number of eggs

y_3 = average egg weight

x_1 = grams of protein intake per bird per day

x_2 = (calories of energy intake per bird per day)/10

β, b_i and a_{ij} are unknown regression parameters.

e is a random error that is assumed to be normally and independently distributed with zero mean and constant variance.

These researchers found no response in body weight gain (y_1) for variation in protein intake, either linear or quadratic. There was however a significant ($p < 0.05$) linear effect of energy intake on body weight gain.

$$y_1 = -1134.91 + 22.89\, x_1 \;\; 41.47\, x_2$$
$$-0.197 x_1 x_2 + 0.235 x_1^2 - 0.203\, x_2^2$$

When the quadratic model for egg production (number) was fitted to the data, the parameters: protein linear, energy linear, protein quadratic and energy quadratic, were significantly different from zero at the $p < 0.1$ level. The estimated function was:

$$y_2 = -205.69 + 22.49\, x_1 + 10.15\, x_2 + 0.033\, x_1\, x_2$$
$$-0.673\, x_1^2 - 0.156\, x_2^2$$

The estimates of the parameters of the egg weight regression were:

$$y_3 = 49.41 + 1.079\, x_1 - 0.47\, x_2 + 0.0009\, x_1\, x_2$$
$$-\ 0.029\, x_1^2 + 0.011\, x_2^2$$

The parameters for protein linear and protein quadratic were significantly different from zero at the $p < 0.01$ level. Energy quadratic is significantly different from zero at the $p < 0.05$ level.

Although research has continued on determining production responses to protein intake it has been shown by Childs (1963) and Biely and March (1963) that supplementing protein levels with lysine and methionine gave a response which suggests that amino acid levels are as important as protein levels.

With the availability of synthetic amino acids it is possible to supplement rations so that these amino acids are not limiting. This method was used by Childs (1963) who supplemented 2860-3025 k. cal. M.E. per kg rations with methionine and concluded that 13.7 percent protein supported satisfactory performance. An increased feed intake for a dietary protein concentration of 12.8 percent suggested that a second amino acid became limiting and there was compensatory feed intake. This experiment stresses the importance of consideration of protein quality. Amino acid nutrition in layer production will now be discussed.

2.7 Amino acid relationships in layer nutrition

Unlike plants, hens are incapable of synthesising all the amino acids required for maintenance of body functions. Amino acids that cannot be synthesised by the hen must be fed in the diet. These are known as the "essential" amino acids. The ten "essential" amino acids are listed in Figure 2.2. In addition there are three amino acids which can be synthesised only from limited substances.

Figure 2.2: Essential Amino Acids

Essential Amino Acids	Amino Acids synthesised from limited substances (1)
Arginine	Tyrosine
Lysine	Cystine
Histidine	Hydroxylysine
Leucine	
Isoleucine	
Valine	
Methinionine	
Threonine	
Tryptophan	
Phenylalanine	

(1) Tyrosine is synthesised from phenylalanine, cystine from methionine and hydroxylysine from lysine.

The inclusion of tyrosine, cystine and hydroxylysine in the ration can exert a sparing action on the essential amino acids. Should cystine be present in the diet the conversion of methionine to cystine is diminished and the methionine requirement is reduced.

Amino acid recommendations for layers can be expressed in several ways:

(a) grams per hen per day
(b) grams per 1000 k. cal. M.E.
(c) percentage of the diet
(d) percentage of the dietary protein.

The expression of amino acid recommendations in relation to the dietary energy concentration recognises the relationship between feed intake and dietary energy concentration. Only recently have amino acid recommendations been expressed in this way.

Amino acid recommendations have traditionally been expressed as a percentage of the diet. Summers (1967) and Combs (1967) both noted that the dietary percentage recommendation was modified by the voluntary feed intake. They concluded that the percentage recommendation of an amino acid should be related to the dietary energy and protein level, amino acid balance and factors of environment and animal growth.

As with research in protein nutrition, recommendations for dietary amino acid inclusion are based on the nutritionists understanding of the laying hens "requirement" for amino acids. This "requirement" of an amino acid for any period in the laying cycle, is based on the intake of that amino acid which will support maximum production of that period, dependent on other nutrients not limiting performance.

Grau (1948) and Almquist (1949) showed that as the dietary crude protein percentage was increased a resultant increase in the growth rate of hens demanded that amino acid intake had to be increased if maximum production was to be maintained. This was explained by Fisher et al. (1970) who proposed that the amino acid requirement was represented by

$$R = b_1 E + b_2 W + b_3 \Delta W$$

Where R = amino acid requirement
E = egg production
W = mean body weight
Δ W = change in body weight.

Should the increase in dietary protein concentration support an increase in body weight then the daily amino acid requirement for maintenance will increase.

Combs (1967) stated that it was necessary to modify dietary percentage recommendations to account for

(a) factors which influence the daily intake of an amino acid
(b) differences in the availability of amino acids, post consumption
(c) differences in the metabolic efficiency with which amino acids are utilized.

Where feed intake was depressed due to an amino acid imbalance, Fisher and Shapiro (1961) and Fisher et al. (1960) showed that the depressed feed intake actually creates a deficiency in at least the first limiting amino acid. This can be overcome by supplementing the ration with the limiting amino acids or by balancing the amino acid composition of the ration to overcome the depression in feed intake.

Early researchers did not appreciate the factors which influence the amino acid intake and utilization. Little regard was directed towards amino acid balance and each amino acid was studied in isolation. Should the amino acid balance not support maximum production then additions of the most limiting amino acid may not support improved performance, should the addition high-light a deficiency in the second most limiting amino acid.

2.8 The relationship between amino acid intake and production responses

It is common to note in the literature a response in egg number to lysine and methionine intake. This is because most United States attention has been focused on the relationship between layer production and the intake of these two amino acids, which are the most limiting in corn and soya-bean diets.

The common method of determining the amino acid intake that supported maximum rate of lay in any period was that used by Novacek and Carlson (1969). Using a basal diet of 3340 k. cals. M.E. per kg. and 9.4 percent protein, they studied the effect of increasing the amino acid concentration of the diet. The addition of methionine and lysine increased egg number, egg weight and improved the feed conversion rate. They concluded that methionine and lysine were limiting in the basal ration. The addition of tryptophan, isoleucine, arginine and valine had no effect on layer performance.

Combs (1962) using rations of 10.5 and 13.7 percent crude protein noted that there was an improvement in rate of lay, body weight gain and feed efficiency when DL-methionine was supplemented in the ration. Combs (1964) related egg production to methionine intake for pullets early in the laying period.

$$y = 0.105\ X + 15.7$$

Where y = grams of egg produced per day

X = available methionine consumed per day (milligrams).

Combs (1960) had earlier described the methionine requirement of laying hens as a function of egg production, body weight and rate of weight gain.

$$M = 0.05\ W \pm 6.2\ \Delta W + 5\ E$$

Where M = methionine requirement (mg. per hen per day)

W = average body weight (grams)

E = average egg product (grams per hen per day)

ΔW = average daily change in body weight (grams).

Combs made the comment that the methionine level which will support maximum production in any period can vary considerably when expressed as a percentage of the diet due to variation in bird size, rate of lay and the energy content of the feed. A correction factor including the dietary energy percentage was given:

$$A = \frac{(0.2204.E)\ M}{(1000.C)\ T}$$

Where A = dietary methionine recommendation (%)

E = dietary energy concentration (cal. per pound)

M = methionine recommendation (mg. per hen per day)

C = energy recommendation (cals. per hen per day)

T = temperature conversion factor.

Combs (1968) quoted the modification of his 1960 methionine recommendation as presented by Shank as:

$$M = 0.037\ W \pm 4.50\ \Delta W + 5.39\ E.$$

This equation was obtained from individual hen data, whereas Combs' 1960 equation was based on flock averages. The two equations provide similar estimates for the methionine recommendations for laying hens.

Bray (1965) also related layer production to methionine intake for young laying pullets. He established that the methionine intake which supported maximum egg production was 223 mg. per hen per day. This, he admitted, was considered to be low. The reason for this, as later shown by Fisher and Morris (1970) was that the mathematical function was in error. Bray fitted two linear regression lines which intersected such that egg yield was constant when methionine intake was greater than 223 mg. per hen per day.

$$y = 40.58 \text{ for } x \geq 223.5$$

$$y = 40.58 + 0.1004\ (x-223.5) \text{ for } x < 223.5$$

Where y = egg yield (grams per bird per day)

x = methionine intake (mg. per bird per day).

Relating egg yield to dietary methionine concentration, the regression equation was modified to:

$$y = 40.58 + 133.2\ (x-0.216)$$

Where x = dietary methionine concentration (%).

Fisher and Morris (1970) noted the relationship between egg yield and methionine intake and fitted Bray's data to the form:

$$y = 12.66 + 18.1101\ x - 2.8441\ x^2$$

Where y = egg yield (grams per bird per day)

x = methionine intake (mg. x 10^{-2} per bird per day).

This increased to daily methionine intake which supported maximum egg production to 318 mg. per hen.

Fisher and Morris (1970) examined methionine relationships in layer production using a dilution technique. The response to the dilution of one amino acid is interpreted as the response to that amino acid. The experiment was designed to study the response to methionine intake when the dietary protein was both "balanced" and "unbalanced". The "unbalanced" protein rations contained less methionine as a percentage of the dietary protein. The response was analysed for birds from 35 to 38 weeks of age. Although there was a significant ($p < 0.05$) effect of protein in the response to methionine intake, this difference was trivial when compared with the main effect of methionine intake.

The quadratic regression lines fitted for "balanced" and "unbalanced" protein were respectively:

$$y = -38.6778 + 52.3891\ x - 8.5545\ x^2$$

$$y = -14.6836 + 36.9573\ x - 6.2451\ x^2$$

Where y = egg yield (grams per bird per day)

x = methionine intake (mg. x 10^{-2} per bird per day).

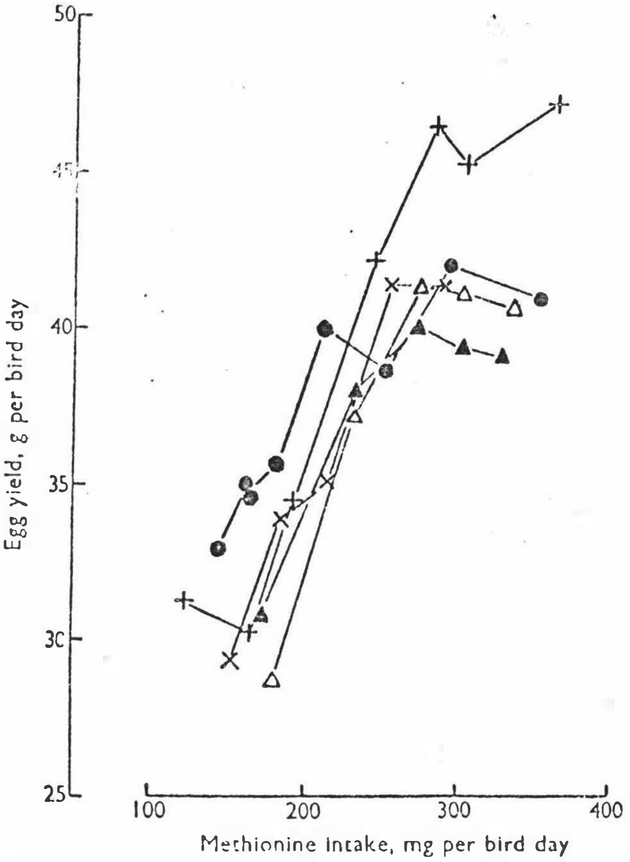
These functions are maximised with a daily methionine intake of 306 and 295 mg. respectively. However, the experimental results show that maximum egg yield was supported by an intake of 278 mg. of methionine per hen per day.

The results of Fisher and Morris (1970), Combs (1962), (1964) and Bray (1965) are shown in Figure 2.3 (after Fisher and Morris, 1970).

Taken together the results of Combs (1962, 1964), Bray (1965) and Fisher and Morris (1970) are in good agreement. They conclude that for young pullets at the beginning of their laying period approximately 275 mg. methionine per bird per day will support maximum egg yield.

Taylor *et al*. (1966) supplementing 10.5, 12.5 and 14.5 percent protein diets, showed that the first limiting amino acid was lysine for rations of 10.5 percent protein. Isoleucine became the first limiting amino acid at 12.5 percent protein and tryptophan at 14.5 per cent protein. The addition of isoleucine reduced responses to other amino acids. This was attributed to possible amino acid imbalances with isoleucine. Performance was measured by rate of egg lay. There was no response in food intake to variation in dietary protein or amino acids.

Figure 2.3: <u>The response of egg yield to methionine intake</u>



The response of egg yield to methionine intake. Results from several studies:

+——+ Combs (1964).
×——× Combs (1962).
●——● Bray (1965).
△——△ Present work. Balanced protein series.
▲——▲ Present work. Unbalanced protein series.

Note: "Present work" referred to in Figure 2.3 are the results of Fisher and Morris (1970).

Due to the research effort into corn and soya-bean diets there is little work that has studied the response to isoleucine intake, an amino acid deficient in New Zealand type diets relying on meat meals as a protein source. It is reasonable to assume though that the response to supplementation with the first limiting amino acid will follow the pattern as described by Fisher and Morris (1970).

Scott et al. (1969) used the "efficiency of deposition" of amino acids as the same for egg production as it is for growth. Daily amino acid intakes which will support maximum production for three phases in the laying cycle are then estimated, given an amino acid production from egg yield and tissue growth. These recommendations for high producing White Leghorn hens are given in Table 2.1 (after Scott et al. 1969).

Table 2.1: Amino acid recommendations for laying hens daily requirement (gms.)

Amino acid	Phase I	Phase II	Phase III
Methionine	0.343	0.320	0.290
Lysine	0.670	0.585	0.595
Isoleucine	0.730	0.680	0.603
Valine	0.620	0.523	0.463

These amino acid levels can be met by providing a "minimum" level of dietary protein and supplementing with limiting amino acids or by using high dietary protein levels which will provide adequate supplies of the essential amino acids. In addition a combination of protein sources can be used which will overcome the amino acid deficiencies of individual ingredients.

2.9 Calcium and phosphorus utilization by laying hens

There is a daily calcium output of some two grams by laying hens in the form of egg shell. As the efficiency of calcium absorption is only 50-60 percent the daily intake required to support egg production is somewhat higher than two grams. Scott et al. (1969) have summarised the daily calcium recommendations for different ages of hens at various rates of lay. Their summary is presented in Table 2.2.

Table 2.2: Calcium recommendations for laying hens

Production percent	Dietary calcium per day (grams) Age of hens (weeks) 22-40	 40+
100	3.3	3.7
90	3.0	3.3
80	2.7	3.0
70	2.3	2.6

An increase in egg size during the laying period increases the daily intake of calcium required to support maximum egg production during the later stages of the laying period.

The ratio of calcium to phosphorus may be varied over a range before production responses are noted. An excess of one of the elements retards the absorption of the other. Combs (1964) however found no adverse effect in egg production to the feeding of calcium at 6.8 grams per hen per day. This intake was from a dietary calcium level of 3.66 percent plus free fed grit. When total daily calcium intake was from mash, Combs (1962) found that a daily intake of 4.8 grams per hen had no adverse effect on production.

Scott _et al_. (1969) recommend that the available phosphorus level for laying hens be 0.55 percent of the ration. Large differences exist in the literature as to the phosphorus recommendation. These differences can be explained by environmental temperature, rate of production, duration of the laying period and the strain of layer. Total phosphorus recommendations for layers vary from 0.28 to 0.42 percent (Crowley, 1961) to 0.60 percent (Singsen *et al*. 1961; Marr *et al*. 1961). The inclusion of 0.6 percent of the ration for total phosphorus represents an inclusion of 0.50 to 0.55 percent for available phosphorus. Utilization is affected by the levels of calcium and vitamin D in the diet and the presence of plant source phosphorus.

The wide range of ration inclusion for calcium quoted and the absence of severe toxic effects makes the determination of calcium concentration in the ration of secondary importance to other nutritional factors.

2.10 Factors affecting egg size

The economic importance of egg size under the New Zealand grading system is stressed in the profit function described by Swan (1970). Assuming consistancy in factors such as strain and age of bird the most important nutritional factors affecting egg size are the amino acid adequacy of the diet and the intake of energy and linoleic acid.

Scott *et al*. (1969) state that striking reductions in egg size can be achieved by limiting the linoleic acid intake. Reductions of 20 grams weight per egg have been noticed. It is noted that the main source of linoleic acid in corn soy diets is from yellow corn and added fat. Additions of linoleic acid to barley and wheat diets has increased egg size. Scott <u>et</u> <u>al</u>. thus conclude that barley and wheat diets may be limiting in linoleic acid levels. This may be overcome by supplementation with high fatty acid concentrated fats. Should supplementation take place then care must be taken to avoid rapid oxidation of linoleic acid by exposure to air.

The effect that linoleic acid had on egg weight was originally considered to be an unidentified substance in corn oil. Combs (1961) and Bray (1967) conducted experiments where the positive response in egg weight to corn oil addition was noted. This was considered to be due to an increased caloric intake, since and increase in egg size was not observed when the caloric intake was restricted for birds fed a high corn oil diet. Edwards and Morris (1966) demonstrated that there was an increase in egg size due to an increased maize oil level, independent of energy level.

Shutze and Jensen (1963) identified linoleic acid as the constituent of vegetable oils which increased egg weight. This was confirmed by Menge <u>et</u> <u>al</u>. (1963). Experiments by Childs (1963) and Blamberg (1964) to quantify the linoleic acid requirement have confusing results. A third factor other than caloric and linoleic acid intake was considered to affect egg size. Blamberg speculated that this may be a ratio of saturated to unsaturated fatty acids.

CHAPTER THREE

LAYER NUTRITION TRIAL 32 - EXPERIMENTAL DETAILS

3.1 Aims

Layer Nutrition Trial 32 (LN/32) was designed to study the effects of dietary nutrient concentration upon feed consumption and the production responses of egg number, egg weight and grade and body weight change of three strains of laying hens fed under *ad libitum* conditions.

The experiment was conducted by the Massey University Poultry Research Centre (P.R.C.).

3.2 Experimental design

Five dietary energy concentrations were chosen, each with three dietary protein levels. Three additional treatments plus the control treatment increased the total number to nineteen. The dietary nutrient concentrations chosen are discussed in section 3.5.

The breeding work commitment for the three laying strains used in this experiment necessitated a non-random arrangement of strains in the laying shed used. Treatments were randomly allocated to locations so that all three strains in a given position received the same treatment. Economic considerations determined that each treatment could be replicated only once.

3.3 Materials and methods

The stock used were strain cross White Leghorn pullets from the P.R.C. White Base (a), White Base (b) and M-Line strains.

Pullets were housed in the laying shed at 19 weeks of age (19 April, 1971), one per 11 inch cage, in 3 tiered, 504 cage batteries (Cope and Cope Ltd., England). Twenty-eight birds were assigned per strain with eighty-four per treatment (the cage length of the battery). During the first two weeks of the trial the birds were fed the P.R.C. Random Sample Test ration which was also used as the control ration. The experiment began on May 5, 1971 and ended on March 15, 1972. Hence peak production occurred in the middle of winter and the gradual decline in lay was associated with increasing mean daily temperatures in the shed with the approach of spring and summer.

Dividers were inserted in the feed troughs between each strain so that intake data per strain could be collected for each treatment.

A semi-controlled environment shed was used with no windows. An oil burner was set to operate if the inside temperature dropped to 52°F.

The light pattern was 12 hours per day at housing, increasing to 14 hours per day at 21 weeks. The intensity of light was controlled at 5 lux at the food trough level of the middle row of each battery.

3.4 Preliminary research

At the time LN/32 was being designed (early 1971) there was an increasing supply of stockfeed maize. At the then current prices for available feedstuffs, maize was included in least cost rations formulated to medium (2800 k. cal. M.E. per kg.) and high(3200 k. cal. M.E. per kg.) energy levels.

Although cost per kilogram of feed increases with increasing energy density it is well recognised (Morris, 1968; De Groote, 1972) that daily feed consumption per hen decreases with increasing energy density of the ration. A preliminary economic analysis, based on the assumption of a constant daily *ad libitum* energy intake of 305 k. cal. M.E., suggested that daily feed cost per hen reached a minimum when high energy density rations were fed. This preliminary economic analysis highlighted the fact that, given the then current feed supply and price situation, high energy density rations were of considerably more interest in New Zealand than they had been in the past. Previous to 1971, much of the layer nutrition research in New Zealand had been based on relatively low energy density rations (around 2600 k. cal. M.E. per kg.). Since future price/supply situations could just as easily reverse the position again, this trial was designed to study a wide range of ration energy density levels (2315-3197 k. cal. M.E. per kg.).

As discussed in Chapter Two, nutrient requirements of laying hens are best expressed in terms of daily intake per hen (at various stages of lay). Since it was proposed to study a wide range of energy density levels, and recognising that as a result daily ration intake per hen would vary, it was necessary to consider in as much detail as possible the likely quantitative nature of this relationship before attempting to formulate final rations for this trial. If we consider formulating a ration of energy density 3000 k. cal. M.E. per kg. with an M.E. intake of 305 k. cal. per hen per day and a protein intake of 17 grams per hen per day then over or under-consumption of energy in relation to 305 k. cal. M.E. per day will result in a corresponding over or under-consumption of protein in relation to 17 grams per day.

Previous trials for layers at P.R.C. had used rations in the range 2425-2645 k. cal. M.E. per kg. Hen day metabolisable energy intake on rations with a dietary energy concentration of 2425 k. cal. M.E. per kg. were of the order of 306 k. cal. (Swan, 1970). This compared with the predicted metabolisable energy intake of 305 k. cal. per hen day of Scott *et al*. (1969).

Although it was not considered likely that daily metabolisable energy intake would remain constant over the range of energy densities to be used in this trial, the degree of over or under-consumption that would in fact occur was open to speculation.

Given the limited information relating to voluntary energy consumption levels under New Zealand production conditions, it was decided to base daily intakes of nutrients other than metabolisable energy on the simple assumption: M.E. intake = 305 k. cal. per day. To the extent that over or under consumption of nutrients occurred in relation to daily requirements, the response data would be examined with a view to generating hypotheses about the possible relationships between nutrient intakes and response levels.

Where energy density was considered to be the nutrient most likely to influence feed consumption, crude protein intake was considered most likely to influence layer production. Although Swan (1970) had found no egg production response with relatively high levels of crude protein intake (15.1 to 21.6 grams per hen per day) with a dietary energy density of 2425 k. cal. M.E. per kg., staff at P.R.C. considered that there may be a response to protein when the dietary energy density was increased.

3.5 Ration formulation

Constrained by research resources it was possible to formulate rations for five dietary energy densities (2315, 2535, 2756, 2976, 3197 k. cal. M.E. per kg.)(1) and assuming one level of metabolisable energy intake (305 k. cal.), for three daily protein intake levels (16, 17 and 18 grams). This resulted in fifteen rations to be fed *ad libitum* (Treatments 1-15).

When the range of energy densities was considered it was thought that over consumption of energy (and hence protein and other nutrients) would most likely occur at high energy density levels (Morris, 1967). Although these levels were economically efficient in terms of minimum feed cost per day at an energy intake of 305 k. cal. M.E. per day over consumption might reverse this result. It was thought interesting therefore to limit intake on a higher energy ration so that metabolisable energy intake of 305 k. cal. per day was actually achieved. A comparison of production levels would then enable an investigation of any production

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(1) These correspond to 1050, 1150, 1250, 1350 and 1450 k. cal. M.E. per lb. - the unit of energy concentration commonly in use in New Zealand at the time of ration formulation.

response to "over consumption" of energy and other nutrients. This could be followed by a preliminary investigation of likely economic benefits from restricted feeding of high energy rations. Given the limited experimental resources available, only one ration (3197 k. cal. M.E. per kg., 17 grams protein per day) was fed on this restricted basis (Treatment 16).

The hypothesis was frequently proposed that ingredients (especially protein sources) can be important variables affecting production responses under New Zealand conditions. In order to obtain a small amount of information on this hypothesis, the 3197 k. cal. M.E. per kg., 17 gram protein per day ration was reformulated to least cost after adding the constraints that it should contain a minimum of 1.5 percent buttermilk powder and 10.0 percent pollard (Treatment 17). This ration was also fed on a restricted basis to achieve a daily metabolisable energy intake of 305 k. cal. per bird (Treatment 18).

The P.R.C. Random Sample Test ration (1971), of proven quality, used as the control ration, was also fed _ad libitum_ (Treatment 19).

The dietary energy densities and the daily crude protein intakes to be constrained in the ration formulation have been discussed. These are presented in Table 3.1 and Figure 3.1. For a given nutrient intake, it is a simple matter to express the nutrient intake on a percentage of the ration basis given the dietary M.E. concentration (M) and M.E. intake (E) since daily ration intake (I) is given

Table 3.1: Energy and protein constrains used in ration formulation for LN/32.

Treatment	Ration	M.E. (k. cal./kg.)	Crude protein (gms/hen/day)(4)	Crude protein (% of rations)
1	1	2315	16	12.14
2	2	2315	17	12.90
3	3	2315	18	13.66
4	4	2535	16	13.30
5	5	2535	17	14.13
6	6	2535	18	14.96
7	7	2756	16	14.45
8	8	2756	17	15.36
9	9	2756	18	16.26
10	10	2976	16	15.61
11	11	2976	17	16.59
12	12	2976	18	17.56
13	13	3197	16	16.77
14	14	3197	17	17.81
15	15	3197	18	18.86

Table 3.1 (Contd.).

Treatment	Ration	M.E. (k. cal./kg.)	Crude protein (gms/hen/day)(4)	Crude protein (% of rations)
16	14R(1)	3197	17	17.81
17	14I(2)	3197	17	17.81
18	14IR	3197	17	17.81
19	19(3)	2586	18	15.41

(1) R = restricted intake

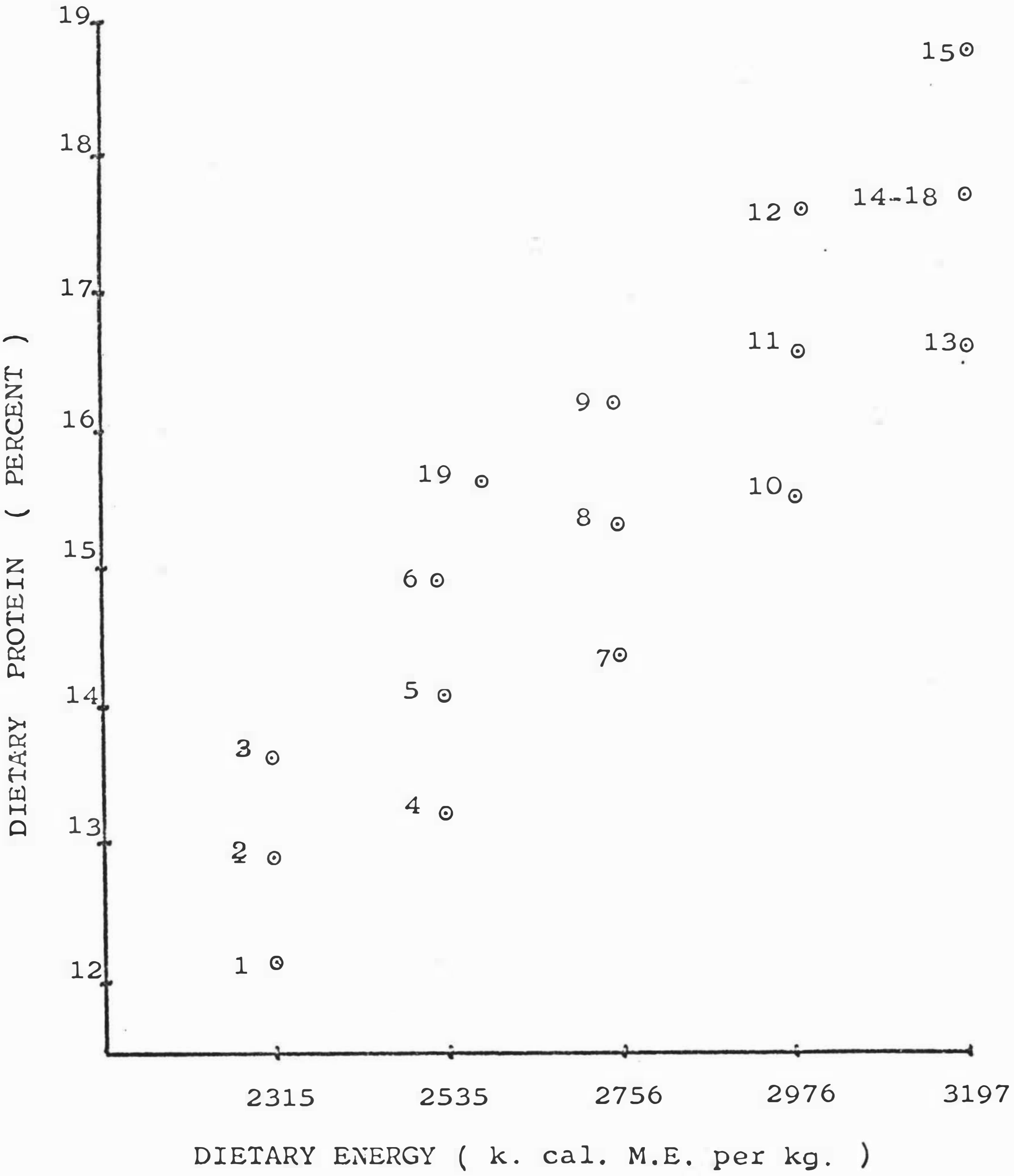
(2) I = ingredient inclusion constrained

(3) CONTROL RATION - not formulated to least cost

(4) Based on an assumed M.E. intake of 305 k. cal./hen/day.

Figure 3.1

DIETARY ENERGY AND PROTEIN LEVELS OF THE TREATMENTS IN LN/32



by:

$$I = \frac{E}{M}$$

Since metabolisable energy intake may not actually equal 305 k. cals. per day and hence nutrient intakes may vary, actual dietary protein percentages are used to describe rations hereafter.

It is recognised that there are other nutrients, apart from energy and protein, which will affect layer performance. The most common of these, calcium and phosphorus, were constrained to levels within the ration such that it was expected that layer performance would not be affected. For all rations calcium was constrained within the range 3.3 to 4.0 grams per hen per day on the basis of 305 k. cal. M.E. intake. Phosphorus was constrained for all rations between 0.60 and 2.0 dietary percent.

Research at P.R.C. had not highlighted any layer response to deficient amino acids in practical New Zealand layer formulations hence amino acid levels were not constrained during ration formulation for LN/32. However, the importance of amino acid intake in layer nutrition is recognised (Chapter Two) and this will be examined with a view to generating hypotheses about the possible relationships between nutrient intakes and response levels.

It has already been stated that ingredients can be important variables in affecting feed consumption and production responses. Ingredient inclusions were constrained to levels recommended by P.R.C. staff. It was thought that pollard and bran inclusion at high levels would decrease the density of the ration to a level where feed consumption would be affected by physiological factors. Ingredients containing uncommon amino acid balances (bloodmeal, livermeal and fishmeal) were restricted so that recommended amino acid balances for layers could be maintained. The inclusion of maize was restricted to a maximum of 65.0 percent because of the limited knowledge of its effect on layer response under New Zealand conditions. Other nutrients were restricted because of the effect they have on yolk colour (lucerne) and feed milling (tallow).

During ration formulation it was noted that when high dietary protein levels were included there was meatmeal inclusion of up to 23 percent. To overcome possible side effects (amino acid imbalance) from reliance on high meatmeal levels for protein, dietary meatmeal inclusion was constrained to a maximum of 18 percent. The complete list of ingredient constraints are contained in Table 3.2.

The feedstuffs considered for inclusion in the rations were those readily available in the Manawatu early in 1971. The nutrient compositions of these feedstuffs were based on analyses carried out by P.R.C. and on established overseas feedstuff analyses. The feedstuffs considered in ration formulation and their nutrient composition are presented in Table 3.3.

All rations, excepting the P.R.C. Random Sample Test ration, were formulated to least-cost using the I.B.M. 1620-1311 Linear Programming System. The results of these formulations are presented in Table 3.4.

Table 3.2: Fixed nutrient and ingredient constrains used in ration formulation for LN/32

Nutrient/Ingredient	Units	Constraint	Value
Calcium	gms/hen/day	Range	3.3-4.0
Phosphorus	%	Range	0.6-2.0
Crude fibre	%	Maximum	8.0
Iodised salt	%	Equality	0.25
Premix	%	Equality	0.25
Meatmeals	%	Maximum	18.0
Bran	%	Maximum	2.0
Lucernemeal	%	Maximum	8.0
Buttermilk powder	%	Maximum	25.0
Pollard	%	Maximum	50.0
Maizemeal	%	Maximum	65.0
Limestone	%	Maximum	6.5
Tallow	%	Maximum	3.0
Fishmeal	%	Maximum	15.0
Bloodmeal	%	Maximum	3.0
Livermeal	%	Maximum	3.0
Molasses	%	Maximum	10.0
Animal protein(1)	%	Minimum	3.0
Pollard	%	Minimum	10.0(2)
Buttermilk powder	%	Minimum	1.5(2)

(1) Animal protein can be contributed to by one or a combination of: meatmeals, meat and bone meals, buttermilk powder, bloodmeal, livermeal and fishmeal.

(2) Only applicable to rations 14I and 14IR.

Table 3.3: Feedstuffs used and their nutrient composition

	Cost/kg (cents)	M.E. (k.cal/kg)	Crude protein (%)	Calcium (%)	Phosphorus (%)	Crude fibre (%)	Ash (%)	Fat (%)
Barleymeal	8.38	2646	11.0	0.3	0.17	2.9	1.6	1.4
Wheatmeal	10.76	3307	11.9	0.04	0.13	2.4	1.5	1.4
Pollard	7.50	2425	15.0	0.15	0.23	5.6	3.8	4.7
Lucernemeal	10.58	1323	19.6	1.43	0.24	14.3	10.2	4.3
Bloodmeal	22.93	2866	79.6	0.28	0.22	3.4	2.5	1.2
Buttermilk powder	23.81	2646	28.9	0.9	0.9	0	6.4	8.8
Livermeal	28.66	2866	75.5	0.3	1.1	1.0	2.9	16.1
Bone Flour	5.29	0	0	27.6	11.9	8	66.7	0.5
Bran	7.50	1323	17.5	0.14	0.33	8.7	4.5	4.75
Molasses	9.35	1984	10.3	9.0	0.2	0	37.3	0.4
Maizemeal	8.71	3527	9.0	0.03	0.1	1.3	1.1	3.6
Fishmeal	18.74	2006	55.0	9.0	5.0	1.0	20.0	4.0
Linseed meal	12.35	1720	32.0	0.4	0.8	9.5	6.0	3.5
Meat and bone meal (Walkers, Hawera)	12.35	2756	45.92	10.5	1.94	2.0	27.5	12.7
Meat and bone meal (Borthwicks)	12.79	2756	50.66	10.33	2.06	2.0	27.5	12.7
Fortified meatmeal (Patea)	14.33	2756	56.17	8.6	1.5	2.0	24.5	12.5

Table 3.3 (Contd.).

	Cost/kg (cents)	M.E. (k.cal/kg)	Crude protein (%)	Calcium (%)	Phosphorus (%)	Crude fibre (3)	Ash (%)	Fat (%)
Meatmeal (Wainaro, Masterton)	13.45	2866	65.0	1.05	0.7	2.5	21.0	8.0
Meatmeal (Whakatu, Hawkes Bay)	17.42	2866	6786	1.05	0.7	2.5	21.0	8.0
Tallow	17.42	7055						96.0
Limestone	15.43			33.0				
Dicalcium phosphate	66.14			24.0	18.0			
Oyster shell	5.84			37.0				
Iodised salt	7.05							
Premix (1)	115.52							

Carophyll red as used in rations 1, 2 and 3 costed 8.828 c/gm.

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(1) The premix analysis is given in Appendix D.

Table 3.4: Summary of the ration composition, nutrient analyses and cost

(All ingredients expressed as a percentage of the ration)

Treatment No.	1	2	3	4	5	6	7	8	9
Ration No.	1	2	3	4	5	6	7	8	9
Pollard	30.05	44.46	50.00	50.00	50.00	50.00	31.44	30.67	29.91
Barleymeal	55.88	43.39	28.86	-	-	-	-	-	-
Maizemeal	-	-	6.27	33.73	32.61	31.50	49.97	49.12	48.28
Wheatmeal	-	-	-	-	-	-	-	-	-
Bran	2.0	0.46	2.00	2.00	1.72	1.38	-	-	-
Buttermilk powder	1.37	-	-	-	-	-	-	-	-
Meatmeal (Wainaro, Masterton)	-	-	3.19	3.71	5.22	6.75	8.06	9.75	11.43
Meat and bonemeal (Walkers, Hawera)	1.63	3.00	-	-	-	-	-	-	-
Meat and bonemeal (Borthwicks)	-	-	-	-	-	-	-	-	-
Bloodmeal	-	-	-	-	-	-	-	-	-
Limestone	5.33	5.13	5.82	6.50	6.50	6.50	6.50	6.50	6.50
Boneflour	3.34	3.06	3.37	3.55	3.45	3.38	3.54	3.46	3.39
Tallow	-	-	-	-	-	-	-	-	-
Iodised salt	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Premix	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Carophyll Red (gms.)	0.25	0.25	0.25	-	-	-	-	-	-

Table 3.4: (Contd.).

(All ingredients expressed as a percentage of the ration)

M.E. (k.cal/kg.)	2315	2315	2315	2535	2535	2535	2756	2756	2756
Crude protein %	12.15	12.9	13.66	13.3	14.13	14.96	14.45	15.36	16.26
Calcium %	3.05	3.05	3.05	3.25	3.24	3.23	3.27	3.26	3.26
Phosphorus	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Crude fibre %	3.5	3.84	4.0	3.53	3.53	3.52	2.64	2.63	2.62
Ash %	5.77	5.17	5.44	5.51	5.73	5.98	5.80	6.06	6.33
Fat %	2.68	3.12	3.39	4.02	4.08	4.14	3.94	4.01	4.07
Cost/kg (c)	8.22	7.97	7.92	7.93	8.01	8.09	8.38	8.48	8.57

Treatment No.	10	11	12	13	14	15	16	17	18	19
Ration No.	10	11	12	13	14	15	14R	14I	14IR	19
Pollard	11.68	10.08	8.50	7.43	5.67	0.55	5.67	10.00	10.00	10.00
Barleymeal	-	-	-	-	-	-	-	-	-	48.00
Maizemeal	65.00	65.00	65.00	65.00	65.00	65.00	65.00	59.85	59.85	20.00
Wheatmeal	-	-	-	-	-	2.67	-	-	-	-
Bran	-	-	-	-	-	-	-	-	-	-
Buttermilk powder	-	-	-	-	-	-	-	1.50	1.50	1.50
Meatmeal (Wainaro, Masterton)	12.32	14.20	16.05	2.13	3.18	7.69	3.18	-	-	-
Meat and Bonemeal (Walkers, Hawera)	-	-	-	-	-	-	-	8.20	8.20	-

Table 3.4: (Contd.).

(All ingredients expressed as a percentage of the ration)										
Meat and bonemeal (Borthwicks)	-	-	-	15.87	14.82	10.31	14.82	13.27	13.27	-
Fortified meatmeal (Patea)	-	-	-	-	-	-	-	-	-	10.00
Bloodmeal	-	-	-	0.48	1.93	3.00	1.93	-	-	-
Limestone	6.29	6.30	6.32	4.12	4.31	5.11	4.31	3.08	3.08	4.00
Boneflour	3.55	3.47	3.39	1.47	1.60	2.16	1.60	0.60	0.60	2.00
Tallow	0.67	0.46	0.24	3.00	3.00	3.00	3.00	3.00	3.00	-
Iodised salt	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Premix	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Lucerne	-	-	-	-	-	-	-	-	-	4.00
M.E. (k.cal/kg.)	2976	2976	2976	3197	3197	3197	3197	3197	3197	2586
Crude protein %	15.61	16.59	17.59	16.77	17.81	18.86	17.81	17.81	17.81	15.41
Calcium %	3.22	3.22	3.22	3.46	3.46	3.46	3.46	3.46	3.46	2.97
Phosphorus %	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.54
Crude fibre %	1.84	1.79	1.75	1.66	1.62	1.46	1.62	1.69	1.69	2.98
Ash %	6.11	6.39	6.67	6.80	6.79	6.74	6.79	7.17	7.17	5.66
Fat %	4.53	4.41	4.27	7.77	7.65	7.25	7.65	8.35	8.35	3.36
Cost/kg (c)	8.90	8.99	9.08	9.61	9.83	10.05	9.83	9.94	9.94	9.20

3.6 Changes in trial design

Examination of egg production figures for the first five months of the laying period of LN/32 showed that production levels on treatments 1, 3, 4, 5 and 6 (Table 3.1) were lower than those for other treatments (see Appendix B, Table B.2). In addition there was a decreased production in month 5 compared with month 4. It was decided to alter the nutrient composition of these rations in the hope of maintaining, or even raising, egg production. Although treatment 2 was performing below the level of treatments on higher energy density rations, it was decided to retain this treatment, to gain some information on layer response to a low energy density ration during the remainder of the laying period.

As the drop in rate of egg lay was causing immediate concern to P.R.C. staff treatments 1, 3, 4, 5 and 6 were allocated rations 7, 9, 7, 8 and 9 respectively for one month beginning September 22, 1971. To correspond a change in rations with the impending monthly feed weighback, it was necessary to feed rations in stock as there was not time to order new formulations. The stocks of rations 7, 8 and 9 determined what could be fed. To try and pin-point the reason for reduced egg production on treatments 1, 3-6, nutrient intakes (Appendix B, Table B4) and ration ingredient inclusions (Table 3.4) were examined(1).

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(1) For a detailed discussion of the analysis of treatments 1-6 for the first 140 days of the laying period and effect of ration reformulation of subsequent production refer to Appendix E.

On the basis of this analysis, it was decided to reformulate rations for treatments 1, 3-6 for the period beginning October 20, 1971, i.e. for the seventh month of the laying period.

Rations were reformulated for treatments 1, 3-6 with the following additional constraints.

(i) Rations of 2315 k. cal. M.E. per kg. were eliminated because of the low intake of nutrients at this energy density.

(ii) Rations formulated to 2535 k. cal. M.E. per kg. had ingredient inclusion constrained:

  (a) Bran was excluded.

  (b) Pollard inclusion was not to be greater than 40 percent.

  (c) Fortified meatmeal (Patea) was to be the only meatmeal source, because of its proven quality in past P.R.C. research.

The reallocation of rations to treatments 1, 3-6 was performed in such a way that some information could be gained on the response to ingredient and/or nutrient changes. The reallocation of nutrient and ingredient constraints for treatment 1, 3-6 is shown in Table 3.5.

(i) Treatment 1 has an increase in energy density from 2315 to 2756(1) k. cal. M.E. per kg.

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(1) As layer performance on rations of 2756 k. cal. M.E. per kg. was considered to be satisfactory it was not necessary to constrain ingredient inclusion as for rations of 2535 k. cal. M.E. per kg.

Table 3.5: Reallocation of nutrient constraints for treatments 1, 3-6.

Treatment	1	3	4	5	6
Ration (May 5-Sept 22)	1	3	4	5	6
Energy (k.cal. M.E./kg.)	2315	2315	2535	2535	2535
Protein intake (gms)	16	18	16	17	18
Protein (percent)	12.15	13.66	13.30	14.13	14.96
Ration (Sept 22-Oct 20)	7	9	7	8	9
Energy (k.cal. M.E./kg.)	2756	2756	2756	2756	2756
Protein intake (gms)	16	18	16	17	18
Protein (percent)	14.45	16.26	14.45	15.36	16.26
Ration (Oct 20-March 15)	23	21	20	24	22
Energy (k.cal. M.E./kg.)	2756	2535	2535	2756	2535
Protein intake (gms)	17	17	16	17	18
Protein (percent)	15.36	14.13	13.30	15.36	14.96

Table 3.6: Summary of ration composition (percent of the ration), nutrient analysis and cost for the new rations specified for treatments 1, 3, 4, 5 and 6.

Treatment No. (May 5-Oct 19)	1	3	4	5	6
Ration (Sept 23-Oct 19)	7	9	7	8	9
Ration/Treatment No. (Oct 20/ March 15)	1'	3'	4'	5'	6'
Pollard	30.67	40.00	40.00	30.67	40.00
Barley meal	-	21.00	20.60	-	21.45
Maizemeal	49.12	23.45	25.05	49.12	21.85
Fortified meatmeal (Patea)	-	6.60	49.50	-	8.25
Meatmeal (Wainaro	9.75	-	-	9.75	-
Limestone	6.50	5.50	5.75	6.50	5.20
Boneflour	3.46	2.95	3.15	3.46	2.75
Iodised salt	0.25	0.25	0.25	0.25	0.25
Premix	0.25	0.25	0.25	0.25	0.25
M.E. (k.cal/kg.)	2756	2535	2535	2756	2535
Crude protein %	15.36	14.13	13.3	15.36	14.96
Calcium %	3.26	3.32	3.32	3.26	3.32
Phosphorus %	0.6	0.6	0.6	0.6	0.6
Crude fibre %	2.63	3.24	3.24	2.63	3.25
Ash %	6.06	5.67	5.42	6.06	5.93
Fat %	4.01	3.86	3.70	4.01	4.01
Cost per kg (c)	8.48	8.29	8.18	8.48	8.41

(ii) Treatment 3 has a single increment in energy density to 2535 k. cal. M.E. per kg.

(iii) The protein intake for treatments 1 and 3 were both set at 17 grams per day (305 k. cal. M.E. per day basis).

(iv) Treatment 4 and 6 were retained at the same energy density and protein intake but the reformulation of rations is subject to the ingredient constraints.

(v) While the intake of protein is retained at 17 grams per day for treatment 5, the energy density is increased to 2756 k. cal. M.E. per kg.

(vi) As ingredient constraints were not superimposed on rations of 2756 k. cal. M.E. per kg. rations formulated for treatments 1 and 5 are identical to ration 8.

Although LN/32 was initially concerned with the effect of dietary nutrient density on feed intake and production responses it was recognised that other dietary factors (ingredient inclusion) may affect production responses (hence the logic treatments 17, 18). The results for treatments 1-6 for the first 140 days of the laying period highlighted the presence of other dietary factors. We have attempted to isolate these factors by constraining nutrient inclusion. Until we isolate these factors we cannot satisfactorily express production responses in terms of nutrient concentration alone.

Should hens on treatments 4 and 6 respond to ingredient changes then we may be satisfied that we have isolated dietary ingredient factors affecting a production response. We can judge the response to treatments 4 and 6 by comparing these treatments with treatment 5 which was placed on a proven ration (8). Similarly we may judge the response of treatment 3 to a change in ration nutrient and ingredient inclusion by comparing this treatment with treatment 1 also placed on a proven ration (8). Should we be satisfied that treatments 1, 3-6 have responded to the dietary nutrient and ingredient change then we may use these treatments when expressing production responses in terms of the dietary nutrient density after October 20. Rations reformulated for treatments 1, 3-6 are presented in Table 3.6 together with their cost and nutrient analysis. For the period October 20, 1971 until the end of the laying period, treatments 1, 3-6 will be known as treatments 1', 3'-6' respectively.

3.7 Measurements

3.7.1 Body weight

Hens were weighed individually at 21 weeks and 56 weeks of age to provide information on weight gain during the laying period. Weight gain was not available for hens which did not survive the total laying period.

3.7.2 Feed consumption

Hens were fed three times weekly on an ad libitum basis. For treatments 16 and 18, the food was initially weighed so that birds would receive 305 k. cal. M.E. per bird per day. Early indications showed that egg production was suffering at this intake level and adjustments were made so that energy consumption increased to 315-320 k. cal. M.E. per bird per day.

At the end of each 28 day period, refusals were weighed back and 28-day food consumption calculated. From this, 28 day nutrient intakes could be estimated.

3.7.3 Mortality

All deaths or obviously sick hens were recorded and sent to Wallaceville for diagnosis.

3.7.4 Egg number

Each cage was equipped with a moveable counter which recorded individual hen production for a 14 day period. This record was transferred to master cards every 14 days and the counter zeroed.

3.7.5 Egg weight and grading

A single days egg collection (taken on the 14th day of each intake and egg production period) was weighed and graded. From this, the months average egg weight and grade was established. The total egg weight and eggs within each grade per month were estimated with reference to the monthly egg production.

3.8 Experimental results

As LN/32 was designed in an endeavour to quantify the physical input/output relationships of layer production the analysis of data includes production function estimations. The input/output relationships that are of direct interest to the economist are those that predict the responses that are included in the economic model. Swan (1970) has presented an economic model which can be used for layer production under New Zealand conditions. Although this model can be used for any length of laying period this study is primarily interested in its application to the total laying period. For hens fed under ad libitum conditions we are limited to the results obtained from treatments 7-15, 17, 19 in LN/32. Results applicable to the estimation of production functions for the total laying period are presented in Tables 3.7-3.15. Production function estimation for the dependent variables included in the economic model for the total laying period is analysed in Chapter Five. The problems associated with production function estimation are discussed in Chapter Four. Once the production functions have been estimated it will be possible to analyse our economic model (Chapter Six).

Included in LN/32 were treatments 16, 17 and 18 to study the effect of feed restriction and ingredient changes on ration 14. An analysis of these treatments will be presented in Chapter Seven.

Although LN/32 was not designed to study the effect of phase feeding (changing the nutrient content of the ration throughout the laying period) it will be possible to analyse the results of LN/32 for two periods within the total laying period.

Table 3.7: H.D. food consumption per bird per day for each treatment strain for the total 315 days of the laying period.

Treatment	Ration	M.E. (k.cal./kg.)	C.P. (%)	Consumption (gms/day) strain		
				W.B.(a)	W.B.(b)	M.L.
1	+	+	+	116.3	123.4	124.3
2	2	2315	12.9	127.6	131.3	126.4
3	+	+	+	115.9	134.9	123.1
4	+	+	+	122.2	123.5	127.6
5	+	+	+	111.0	118.1	118.6
6	+	+	+	133.4	126.0	128.4
7	7	2756	14.45	115.6	114.6	117.6
8	8	2756	15.36	118.5	122.3	118.0
9	9	2756	16.26	117.1	117.8	125.3
10	10	2976	15.61	112.0	110.6	115.6
11	11	2976	16.59	109.7	116.2	116.1
12	12	2976	17.59	105.8	122.1	113.8
13	13	3197	16.77	100.2	103.9	111.8
14	14	3197	17.81	116.1	116.1	113.4
15	15	3197	18.86	103.0	112.2	111.3
16	14R	3197	17.81	97.2	103.2	101.3
17	14I	3197	17.81	101.2	115.7	111.3
18	14IR	3197	17.81	97.4	99.9	99.1
19	19	2586	15.41	106.0	121.7	115.9

+ Ration changes after 140 days resulted in a change in energy and protein concentration.

Table 3.8: H.D. egg number per bird for each treatment strain for the total 315 day laying period

Treatment	Ration	M.E. (k.cal./kg.)	C.P. (%)	H.D. egg number strain W.B.(a)	W.B.(b)	M.L.
1	+	+	+	176.53	166.31	200.53
2	2	2315	12.90	173.30	183.00	180.39
3	+	+	+	179.13	193.76	193.36
4	+	+	+	177.89	181.50	211.23
5	+	+	+	188.18	158.87	198.23
6	+	+	+	189.93	180.89	200.44
7	7	2756	14.45	183.36	183.93	219.18
8	8	2756	15.36	198.91	198.18	205.50
9	9	2756	16.26	176.99	193.25	201.39
10	10	2976	15.61	200.73	201.42	223.46
11	11	2976	16.59	178.14	205.15	221.18
12	12	2976	17.59	218.50	220.49	209.40
13	13	3197	16.77	194.40	186.56	220.68
14	14	3197	17.81	216.57	207.42	216.94
15	15	3197	18.86	188.21	209.12	226.12
16	14R	3197	17.81	180.53	180.62	225.55
17	14I	3197	17.81	200.03	206.32	214.74
18	14IR	3197	17.81	177.89	199.68	210.99
19	19	2586	15.41	190.11	184.11	219.43

Table 3.9: H.D. percentage egg number for each treatment strain for the total 315 day laying period

Treatment	Ration	W.B.(a)	Strain W.B.(b)	M. Line
1	+	56.04	52.80	63.66
2	2	55.02	58.10	57.27
3	+	56.87	61.51	61.38
4	+	56.47	57.65	67.06
5	+	59.74	50.44	62.93
6	+	60.30	57.43	63.63
7	7	58.21	58.39	65.58
8	8	63.15	62.91	65.24
9	9	56.19	61.35	63.94
10	10	63.72	63.94	70.94
11	11	56.55	65.13	70.22
12	12	69.37	70.00	66.48
13	13	61.73	59.23	70.06
14	14	68.75	65.85	68.87
15	15	59.75	66.39	71.79
16	14R	57.31	57.34	71.60
17	14I	63.50	65.50	68.17
18	14IR	56.47	63.39	66.98
19	19	60.35	58.45	69.66

Table 3.10: Average egg weight per strain per treatment for the 315 day laying period (grams)

Treatment	Ration		Strain	
		W.B.(a)	W.B.(b)	M.Line
1	+	53.62	55.44	55.08
2	2	53.18	55.63	54.94
3	+	53.33	54.62	53.08
4	+	56.93	56.11	54.68
5	+	54.01	55.40	54.46
6	+	56.69	58.50	54.49
7	7	56.23	55.50	53.43
8	8	53.96	56.66	52.66
9	9	55.08	55.43	54.00
10	10	55.66	57.54	55.48
11	11	53.86	57.38	53.95
12	12	54.19	55.09	53.85
13	13	52.88	57.63	55.20
14	14	55.29	58.54	54.49
15	15	57.64	55.75	52.31
16	14R	53.33	54.52	52.64
17	14I	54.09	58.06	54.30
18	14IR	54.67	56.55	52.23
19	19	55.64	56.36	54.55

Table 3.11: Egg grades for the period 1-315 days (by treatment strains)

Treatment	Large	Standard	Medium	Pullet	Other(1)
White base (a)					
1	11.59	56.34	25.57	5.41	1.09
2	7.56	50.85	38.27	3.32	-
3	6.75	64.24	23.79	4.53	0.69
4	22.98	64.06	10.40	1.22	1.43
5	8.84	57.54	30.56	1.83	1.23
6	16.02	66.65	12.24	1.48	3.61
7	23.73	58.51	13.43	2.57	1.76
8	10.64	56.84	25.40	4.75	1.77
9	14.12	61.33	22.88	1.67	-
10	16.93	54.46	23.03	3.43	2.15
11	8.69	66.34	20.29	3.58	1.09
12	5.26	70.76	21.17	2.32	0.49
13	5.77	59.43	31.25	3.56	-
14	10.91	61.52	22.40	3.79	1.37
15	25.18	61.91	11.06	1.23	0.61
16	7.66	63.54	21.88	5.38	1.56
17	7.69	61.09	28.02	2.63	0.56
18	14.15	62.54	19.13	3.69	0.48
19	16.39	63.31	18.07	1.73	0.51
Average	12.68	61.12	22.04	3.06	1.10
White base (b)					
1	12.59	63.14	20.97	3.30	-
2	18.92	49.82	26.72	4.06	0.49
3	11.71	59.56	22.49	4.23	2.00
4	22.52	56.45	17.35	2.38	1.30
5	23.17	49.95	23.01	3.87	-
6	30.19	57.30	10.05	0.79	1.80
7	17.80	56.13	21.70	3.26	1.11
8	14.29	60.81	23.56	1.34	-
9	18.65	58.20	18.19	2.61	2.37
10	23.11	61.15	13.29	1.46	0.98
11	26.60	63.00	8.87	2.19	1.09
12	15.81	59.14	22.10	2.95	-
13	18.49	61.55	17.07	2.89	-

Table 3.11: (Contd.).

Treatment	Large	Standard	Medium	Pullet	Other(1)
14	33.06	53.11	9.79	0.66	3.38
15	20.68	58.49	17.48	1.86	1.50
16	15.98	57.66	22.51	2.51	1.35
17	27.36	55.79	13.91	2.45	0.52
18	21.15	65.37	9.33	2.41	1.15
19	22.68	59.17	14.01	2.48	1.67
Average	20.78	58.20	17.49	2.51	1.02
M. Line					
1	16.21	59.27	18.23	3.96	1.64
2	17.46	42.45	37.06	1.68	1.35
3	8.85	53.29	29.09	1.97	1.00
4	19.62	57.90	18.40	3.67	0.41
5	7.28	62.71	23.52	5.22	1.24
6	3.46	65.43	24.94	4.29	1.88
7	6.47	54.46	33.79	4.21	1.05
8	7.04	49.58	39.71	3.13	0.54
9	10.54	58.22	23.56	4.69	2.99
10	13.05	60.32	21.93	1.88	2.82
11	6.94	61.59	24.69	3.52	3.26
12	13.21	64.37	20.25	1.74	0.43
13	11.33	66.71	20.60	0.89	0.47
14	13.35	53.91	30.35	0.97	1.41
15	5.68	54.30	30.61	5.19	4.22
16	5.00	54.96	33.41	3.27	3.36
17	8.98	57.07	29.07	3.63	1.24
18	5.53	59.42	30.22	4.83	-
19	8.97	67.58	19.63	2.36	1.47
Average	9.95	58.08	26.83	3.22	1.92

(1) Other: Includes all eggs that were broken, cracked, dirty, soft shelled or undersize.

Table 3.12: Initial body weight (grams(1) per hen liveweight)

Treatment	White base (a)	White base (b)	M. Line
		Strain	
1	1433	1569	1547
2	1474	1501	1438
3	1325	1637	1569
4	1538	1610	1551
5	1411	1529	1315
6	1574	1610	1420
7	1424	1483	1365
8	1492	1515	1411
9	1492	1628	1506
10	1492	1442	1420
11	1379	1501	1479
12	1411	1642	1569
13	1315	1501	1438
14	1547	1489	1433
15	1492	1678	1569
16	1388	1465	1397
17	1452	1656	1447
18	1361	1510	1488
19	1379	1579	1438

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(1) Hens were weighed in pounds per hen, to two decimal places, and the conversion to grams was made.

Table 3.13: Liveweight gain per hen (grams per hen per 315 days).

Treatment	Strain White base (a)	White base (b)	M. Line
1	435	635	340
2	354	458	281
3	327	658	354
4	485	481	354
5	320	513	381
6	523	472	417
7	444	553	344
8	390	571	362
9	458	408	317
10	698	717	589
11	653	798	462
12	303	589	435
13	535	721	548
14	752	879	449
15	703	793	467
16	640	1070	685
17	557	984	589
18	699	764	472
19	430	775	489

Table 3.14: Mortality

	Strain		
Treatment	White base (a)	White base (b)	M. Line
1	1	1	1
2	1	2	0
3	1	6	2
4	1	1	2
5	1	3	3
6	3	0	1
7	3	1	3
8	1	2	0
9	1	0	2
10	2	1	1
11	3	1	0
12	0	2	1
13	1	8	0
14	2	3	1
15	3	2	1
16	0	2	4
17	4	2	1
18	0	1	3
19	1	0	0
Total	29	38	26
Percentage	5.45	7.14	4.89

Table 3.15: Daily nutrient intake per hen for the total laying period (for treatments 7-15)

Treatment	M.E. (k.cals.)	C.P. (grams)	Calcium (grams)	Methionine (gms)	Isoleucine (gms)	Lysine (gms)
7	319	16.76	3.79	0.259	0.545	0.619
8	329	18.38	3.90	0.287	0.600	0.688
9	331	19.52	3.91	0.308	0.640	0.741
10	335	17.61	3.63	0.298	0.606	0.657
11	339	18.94	3.68	0.323	0.654	0.716
12	338	20.04	3.67	0.344	0.692	0.764
13	337	17.69	3.65	0.249	0.511	0.682
14	368	20.53	3.99	0.292	0.585	0.850
15	348	20.55	3.77	0.311	0.598	0.887
16	321	17.91	3.48	0.255	0.510	0.741
17	349	19.51	3.79	0.286	0.631	0.849
18	316	17.61	3.42	0.258	0.569	0.767
19	296	17.67	3.41	0.235	0.631	0.804

(i) Analysis of the data for the first 140 days of the laying period for those treatments fed _ad libitum_ whose performance was judged as satisfactory.

(ii) Analysis of the data for the final 168 days of the laying period for those treatments fed _ad libitum_ whose performance was judged as satisfactory.

The analysis of these two periods will include production function estimations to determine what variables are responsible for affecting a change in layer production responses. By a comparison of these models with those for 1-315 days it will be possible to hypothesise on the effect of different nutrients on layer production at different stages in the laying cycle. This analysis will also be presented in Chapter Seven.

Experimental results for LN/32 for the first 140 days of the laying cycle are presented in Appendix B which also contains the results relevant to the final 168 days of the laying period.

3.8.1 Results 1-315 days

Experimental results from LN/32 for the total 315 days laying period are presented here. These results are presented on a hen day basis(1).

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(1) One hen day is allocated for every day that each hen lives. Therefore hen day production equals total eggs laid, divided by the total hen days.

CHAPTER FOUR

DATA ANALYSIS, ESTIMATION PROCEDURES AND PROBLEMS

4.1 Introduction

It is assumed that the biological relationships we are interested in quantifying can be expressed in the form of a model (usually mathematical). The mathematical model of the relationships in biological systems consists of a set of equations known as production functions. These equations express the interdependencies among defined variables within the production process.

The expected value of one variable (output) is defined as a function of the observed values of other variables. This is commonly expressed:

$$E(Y) = f(X_1, X_2, \ldots, X_n)$$

Where E (Y) is the expected value of the output, for given levels of the variables $X_1, X_2, \ldots, X_n$.

Estimation of the production function has usually been by the single equation approach. The methodology for this is contained in the technique of least squares multiple regression. Implicit in the application of multiple regression is a knowledge of the form of the production function and the variables which constitute the relationship, as well as other assumptions discussed in Section 4.4.

4.2 Specification of the model

The initial problem is one of specification of the model which most adequately expresses the relationships with which the researcher is concerned. In biological processes there exists an understanding (either complete or incomplete) of the physical and biological logic underlying a production relationship. The more complete the knowledge of the system, the greater ability the researcher has in formulating a mathematical model to adequately express the production relationships. Formulation of the model involves two considerations:

(i) Choice of the algebraic form of the model
(ii) Choice of the variables to be included within the model.

Appropriate algebraic forms can initially be postulated by the pure researcher whose understanding of the system is more complete than that of the applied researcher. Not only will previous experimentation be of use in the formulation of the type of model to be specified but a guide may be given as to the variables which most adequately express the production process. Care must be taken to include all relevant variables to avoid bias in fitting the model. The models chosen must be consistent with physical and biological logic. However, when knowledge of the production relationships is incomplete it may be necessary to decide the relevant variables by trial and error.

The nutritional relationships of feed intake and egg-production of the laying hen have been discussed in Chapter Two. This knowledge will be used in selecting the particular form of, and variables to be included in, the production functions to be estimated.

4.3 Analysis of variance

As a first step in analysing the data, we can postpone the matter of the appropriate functional model (production function) and subject the data to a classification model (analysis of variance). This will help us to:

(1) determine any treatment differences in the dependent variable.

(2) explore the general nature of the interrelationships which might account for this variation.

The experimental design of LN/32 can be treated as a systematic split-plot (Cochrane and Cox, 1957). In this case, whole plot treatments (rations) were randomly assigned to rows of a battery within the laying shed. Within each treatment (and row) strains of birds (split-plot treatments) were systematically assigned to cages 1-28, 29-56, 57-84.

Consider the general form of the analysis of variance for five energy concentrations by three protein intakes (5 x 3) as a whole-plot treatments and three strains of layer as split-plot treatments, without treatment replication. The appropriate analysis of variance is presented in Table 4.1.

In the absence of treatment replication we are unable to estimate whole-plot or split-plot error variance without additional assumptions. If we were to assume that the Energy x Protein interaction is zero, then the mean square associated with this source of variation in the analysis of variance would estimate the whole-plot error variance and could be used for tests of significance about differences in Energy and Protein levels. If, in fact, Energy x Protein interaction does not equal zero, the error mean square will over estimate the whole-plot error variance, thus underestimating the value of the F-statistic. In this situation differences that are judged significant are not a problem. Differences that are judged to be not significant at say the ten percent level ($p > 0.10$), may in fact be significant at this level given an unbiased estimate of error variance.

Table 4.1: Analysis of variance

Source of variation		d.f.
Mean		1
Whole-plot treatments		14
Energy levels	4	
Protein levels	2	
Energy x protein	8	
Split-plot treatments (strains)		2
Strain x whole plot interactions		28
Strain x Energy	8	
Strain x Protein	4	
Strain x Energy x Protein	16	
TOTAL		45

If we were to assume that the Strain x Energy x Protein interaction is zero, the mean square associated with this source of variation in the analysis of variance would estimate the split-plot error variance. Since split-plot treatments (strains) are systematic in this experiment, we do not have a valid test of significance for strain differences. However, given an independent estimate of the split-plot error variance we could test for Strain x Energy and Strain x Protein interactions (Cochrane and Cox, 1957). As for the whole-plot case, should the Strain x Energy x Protein interaction not equal zero, then the appropriate F-statistic will be overestimated and significance levels will also be over estimated (differences "significant" at the ten percent level may in fact be significant at the five percent level).

4.4 Estimation procedure

Least Squares multiple regression is an appropriate method of estimating the single equation model. Conditional upon certain assumptions holding true, there are situations when Least Squares yields the best and unbiased prediction of the expected value of the dependent variable E(Y) and also the best unbiased linear estimates of the regression coefficients. These assumptions are:

(i) the expected value of the error is zero
(ii) the covariance between the error associated with one value of Y and that associated with any other value of Y is zero
(iii) the variance of the error associated with one value of Y is the same as the variance of the error associated with any other value of Y
(iv) the covariance between the error and each of the independent variables is zero

(v) the observations of the independent variables are measured without error.

If we are interested in predicting Y, and we are not concerned with the properties of the estimated parameters of the regression equation, then Least Squares may be appropriate even though some of these assumptions are violated.

4.5 Goodness of fit

We require a measure of how closely the predicted series coincides with observed values of the dependent variable. This is known as the "goodness of fit" of the estimated regression equation (Heady and Dillon, 1961).

The percentage of the variation in the n observed values of Y that is explained by the fitted regression equation is known as the coefficient of multiple determination, R^2. Hence, R^2 is defined as the ratio:

$$\frac{\text{Variance of observed values - Variance of residuals}}{\text{Variance of observed values}}$$

The R^2 is of use in choosing between alternative single equation models of a production process in the absence of strong *a priori* evidence as to what form the model should take.

In two cases there is a tendency for R^2 to be overestimated:

(1) When there is a large number of parameters (k) to be estimated

(2) When the number of observation sets (n) is small.

In these cases a "corrected" coefficient of multiple determination, R^2, may be used, where

$$\bar{R}^2 = 1(1-R^2)(\frac{n-1}{n-k})$$

4.6 Testing forms of the production function

Often the incomplete knowledge of biological systems makes description of the process under study difficult. Not only is the form of the function subject to debate but so also are the variables included within it. Statistical tests of significance can be used as an aid in deciding the function which describes the production process most adequately.

When there is replication of treatments an analysis of variance will produce an estimate of the experimental error. Least Squares regression minimises the sums of squared deviations between the observed Y values and the estimated values $\hat{Y}$. The treatment sums of squares will be divided into sums of square due to the regression and deviations of the treatment means from the regression (lack of fit) sums of squares as shown in Table 4.2 (Heady and Dillon, 1961).

Experimental designs containing no treatment replication require special attention. In the absence of replication it may not be possible to obtain an estimate of the experimental error. If similar research has been analysed, an a priori estimate of the error can be substituted (Heady and Dillon, 1961). In its absence it is not possible to compare functions for their "goodness of fit" because it is not possible to differentiate between experimental error and deviations from regression attributable to the function being tested.

Table 4.2: Analysis of variance for multiple regression based on a replicated experiment

Source of variation	d.f.
Replications	r-1
Treatments	t-1
Regression	k
Deviations from regression	t-k-1
Experimental error	(t-1)(r-1)
TOTAL	tr-1

The absence of replication in LN/32 precluded an estimate of experimental error hence deviations from regression cannot be subdivided to obtain error sums of squares. Despite this, an attempt can be made to analyse various functions.

When various functional forms are estimated there is consistency in total, replicate, treatment and error mean squares. Changes only occur in regression and lack of fit mean squares.

The standard analysis of variance can be used to compare two regression equations. The test used between the two regressions is then:

$$\frac{\frac{\text{R.S.S.1} - \text{R.S.S.2}}{\text{d.f.}}}{\text{E.M.S.}_1} = \frac{\frac{(\text{T.S.S.} - \text{E.S.S.})_1 - (\text{T.S.S.} - \text{E.S.S.})_2}{\text{d.f.}}}{\text{E.M.S.}_1}$$

$$= \frac{\frac{\text{E.S.S.}_2 - \text{E.S.S.}_1}{\text{d.f.}}}{\text{E.M.S.}_1}$$

This statistic follows the F distribution with d.f.$_1$ (difference) and d.f.$_2$ (E.M.S.).

In the absence of replication there is no error term hence the error sums of squares is included in the deviation sums of squares. From this:

$$\frac{\text{DEVIATION S.S.}}{\text{ERROR S.S.}} > 1$$

When treatment sums of squares are divided into sums of squares due to each individual regression and sums of squares due to the difference we know

$$\frac{\text{Difference M.S.}}{\text{Deviation M.S.}} < \frac{\text{Difference M.S.}}{\text{Error M.S.}}$$

The F distribution is such that the use of Difference M.S./Deviation M.S. as the test statistic will "underestimate" the significance of the test.

In the absence of degrees of freedom associated with the difference between regression sums of squares the analysis of variance as outlined is invalid as there is no test statistic. An analysis of variance can be computed for each regression to test whether the regression is "satisfactory". There is limited use for this test because of the absence of an estimate of what is "satisfactory".

The only statistical analysis of regressions applicable to the design of LN/32 is one of "ranking" using the error mean square of each regression as the test statistic for comparison. The regressions can be "ranked" for their individual "goodness of fit", but an estimation of which are satisfactory is an arbitrary judgement.

4.7 Multicollinearity

In the single equation model, multicollinearity is when two or more of the independent variables are so highly correlated that there exists one or more linear relationships between some or all of the independent variables. It is possible in this study, that due to the linear relationship between protein intake and dietary energy concentration that there will be a high correlation between the two.

The inclusion of variables into a model must be consistent with nutritional theory. Should any of these variables be highly correlated then multicollinearity exists. Should two independent variables be perfectly correlated then the value of their partial regression coefficients could be anywhere between $+\infty$ and $-\infty$ provided an adjustment is made to the other coefficient. Should a model contain two or more highly correlated variables then the estimates of their structural coefficients should be treated with caution (Heady and Dillon , 1961).

Multicollinearity does not reduce the predictive power of the regression equation, but this equation may only be of use if the structural coefficients are correct.

Before we become concerned with the effect of multicollinearity in our regression analysis we will analyse the regression equations with respect to their "goodness of fit". Should the equations whose "goodness of fit" is best, not contain highly correlated variables ($r = 0.8$) then we do not have a problem of multicollinearity (Heady and Dillon, 1961).

Should we decide that multicollinearity is present between two or more of the independent variables we are posed with the question of which variable (s) to omit from the regression analysis. The dropping of one of two highly correlated variables results in the effect of the omitted variable being "credited" to the remaining variable. The variable that is to be omitted will depend on the nature of the model we are interested in.

4.8 General nature of the production model

We can describe any ration (input to a production process) in terms of nutrient composition and qualitative factors (such as palatability and density).

The vector

$$(X_1, \ldots, X_m; q_1, \ldots, q_r)$$

completely describes the ration where X_d is the level of the d^{th} nutrient in the ration and q_k is the k^{th} qualitative factor in the ration.

If we feed any ration ad libitum to laying birds, (say from the start of lay) with given physiological characteristics, we can observe production responses (Y) and total feed consumption (I) for some production period (t).

In layer production we are concerned with a number of production response functions. For example, Y would be a vector of response variables : egg number, egg weight (grade distribution), and liveweight change of birds during the production period. This model corresponds closely to that of Townsley (1969).

Assume that for any given nutrient specification the qualitative factors are constrained so that these do not adversely affect the production responses.. We assume that the constraints on the qualitative factors can be written as linear functions of the individual feedstuffs in the ration. Given these constraints on the levels of individual feedstuffs in the ration (as discussed in Chapter Three), rations can be described by the vector of nutrient levels:

$$(X_1, \ldots, X_m)$$

We can now write the model describing the production responses (Y) and feed consumption (I) for given birds for some production period (t), as

$$Y_k = Y_k \, (x_1, \ldots, x_m \; ; \; v_1, \ldots, v_n \; ; \; t) \qquad (4.1)$$

where the k^{th} production response (Y) is a function of nutrient intake ($x_1, \ldots, x_m$), and physiological characteristics ($v_1, \ldots, v_n$) during the t^{th} production period.

$$I = I\ (X_1, \ldots, X_m\ ;\ v_1, \ldots, v_n\ ;\ t) \tag{4.2}$$

where feed consumption (I) is a function of the nutrient concentrations ($X_1, \ldots, X_m$) and physiological characteristics ($v_1, \ldots, v_n$) during the t^{th} production period.

The vector ($v_1, \ldots, v_n$) describes the physiological characteristics of the bird such as strain and weight.

In equation (4.1) the intake of the d^{th} nutrient (x_d) is a function of the feed intake (I) and dietary nutrient concentration (X_d).

$$x_d = X_d . I \tag{4.3}$$

Taken together, equations (4.1), (4.2) and (4.3) will be called Model I.

Substituting for x_d in (4.1), as defined in (4.3) we obtain:

$$Y_k = Y_k\ (X_1 I, \ldots, X_m I\ ;\ v_1, \ldots, v_n\ ;\ t) \tag{4.4}$$

and since I is a function of

$$(x_1, \ldots, X_m),\ (v_1, \ldots v_n)$$

and t, we have

$$Y_k = Y_k'\ (X_1, \ldots, X_m\ ;\ v_1, \ldots, v_n\ ;\ t) \quad (4.5$$

$$I = I\ (X_1, \ldots, X_m\ ;\ v_1, \ldots, v_n\ ;\ t) \tag{4.6}$$

Equations (4.5) and (4.6) constitute Model II.

Although Model I is in the form consistent with nutritional theory, since x_d is a random variable under ad libitum feeding one cannot obtain unbiased or consistent estimates for the parameters of equation (4.1) by applying Least Squares to the observed x_d values. In this situation one must either use methods such as Two-stage Least Squares to estimate (4.1) or simply estimate the reduced form of Model I, that is, estimate Model II. This is recognised in a statement made by Tonkinson et al. (1968),

> "... if there is some direct effect of the dietary level of the dietary factors upon production responses, then it would be invalid from a statistical standpoint to study actual nutrient intake in relation to production responses, independent of the dietary level of the dietary factors."

Battese et al. (1968) criticise production functions that are not expressed in terms of the experimentally controlled variables. They point out that using the actual quantities of nutrients consumed as "independent" variables in the regression analysis leads to simultaneous equations bias in parameter estimates. Valid estimations of the response functions must use "independent" variables which, in our case, are "predicted nutrient intake" (Model I by Two-Stage Least Squares) or nutrient concentrations (Model II).

The actual estimation method used will depend on whether or not equation (4.1) is just identified and whether one wishes to estimate the parameters of equation (4.1) or simply predict production response levels as a function of the independent variables that appear in the reduced form equations. In addition we should note that the mathematical form of the reduced form equation (4.5) is governed by the mathematical form of equations (4.1) and (4.2). For an example see Appendix F.

As far as the economic analysis is concerned it does not matter whether we specify rations in terms of nutrient levels in the rations or in terms of (daily) intake of nutrients by the birds as controlled by the ad libitum intake function. We therefore have a choice between Models I and II. It is apparent that, at least in this study, the reduced form equation may be relatively complex (Appendix F) and because of the relatively simple nature of the experiment (few treatments, lack of replication) preference has been given to estimating the structural equation (4.1) by Two-Stage Least Squares rather than estimating the reduced form equation by ordinary Least Squares.

CHAPTER FIVE

PRODUCTION FUNCTION ANALYSIS FOR THE TOTAL LAYING PERIOD

5.1 Introduction

Swan (1970) identified the production response variables of interest in the economic model:

N_j = total number of eggs laid on the j^{th} ration

G_{ij} = proportion of eggs laid in the i^{th} grade for the j^{th} ration

I_j = feed intake on the j^{th} ration

ΔW_j = weight change on the j^{th} ration.

We are therefore interested in estimating response functions for these variables from LN/32. Since LN/32 primarily involved the use of rations over the total period of lay (45 weeks), estimated production functions must relate to this period.

5.2 Feed consumption

Feed consumption for the total laying period for treatments 7-15, 17, 19 are graphed against the dietary energy concentration for each strain of laying hen in Figure 5.1(1). It can be seen that feed intake is reduced as the dietary energy concentration is increased. This reduction

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(1) In Figures 5.1, 5.2, 5.3, 5.9, 5.10, the graphs subscripted 1, 2, 3 correspond to the low, medium and high protein treatments respectively.

Figure 5.1

FEED CONSUMPTION VS DIETARY ENERGY CONCENTRATION

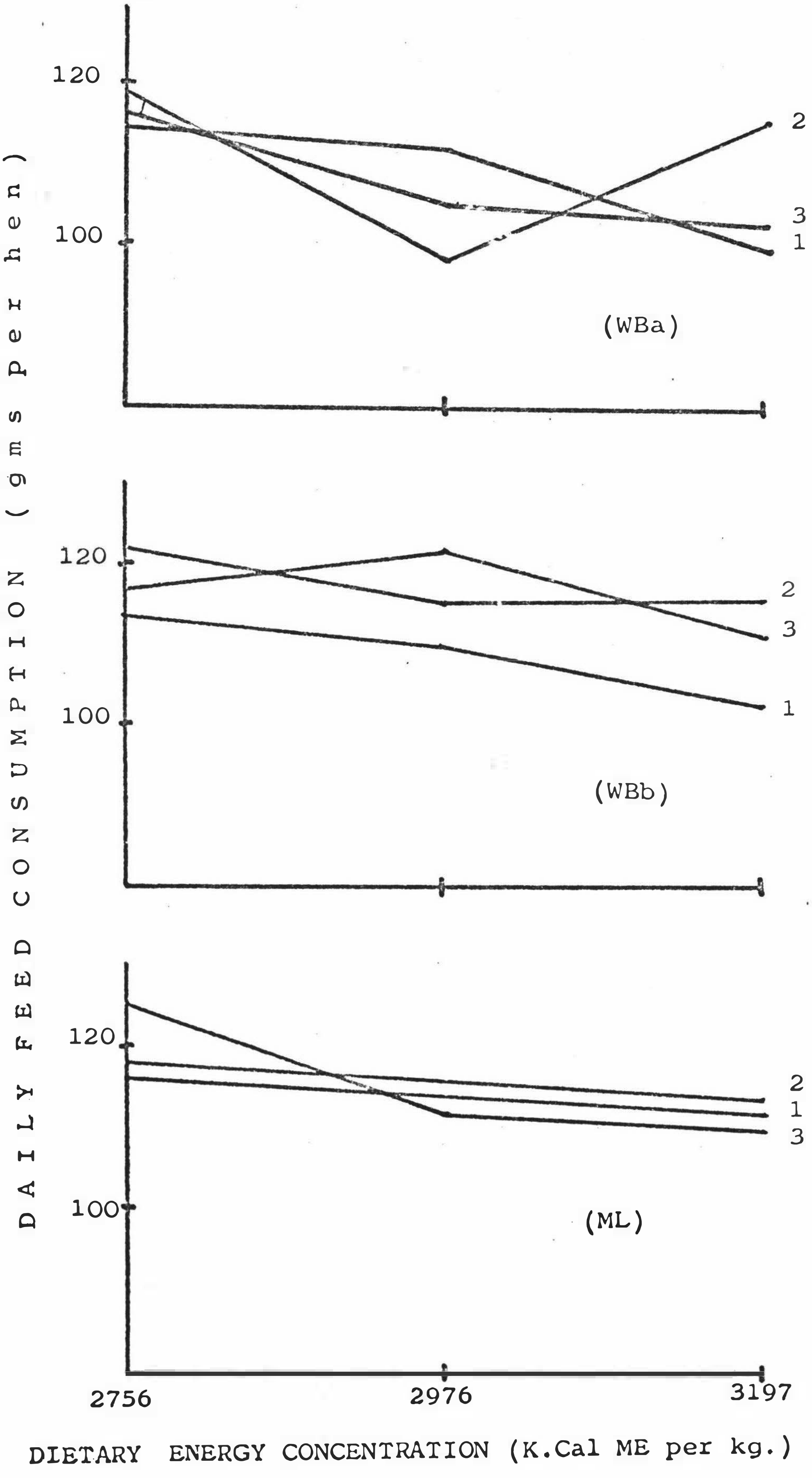
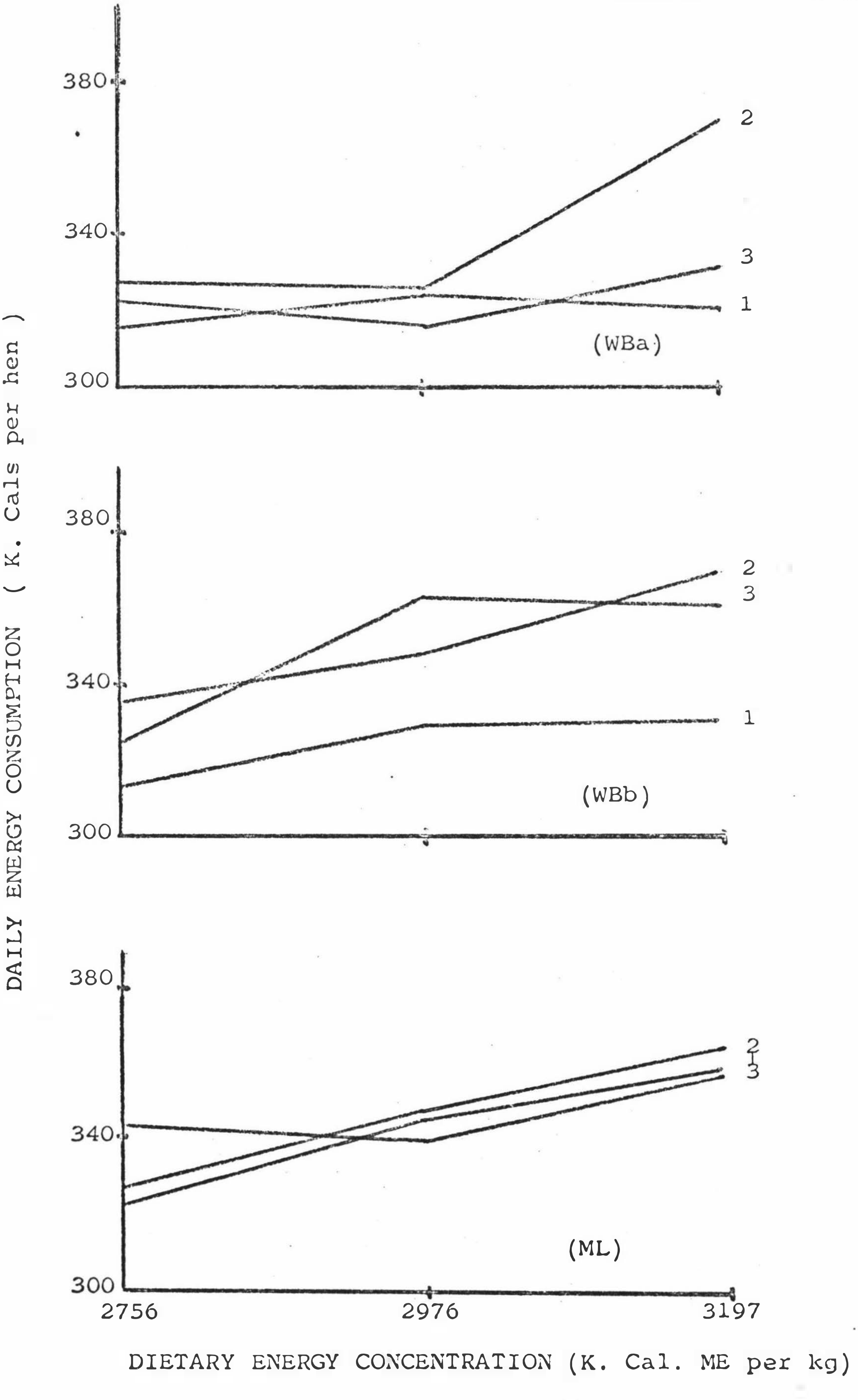


Figure 5.2

ENERGY CONSUMPTION VS DIETARY ENERGY CONCENTRATION



in feed intake does not result in a constant daily energy consumption (Figure 5.2) as was assumed when LN/32 was designed. There is an increase in the daily energy intake per hen as the dietary energy concentration is increased. This automatically results in hens consuming protein in excess of 16, 17, 18 grams per day for each protein treatment respectively. In general, the degree of overconsumption of protein will increase as the dietary energy concentration is increased.

Figure 5.1 also demonstrates that there is no obvious response pattern to the dietary protein concentration.

An analysis of variance for feed consumption including treatments 7-15 (three dietary energy concentration levels by three protein intake levels) is presented in Table 5.1.

Table 5.1: Analysis of variance. Feed consumption

Source	d.f.	s.s.	M.S.	F.
Mean	1	1.69×10^5	1.69×10^5	26511
Energy	2	167.12	83.56	9.45 x(1)
Protein	2	54.00	27.00	3.05 N.S.
Whole plot error	4	35.37	8.84	
Strain	2	62.46	31.23	4.89 x
S x E	4	13.41	3.35	0.53 N.S.
S x P	4	45.06	11.26	1.77 N.S.
Split plot error	8	51.01	6.38	

This analysis of variance detects significant differences in feed intake associated with differences in energy

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(1) See Appendix G for significance levels used.

levels ($p < 0.05$) but is unable to detect significant differences associated with protein levels ($p > 0.10$).

The analysis of variance indicates significance between strain differences in feed consumption ($p < 0.05$) though this test is not valid since the split-plot treatment (strain) was applied systematically over the whole plot treatments.

We can postulate variables to be included in the feed consumption model.

(1) Strain variables

The inclusion of strain variables may be of three forms:

(a) different intercept constants
(b) different transformation constants
(c) both.

There is no evidence of a significant Strain x Energy effect on feed consumption ($p > 0.10$). This allows us to concentrate on different intercept constants (a_j, for the j^{th} strain).

(2) Dietary energy concentration

Dietary energy concentration (E) has been shown to be the factor that accounts for most of the variation in feed consumption (Morris, 1968; De Groote, 1972). This is confirmed by an examination of the correlation matrix (Table 5.2).

Table 5.2: Correlation matrix for variables considered in regression models

	I	ΔW	N	W	ISO	MTH	CA	P	E
I	1	-.09	.15	.40	-.10	-.11	-.35	-.36	-.51
ΔW		1	-.12	.41	.12	.11	.28	.33	.46
N			1	.08	.24	.31	.17	.33	.33
W				1	.33	.35	.13	.41	.13
ISO					1	.66	-.12	.50	.15
MTH						1	.32	.67	.52
CA							1	.64	.87
P								1	.80
E									1

The code for variables included in regression models is presented in Appendix A.

(3) Other controlled variables

For each dietary energy concentration the protein (P) levels were controlled on the basis of an assumed energy intake of 305 k. cals. M.E. per day. The calcium (CA) levels were similarly controlled. The range of dietary calcium levels was 3.04-3.46 percent. This range was chosen so that calcium intake would not limit performance. The range of calcium levels was considered to be too small to affect either feed intake or egg production.

Although phosphorus was controlled within a dietary percentage range, all the rations contained phosphorus at 0.6 percent. The absence of variation in the dietary phosphorus level rules out its consideration as an explanatory variable in feed consumption.

(4) Initial liveweight

The response models discussed in Chapter Four contained physiological factors. Strain variation is one of these factors, another is initial liveweight (W) of the layer. A difference in the liveweight of the bird will effect a difference in the nutrient requirement for maintenance of body functions.

(5) Uncontrolled dietary factors

We have recognised (Chapter Two) that amino acids are important in affecting production responses. Should the intake of amino acids affect a positive production response then we may expect a resultant increase in feed intake to balance the energy equilibrium level of the layer. Amino acids most limiting in LN/32 (and hence most likely to affect a production response) are isoleucine (ISO) and methionine (MTH).

Because of the limited nature of the data (11 experimental points for each strain) we will limit the models for feed intake to linear forms including the variables discussed above. The models proposed for feed consumption, I, (with their error mean square) are presented in Table 5.3(1).

The models for feed consumption proposed by Morris (1968) and De Groote (1972) were expressed in terms of daily energy consumption (e).

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(1) All regression models were estimated using the IBM 1620 statistical program BAR 3.

$$e_j = \alpha_j + \beta_j E \text{ for the } j^{th} \text{ strain}$$

Since $I = \frac{e}{E}$, the intake function based on the energy consumption equation becomes:

$$I = \frac{\alpha_j}{E} + \beta_j$$

An analysis of variance for energy consumption (treatments 7-15) is presented in Table 5.4.

Table 5.3: Regression models.
Feed consumption.

Regression model	E.M.S.
$I = a_j + bE$	21.0
$I = a_j + bE + cW$	16.2
$I = a_j + bE + cP$	21.4
$I = a_j + bE + cCA$	20.3
$I = a_j + bE + cMTH$	20.3
$I = a_j + bE + cISO$	21.7
$I = a_j + bE + cP + dW$	15.2
$I = a_j + bE + cCA + dW$	15.6
$I = a_j + bE + cMTH + dW$	16.8
$I = a_j + bE + cISO + dW$	15.3

This analysis of variance detects significant differences in energy intake associated with differences in energy levels ($p < 0.05$) but is unable to detect significant differences associated with protein levels ($p > 0.10$). The analysis of variance also indicates significant between strain differences in energy intake ($p < 0.10$), this test however is not valid because of the systematic placement of split plot treatments.

Table 5.4: Analysis of variance. Energy consumption

Source	d.f.	S.S.	M.S.	F.
Mean	1	3.09×10^6	3.09×10^6	25957
Energy	2	2661.1	1330.5	7.01 x
Protein	2	1049.7	524.8	2.76 N.S.
Whole plot error	4	759.3	189.8	
Strain	2	1179.8	899.0	4.94 10%
S x E	4	265.3	66.3	0.55 N.S.
S x P	4	858.7	214.6	1.80 N.S.
Split plot error	8	953.4	119.2	

There is no evidence of a significant Strain x Energy effect on energy intake ($p > 0.10$). We can therefore reduce the model proposed by Morris to:

$$e = \alpha_j + \beta E$$

$$\text{or} \quad I = \frac{\alpha_j}{E} + \beta$$

Including the variables considered in the models for feed consumption we may propose linear models for metabolisable energy consumption. These models may be modified such that feed intake is the dependent variable (see above). The models proposed (with their error mean square) are presented in Table 5.5.

5.2.1 Discussion

Features of the results for the linear models for feed intake and energy intake are:

(1) the linear form of the feed intake model

$$I = a_j + bE$$

has a lower error mean square than the linear form of the energy intake model

$$I = \frac{\alpha_j}{E} + \beta$$

For both models the energy parameter is highly significant as judged by the t-test ($p < 0.01$).

Table 5.5: Regression models for feed consumption based on linear energy consumption models.

Regression model	E.M.S.
$I = \frac{\alpha_j}{E} + \beta$	21.6
$I = \frac{\alpha_j}{E} + \beta + \gamma \frac{W}{E}$	16.8
$I = \frac{\alpha_j}{E} + \beta + \gamma \frac{P}{E}$	22.2
$I = \frac{\alpha_j}{E} + \beta + \gamma \frac{Ca}{E}$	20.8
$I = \frac{\alpha_j}{E} + \beta + \gamma \frac{MTH}{E}$	20.4
$I = \frac{\alpha_j}{E} + \beta + \gamma \frac{ISO}{E}$	22.3
$I = \frac{\alpha_j}{E} + \beta + \gamma \frac{P}{E} + \lambda \frac{W}{E}$	15.4
$I = \frac{\alpha_j}{E} + \beta + \gamma \frac{Ca}{E} + \lambda \frac{W}{E}$	15.9
$I = \frac{\alpha_j}{E} + \beta + \gamma \frac{MTH}{E} + \lambda \frac{W}{E}$	17.1
$I = \frac{\alpha_j}{E} + \beta + \gamma \frac{ISO}{E} + \lambda \frac{W}{E}$	15.7

(2) A comparison of the linear models for energy intake and feed intake shows that over the complete range of variable inclusion the linear model for feed intake has a lower error mean square than the equivalent linear model for energy

intake. For this experiment we can tentatively(1) conclude that the linear models for feed intake afford a better fit to the data than do the linear models for energy intake as used by Morris (1968) and De Groote (1972).

To accept that feed intake is a linear model we accept that the energy intake model is quadratic.

$$\begin{aligned} \text{Since} \quad & I = a_j + bE \\ \text{and} \quad & e = E.I. \\ & e = a_j\,E + bE^2 \end{aligned}$$

(3) The inclusion of an initial weight variable (W) in conjunction with energy is significant as judged by the t-test ($p < 0.05$). In addition, there is a dramatic reduction in the error mean square when W is included in models.

(4) The inclusion of protein, calcium, methionine or isoleucine variables in conjunction with energy are not significantly different from zero at the ten percent level.

(5) The model with the lowest error mean square is

$$I = a_j + bE + cP + dW$$

The inclusion of the protein variable reduces the significance of the energy parameter to 22 percent as judged by the t-test. The protein parameter is significant at the 10.2 percent level. This represents a case of multicolliniarity where the correlation between energy and

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(1) We use the word tentative to describe our conclusion since a limited energy range (2756-3197 k. cal. M.E. per kg.) has been used and the experimental design was such that lack of fit tests of significance could not be applied.

protein (r = 0.80) results in part of the effect due to energy being "credited" to the protein parameter. To overcome multicollinearity one variable must be dropped from the model. Where one variable is dropped the resultant equation will only hold where protein and energy levels continue to be highly correlated.

(6) The model with the second lowest error mean square is:

$$I = a_j + bE + cISO + dW$$

The isoleucine parameter is significant at the 11.7 percent level, as judged by the t-test. The coefficient of the isoleucine parameter is negative. An increase in the isoleucine percentage of the diet will result in a decrease in feed consumption. Alternatively, this may be interpreted as a positive response in feed intake to low dietary isoleucine levels.

Where the isoleucine concentration of a ration is low (as in LN/32) we can expect a low isoleucine intake and a possible amino acid imbalance. Both of these factors will cause a reduction in egg production. Only an increase in egg production will result in an increase in feed intake. A reduction in egg production will cause a depressed feed intake (Fisher et al., 1960; Fisher and Shapiro, 1961; Smith, 1973). The significant inclusion of a negative isoleucine parameter is not consistent with nutritional theory.

Smith, W K: pers.comm., Massey University, P.R.C. (1973)

(7) The model with the lowest error mean square that is consistent with nutritional theory is:

$$I = a_j + bE + cW$$

The regression coefficients for this model are presented in Table 5.6.

Table 5.6: Regression coefficients. Feed consumption

Term	Regression coefficient	Students t-statistic	Px100	R^2 ($\bar{R}^2$)
M.L. CONSTANT	116.656			.615
W.B.a CONSTANT	111.336			.560
W.B.b CONSTANT	113.924			
E	-0.161	4.78	0.005	
W	0.032	3.08	0.462	

Where I = feed consumption (grams per hen per hen day

E = dietary energy concentration (k. cals. x 10^{-1} M.E. per kg.)

W = initial body weight (grams liveweight per hen).

Features of the regression coefficients in Table 5.6 are:

(i) The significance of all parameters as judged by the t-test.

(ii) The coefficient for the dietary energy parameter is negative, supporting the earlier observation that as the dietary energy concentration is increased the daily feed intake decreases.

(iii) The coefficient for the initial weight parameter is positive, indicating that an increase in the initial body weight results in an increase in feed intake.

(iv) Analysis of the R^2 value as a guide to the "goodness of fit" of the regression, shows that 61.5 percent of the variation in feed consumption is explained by the model presented in Table 5.6.

5.3 Egg number

Egg number for the total laying period for treatments 7-15, 17, 19 are graphed against the dietary energy concentration for each strain of laying hen in Figure 5.3. Egg number reaches a maximum for two protein treatments, at a dietary energy level of 2976 k. cal. M.E. per kg. Over the whole energy range there is no obvious response in egg number between protein treatments.

An analysis of variance for egg number including treatments 7-15 (three dietary energy concentration levels by three protein intake levels) is presented in Table 5.7.

The analysis of variance does not detect any differences in egg number associated with differences in energy levels ($p > 0.10$) or difference in protein levels ($p > 0.10$). The analysis of variance indicates significance between strain differences in egg number ($p < 0.05$) although this test is not valid (see Chapter 4.3). There is no evidence of a significant Strain x Energy effect on egg number ($p > 0.10$).

Figure 5.3

EGG NUMBER VS DIETARY ENERGY CONCENTRATION

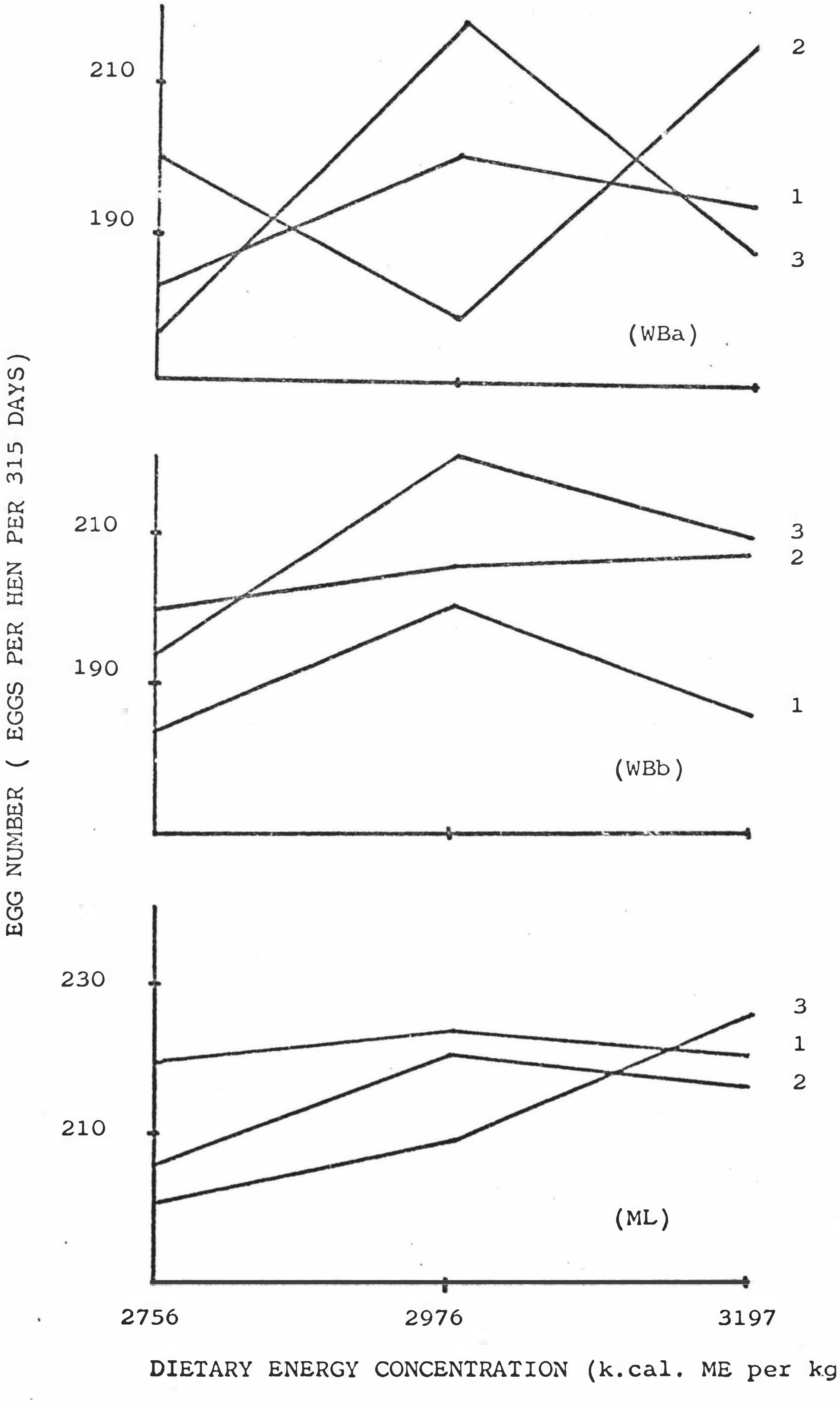

Table 5.7: Analysis of variance. Egg number.

Source	d.f.	S.S.	M.S.	F.
Mean	1	1.12×10^6	1.12×10^6	7663
Energy	2	930.42	465.21	2.81 N.S.
Protein	2	77.03	38.52	0.23 N.S.
Whole plot error	4	662.78	165.69	
Strain	2	2109.83	1054.91	7.20 x
S x E	4	109.70	27.43	0.19 N.S.
S x P	4	560.32	140.07	0.96 N.S.
Split plot error	8	1171.71	146.46	

Nutritional theory (Chapter Two) suggests that egg number and other layer responses will be affected by daily nutrient intakes. The relationship between egg number and daily energy intake is graphed in Figure 5.4(1). There is a positive response in egg number to increasing energy intake, particularly for White Base b layers. White Base b layers also demonstrate a positive response in egg number to increasing methionine intake (Figure 5.5). Due to the correlation between isoleucine and methionine content of the rations (r = 0.66) the same result can be shown for isoleucine intake. There is no obvious response by White Base a layers to methionine intake. If anything, M Line layers show a negative response in egg number to an increase in methionine intake.

If we are to use Model I (Chapter Four) in the economic analysis, and given that the economic control

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(1) In Figures 5.4, 5.5, 5.7, 5.8 treatments with the same dietary energy concentration are joined by straight lines. In Figure 5.5 differences in the response to methionine intake are due to the response to energy intake.

variables are nutrient levels in the ration, we will need to predict nutrient intakes and analyse the relationships between productive variables and predicted nutrient intake levels.

The relationship between egg number and predicted energy intake is presented in Figure 5.7. The response of White Base b layers to predicted energy intake is not as good as the response to observed energy intake (Figure 5.4) because our feed intake model only explains 61.5 percent of the variation in feed intake and hence energy intake (Figure 5.6). In general the slope of the response in egg number to predicted energy intake is the same for each strain.

The relationship between egg number and predicted methionine intake is presented in Figure 5.8. Again, White Base b layers show a response in egg number to methionine intake. The lack of obvious response by White Base a and M Line layers could be due to two things.

(1) LN/32 was not sensitive enough to detect any responses.
(2) White Base a and M Line layers may not respond to the levels of methionine intake in LN/32.

We have discussed (Chapter Four) the statistical implications of using observed nutrient intakes as the independent variables under <u>ad libitum</u> feeding where nutrient intake is a random variable. We have chosen for this study the alternative of Two-Stage Least Squares for estimation of the production response equations in Model I.

Figure 5.4

EGG NUMBER VS OBSERVED ENERGY INTAKE

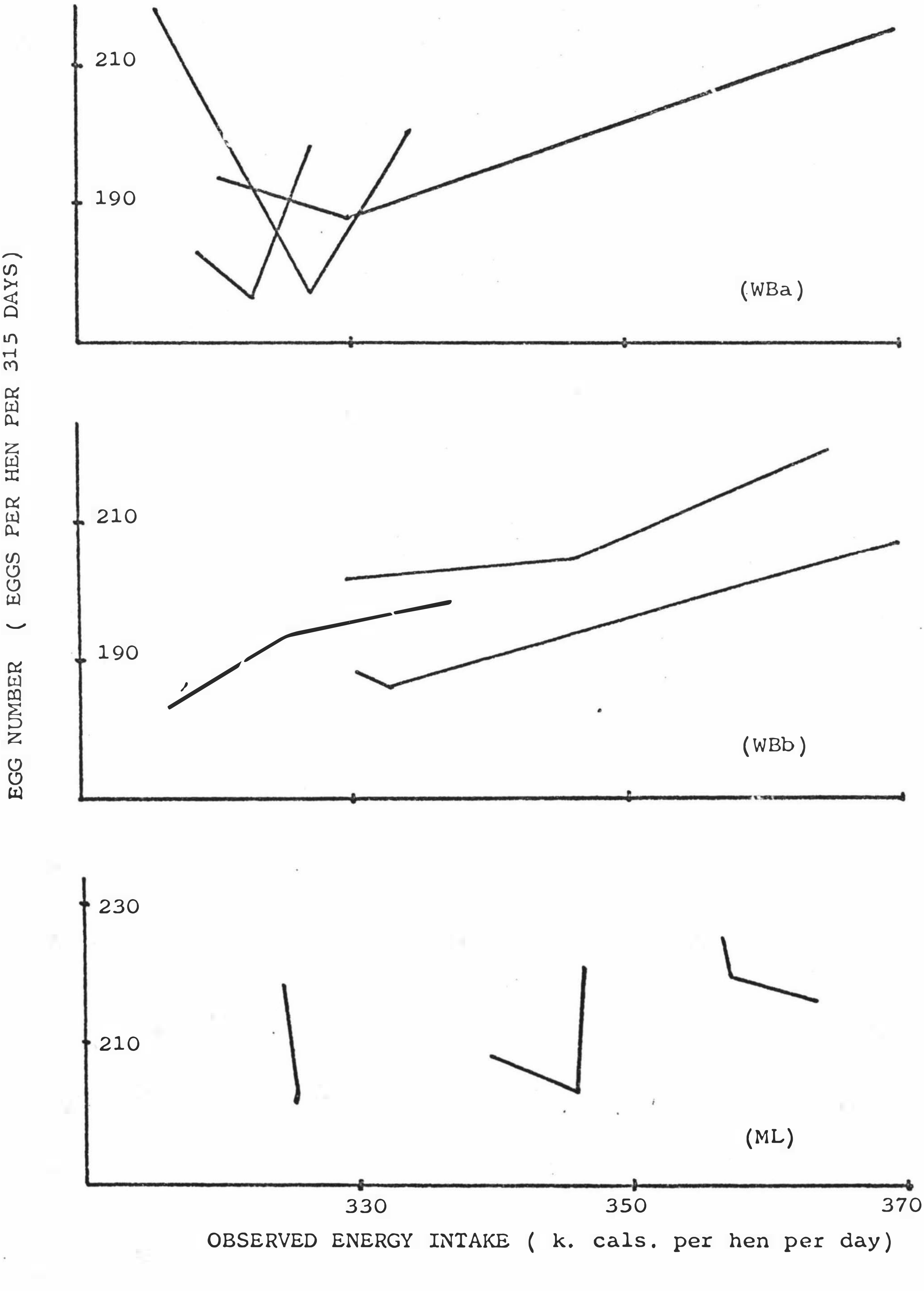


Figure 5.5

EGG NUMBER VS OBSERVED METHIONINE INTAKE

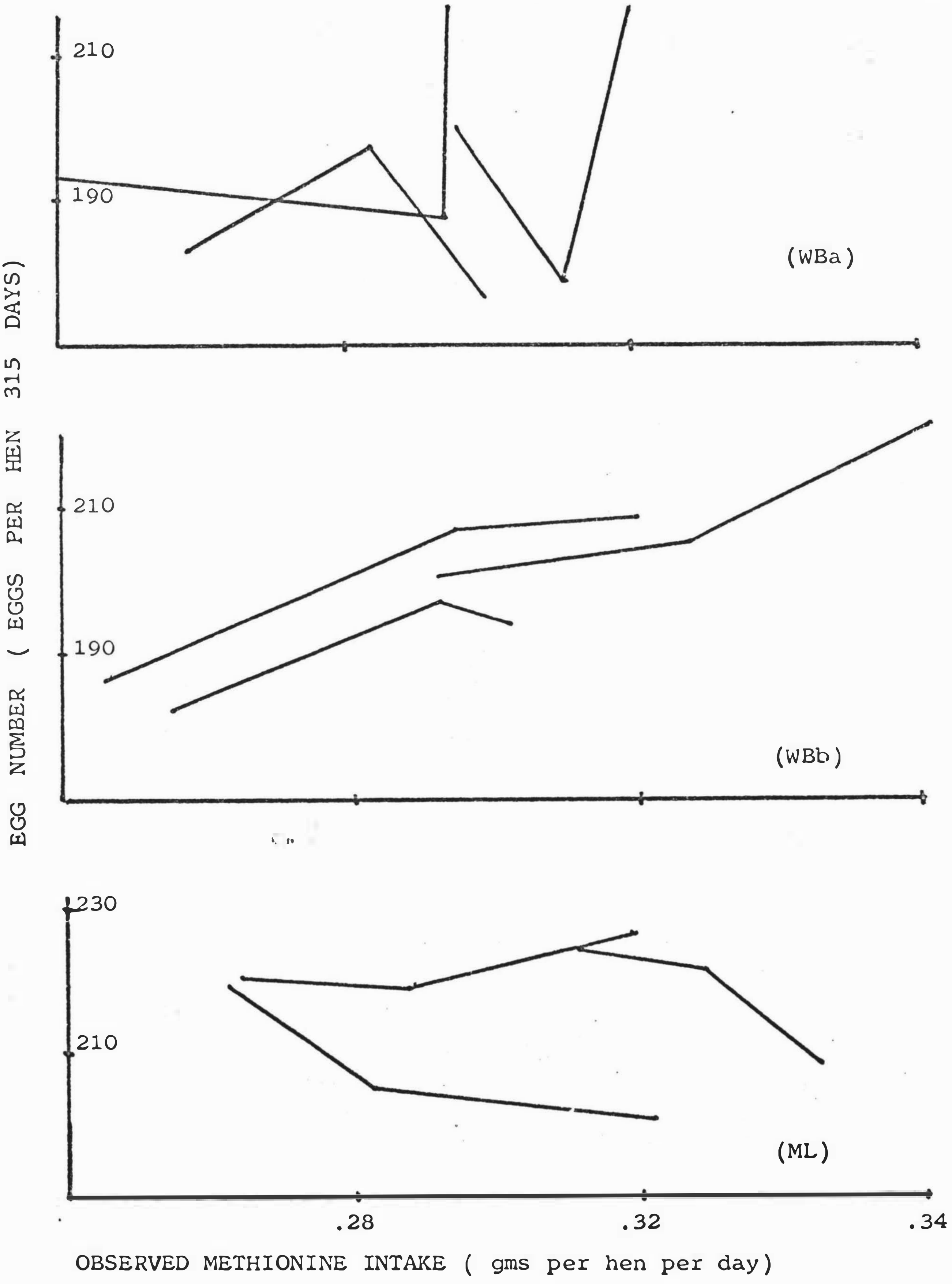


Figure 5.6

PREDICTED ENERGY INTAKE VS OBSERVED ENERGY INTAKE

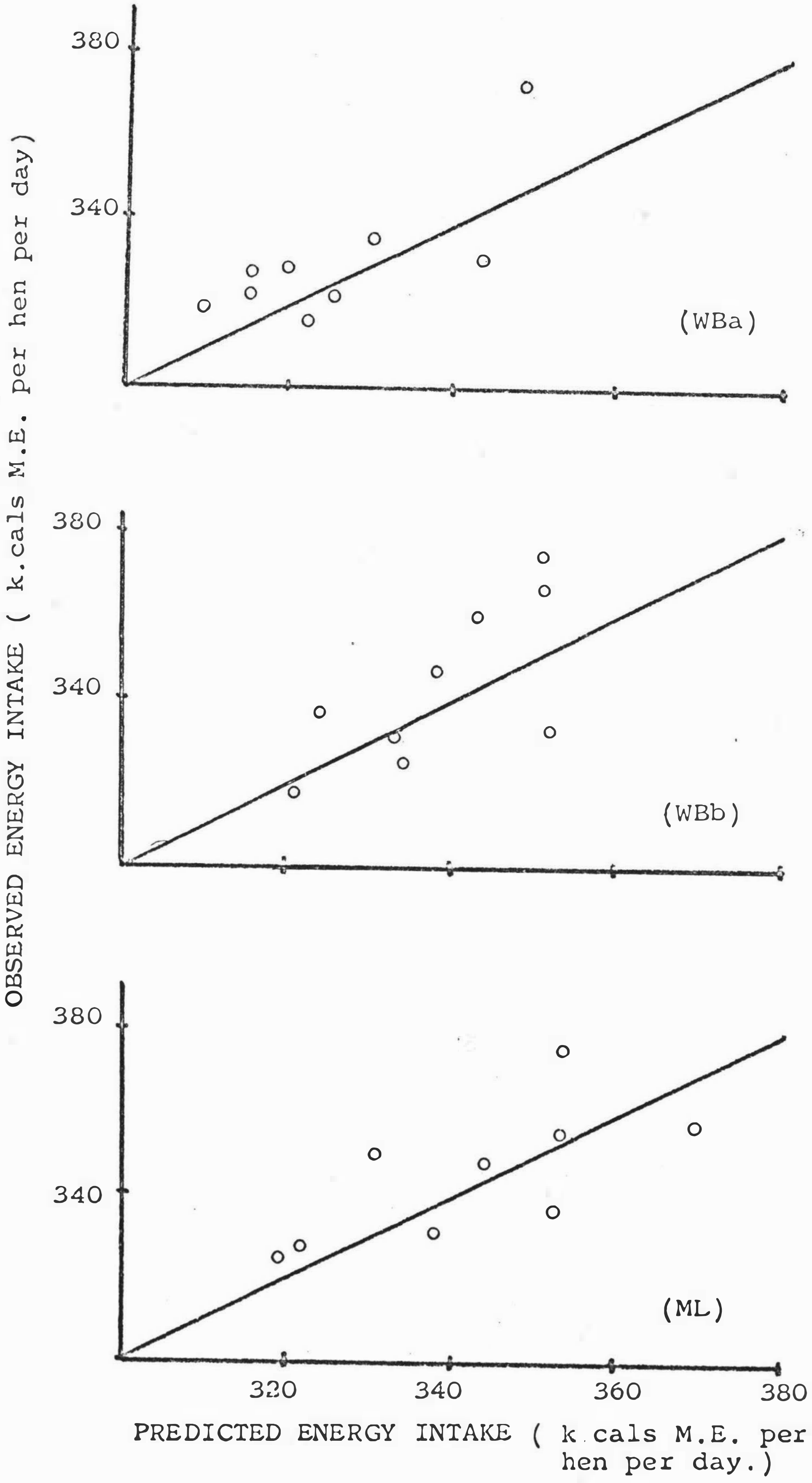


Figure 5.7

EGG NUMBER VS PREDICTED ENERGY INTAKE

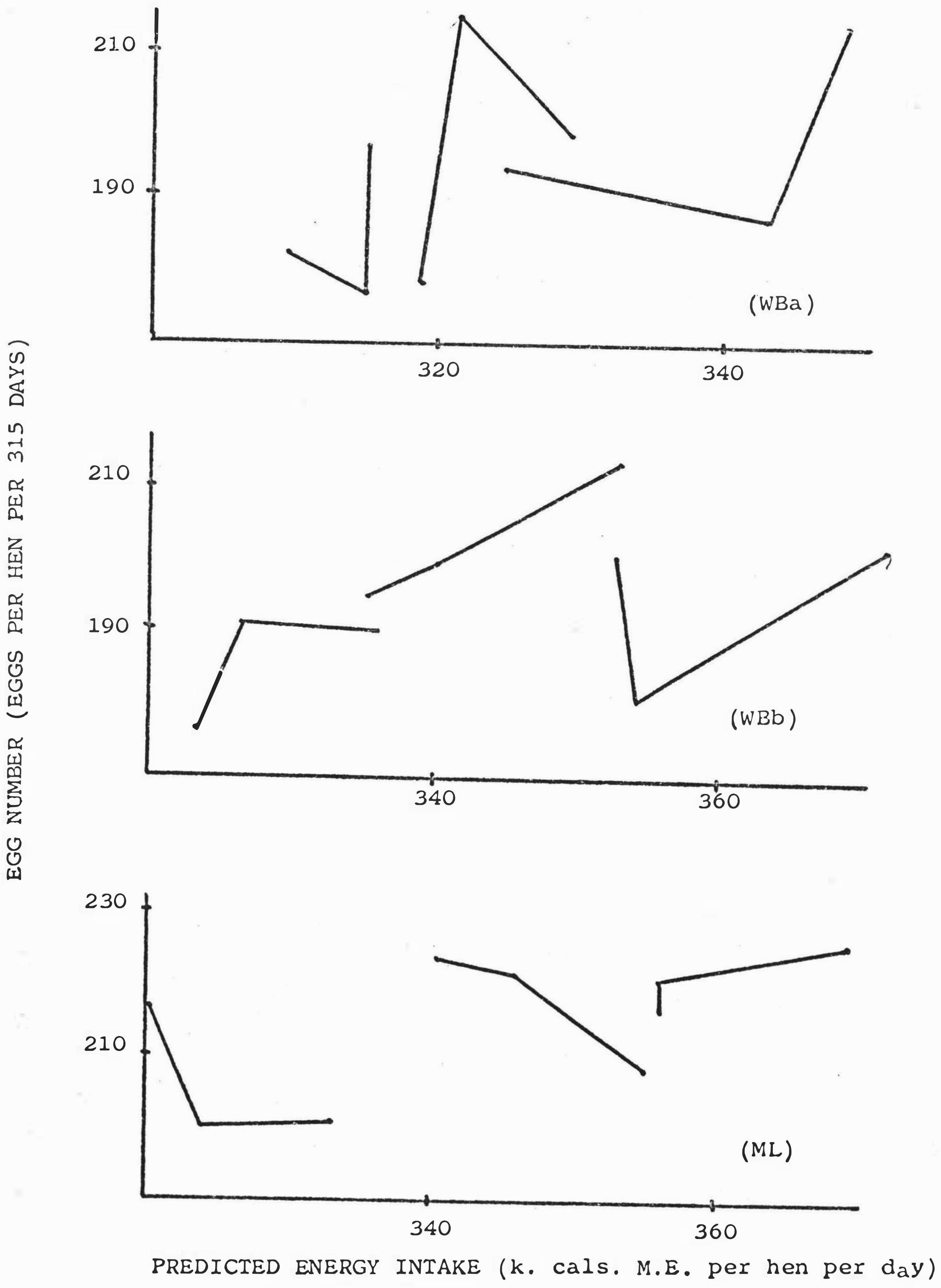
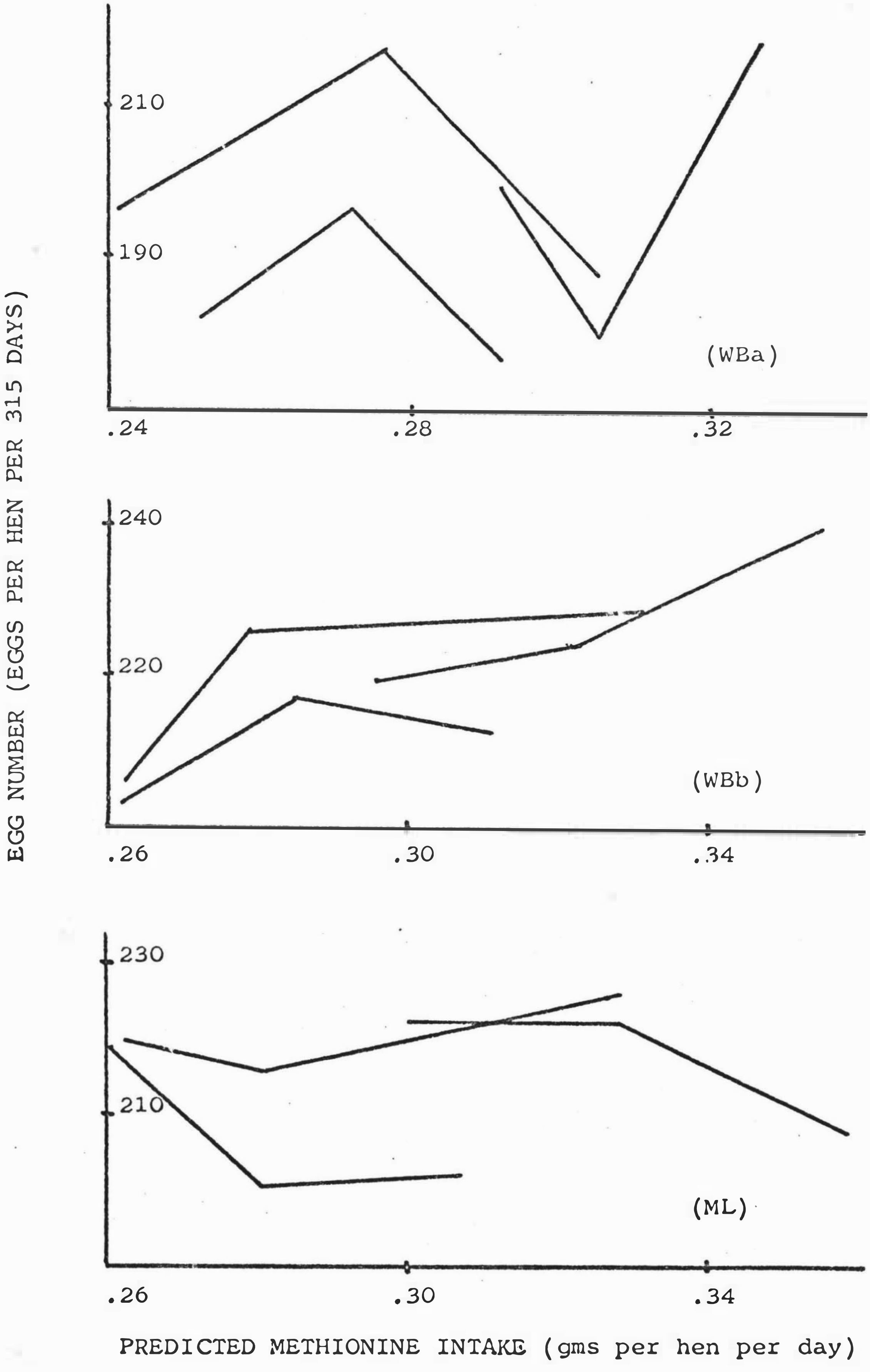


Figure 5.8

EGG NUMBER VS PREDICTED METHIONINE INTAKE



For $Yk = Yk\ (x_1, \ldots, x_m\ ;\ v_1, \ldots v_n\ ;\ t)$ (5.1)

we have $I = I\ (X_1, \ldots, X_m\ ;\ v_1, \ldots v_n\ ;\ t)$ (5.2)

$$\hat{x}_d = X_d . \hat{I} \qquad (5.3)$$

We estimate equation (5.2) by Ordinary Least Squares (since all variables are controlled), then we predict $\hat{x}_d$ by equation (5.3).

The parameters of equation (5.1) are then estimated by application of Least Squares directly to:

$$Y_k = Y_k\ (\hat{x}_1, \ldots, \hat{x}_m\ ;\ v_1, \ldots v_n\ ;\ t) \qquad (5.4)$$

Equation (5.2) is Stage One and equation (5.4) is Stage Two of Two-Stage Least Squares.

We can postulate forms of equation (5.4) for the total laying period (t). The independent variables are the predicted nutrient intakes:

$$(\hat{x}_1, \ldots, \hat{x}_m)$$

Where $\hat{x}_d$ is given by equation (5.3), and

$\hat{I}$ (WBa) = 111.336-0.161 E + 0.032 W

$\hat{I}$ (WBb) = 113.924-0.161 E + 0.032 W

$\hat{I}$ (ML) = 116.656-0.161 E + 0.032 W

The logic used in selecting variables for the egg number function is the same as that used in selecting variables for the feed intake function. In addition models with different strain slopes for the methionine and isoleucine variables were considered. Various forms of the egg number (N) function (with their error mean square) are presented in Table 5.8.

Table 5.8: Egg number models

Form of the model	E.M.S.
$N = \alpha_j + \beta\hat{e}$	104.5
$N = \alpha_j + \beta\hat{e} + \gamma W$	108.2
$N = \alpha_j + \beta\hat{e} + \gamma\hat{p}$	108.2
$N = \alpha_j + \beta\hat{e} + \gamma\,\hat{ca}$	98.8
$N = \alpha_j + \beta\hat{e} + \gamma\,m\hat{t}h$	106.1
$N = \alpha_j + \beta\hat{e} + \gamma\,i\hat{s}o$	105.3
$N = \alpha_j + \beta\hat{e} + \gamma\hat{p} + \lambda W$	111.7
$N = \alpha_j + \beta\hat{e} + \gamma\,\hat{ca} + \lambda W$	99.9
$N = \alpha_j + \beta\hat{e} + \gamma\,m\hat{t}h + \lambda W$	109.1
$N = \alpha_j + \beta\hat{e} + \gamma\,i\hat{s}o + \lambda W$	106.4
$N = \alpha_j + \beta\hat{e} + \gamma_j\,i\hat{s}o$	104.0
$N = \alpha_j + \beta\hat{e} + \gamma_j\,m\hat{t}h$	90.1
$N = \alpha_j + \beta\hat{e} + \gamma\,i\hat{s}o + \lambda\,m\hat{t}h$	109.1
$N = \alpha_j + \beta\hat{e} + \gamma_j\,i\hat{s}o + \lambda_j\,m\hat{t}h$	99.7

Features of these results are:

(1) The inclusion of an initial weight variable (W) does not result in a reduction in the error mean square for any of the models.

(2) The model with the lowest error mean square (90.1) is:

$$N = \alpha_j + \beta\hat{e} + \gamma_j\,m\hat{t}h$$

The regression coefficients for this model are presented in Table 5.9.

Table 5.9: Regression coefficients

Term	Regression coefficient	Students t-statistic	P x 100	R^2 ($\bar{R}^2$)
M.L. CONSTANT	158.945			.644
W.B.a CONSTANT	101.407			.562
W.B.b CONSTANT	43.890			
$\hat{e}$	0.259	2.23	3.430	
M.L. $m\hat{t}h$	-105.842	1.12	27.120	
W.B.a $m\hat{t}h$	34.880	0.33	74.360	
W.B.b $m\hat{t}h$	226.903	2.36	2.590	

Where N = hen day egg number per hen per 315 days

$\hat{e}$ = predicted energy consumption (k. cal.s per hen per day)

$m\hat{t}h$ = predicted methionine consumption (grams per hen per day)

5.3.1 Discussion

The coefficient for the energy parameter (significant at the 3.34 percent level) is positive. An increase in energy intake results in an increase in egg number.

The coefficient of the W.B.b methionine parameter (significant at the 2.59 percent level) is positive. An increase in methionine intake results in an increase in egg number. This result also holds for the W.B.a methionine parameter although this is only "significant" at the 74.36 percent level. The coefficient of the M.L. methionine parameter (significant at the 27.12 percent level) is negative. An increase in methionine intake results in a decrease in egg number for M.L. layers.

Only the result for W.B.b layers can be treated with confidence. There is a positive response in egg number to increases in methionine intake. Although this result was not significant for the other strains ($p > 0.10$) it does not rule out the possibility that this would have been significant had the experiment been designed to study the response of laying hens to amino acid intakes. As the predicted methionine intakes in LN/32 were low (0.24-0.36 grams per hen per day) we could expect a response in egg number to an increase in a limiting amino acid (Fisher and Morris, 1970). There is though, the possibility that this experiment was sensitive enough to detect potential responses to amino acid intake and that W.B.a and M.L. layers in fact did not respond to the methionine intake levels experienced in LN/32.

As a guide to the"goodness of fit" of the regression, the R^2 shows that 64.4.percent of the variation in live-weight gain is explained by the model presented in Table 5.9.

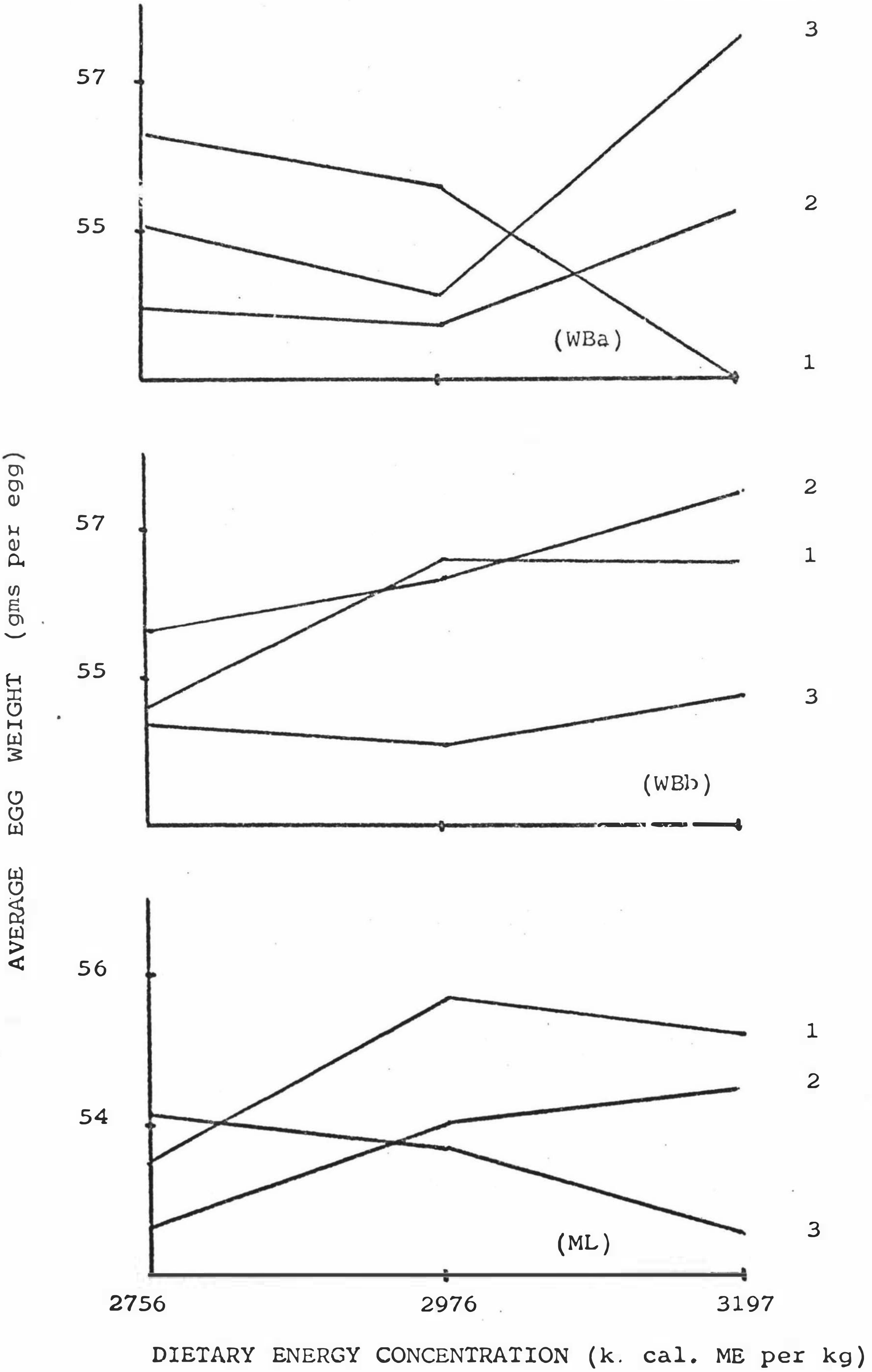
The opportunity was taken to analyse second order polynomial models for energy, energy and methionine, energy and isoleucine, energy and protein and energy and calcium. These models did not represent a better fit to the data than the linear forms. No quadratic term was significant as judged by the t-test ($p > 0.10$).

5.4 Egg weight

Average egg weight for the total laying period for treatments 7-15, 17, 19 are graphed against the dietary energy concentration in Figure 5.9.

Figure 5.9

AVERAGE EGG WEIGHT VS DIETARY ENERGY CONCENTRATION



An analysis of variance for average egg weight including treatments 7-15 (three dietary energy concentration levels by three protein intake levels) is presented in Table 5.10.

Table 5.10: Analysis of variance. Average egg weight

Source	d.f.	s.s.	M.S.	F.
Mean	1	8.21×10^4	8.21×10^4	46492
Energy	2	2.58	1.29	0.98 N.S.
Protein	2	2.15	1.07	0.82 N.S.
Whole plot error	4	5.22	1.31	
Strain	2	32.92	16.46	9.32 xx
S x E	4	3.06	0.77	0.43 N.S.
S x P	4	10.09	2.52	1.42 N.S.
Split plot error	8	14.14	1.77	

This analysis of variance does not detect any significant differnences in average egg weight associated with difference in energy or protein levels ($p > 0.10$).

The analysis of variance indicates significance between strain differences in average egg weight ($p < 0.01$) though this test is not valid (see Chapter 4.3).

The absence of significant responses to dietary energy and protein levels does not rule out the possibility of significant responses to nutrient intakes or physiological factors.

The opportunity was taken to analyse the functions presented in Table 5.8 with average egg weight as the dependent variable. The strain parameters were highly [illegible] all [illegible]

[illegible] parameters were [illegible] models

[illegible]

significant for all models. The nutrient intake and initial weight parameters were not significant in any of the models ($p > 0.15$).

Egg weight is incorporated in the economic model in the form of egg grade distribution. Egg grade is a function of egg weight (van Moer, 1968, 1969; cited De Groote, 1972).

Once we have established that nutrient intake does not account for any differences in egg weight we must accept that nutrient intake does not account for any differences in egg grade distribution.

Should a separate economic analysis be made for each strain of bird then the average egg grade distribution for <u>each</u> strain of layer would be used since we have established that there are strain differences in average egg weight.

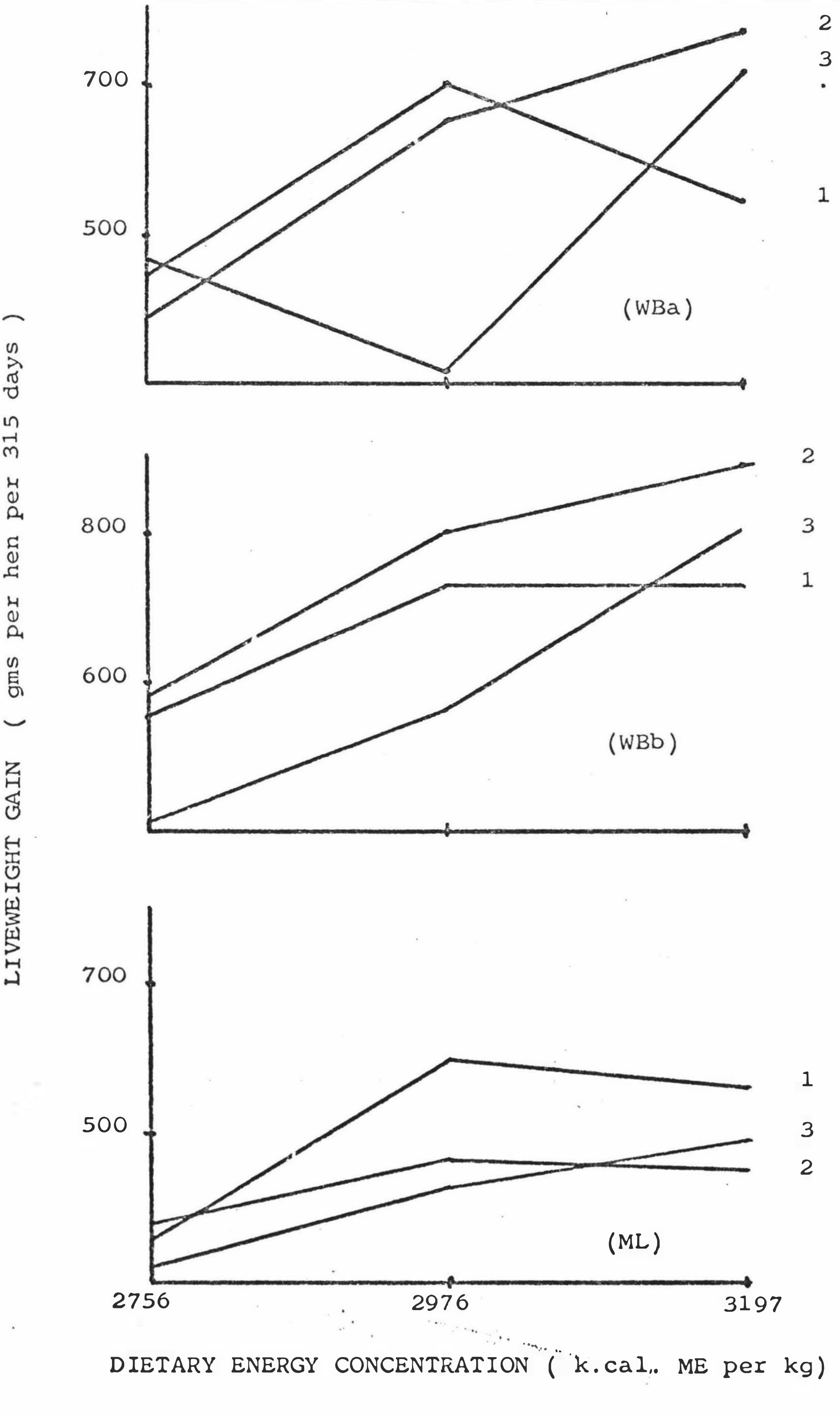
5.5 Body weight gain

Body weight gain for the total laying period for treatments 7-15, 17, 19 are graphed against the dietary energy concentration for each strain of laying hen in Figure 5.10.

In general, there appears to be an increase in body weight gain as the dietary energy concentration is increased. There is no evidence of a consistent effect of dietary protein concentration on body weight gain.

Figure 5.10

LIVEWEIGHT GAIN US DIETARY ENERGY CONSUMPTION



An analysis of variance for body weight gain including treatments 7-15 (three dietary energy concentration levels by three protein intake levels) is presented in Table 5.11.

Table 5.11: Analysis of variance. Body weight gain

Source	d.f.	S.S.	M.S.	F.
Mean	1	8.26×10^6	8.26×10^6	1055
Energy	2	2.34×10^5	1.17×10^5	7.37 x
Protein	2	4.42×10^4	2.21×10^4	1.39 N.S.
Whole plot error	4	6.35×10^4	1.59×10^4	
Strain	2	2.35×10^5	1.76×10^5	15.01 xx
S x E	4	2.08×10^4	5.21×10^3	0.66 N.S.
S x P	4	2.24×10^4	5.59×10^3	0.71 N.S.
Split plot error	8	6.27×10^4	7.83×10^3	

There is a significant difference in body weight gain associated with differences in energy levels ($p < 0.05$) but there are no significant differences associated with protein levels ($p > 0.10$).

The analysis of variance indicates significant between strain differences in body weight gain ($p < 0.05$) though this test is not valid (see Chapter 4.3).

In determining the model which will express the variation in body weight gain we follow the logic used in selecting the models for egg number. Nutritional theory does not suggest that any other factors will affect the liveweight gain of laying hens.

Models for liveweight gain during the total production period (consistent with those in Table 5.8) were estimated by Two-Stage Least Squares.

These models, with their error mean square are presented in Table 5.12.

Table 5.12: Liveweight gain models

Form of the model	E.M.S.
$\Delta W = \alpha_j + \beta\hat{e}$	13855
$\Delta W = \alpha_j + \beta\hat{e} + \delta W$	13614
$\Delta W = \alpha_j + \beta\hat{e} + \delta\hat{p}$	13350
$\Delta W = \alpha_j + \beta\hat{e} + \delta\widehat{ca}$	11498
$\Delta W = \alpha_j + \beta\hat{e} + \delta\widehat{mth}$	12144
$\Delta W = \alpha_j + \beta\hat{e} + \delta\widehat{iso}$	14239
$\Delta W = \alpha_j + \beta\hat{e} + \delta\hat{p} + \lambda W$	13775
$\Delta W = \alpha_j + \beta\hat{e} + \delta\widehat{ca} + \lambda W$	11923
$\Delta W = \alpha_j + \beta\hat{e} + \delta\widehat{mth} + \lambda W$	12529
$\Delta W = \alpha_j + \beta\hat{e} + \delta\widehat{iso} + \lambda W$	14063
$\Delta W = \alpha_j + \beta\hat{e} + \delta_j\,\widehat{iso}$	15176
$\Delta W = \alpha_j + \beta\hat{e} + \delta_j\,\widehat{mth}$	12735
$\Delta W = \alpha_j + \beta\hat{e} + \delta\widehat{iso} + \lambda\widehat{mth}$	11493
$\Delta W = \alpha_j + \beta\hat{e} + \delta_j\,\widehat{iso} + \lambda_j\,\widehat{mth}$	12163

Features of these results are:

(1) The initial weight parameter (W) is not significant in any of the models as judged by the t-test ($p > 0.20$). For LN/32 layers whose initial weight is low do not reach the final weight of heavier layers. There is

no compensatory growth and each hen reaches its individual liveweight potential under a given feeding regime.

(2) The model with the lowest error mean square (11493) is:

$$\Delta W = \alpha_j + \beta \hat{e} + \gamma \hat{iso} + \lambda \hat{mth}$$

The regression coefficients for this model are presented in Table 5.13.

Table 5.13: <u>Regression coefficients</u>

Term	Regression coefficient	Students t-statistic	P x 100	R^2 ($\bar{R}^2$)
M.L. CONSTANT	-1586.992			0.666
W.B.a CONSTANT	-1402.767			0.605
W.B.b CONSTANT	-1343.105			
$\hat{e}$	6.846	4.78	0.005	
$\hat{mth}$	-2771.088	2.77	0.995	
$\hat{iso}$	851.637	1.61	11.943	

Where ΔW = liveweight gain per hen per 315 days (grams)

$\hat{e}$ = estimated energy consumption (k. cals. M.E. per hen per hen day)

$\hat{mth}$ = estimated methionine consumption (grams per hen per hen day)

$\hat{iso}$ = estimated isoleucine consumption (grams per hen per hen day.)

Features of the coefficients in Table 5.13 are:

(1) The coefficient of the energy parameter is positive. An increase in the energy intake of a bird results

in an increase in the birds liveweight gain ($p < 0.01$) due to an increase in the total bodyweight gain (fat).

(2) The coefficient of the methionine parameter is negative. An increase in the methionine intake of a bird results in a decrease in the birds liveweight gain ($p < 0.10$). As an increase in the methionine intake resulted in an increase in egg number, for a given intake of nutrients, we can expect a decrease in one product (weight gain) where there is an increase in the other product (egg number). This has occurred.

(3) The coefficient of the isoleucine parameter is positive. An increase in the isoleucine intake of a bird results in an increase in the birds liveweight gain ($p < 0.12$). As dietary methionine and isoleucine concentration were positively correlated (0.66) the methionine and isoleucine intake will increase together. Where the increased methionine intake resulted in an increase in egg number and a decrease in bodyweight gain the increased isoleucine intake may have resulted in an amino acid balance which resulted in an increase in body weight gain due to an increase in the lean bodyweight gain (protein and water).

(4) As a guide to the "goodness of fit" of the regression the R^2 shows that 66.6 percent of the variation in liveweight gain is explained by the model presented in Table 5.13.

CHAPTER SIX

ECONOMIC ANALYSIS

6.1 Outline of the economic model

Egg production is a continuous output process which has been compared to milk production (Heady, 1947). Amongst other things, egg output from a laying flock will be subject to physiological factors. Given a strain of laying hen of known maturity at start of lay, producing under given housing conditions, the factor which will most affect level of production under a given level of management will be ration composition. In this situation we will consider the economic control variables to be the nutrient concentrations of the ration subject to certain constraints on the levels of various feedstuffs in the ration.

In this Chapter production economics principles will be used to examine the effect of various nutrient concentrations on the net revenue from a laying flock. An economic analysis of a laying flock must be related to some stated production period, or set of production periods.

In this analysis we will assume that the cost of production (or purchase) of the replacement pullets is fixed, and hence can be ignored in the economic analysis of layer rations. In practice this assumption could be relaxed where the relationships between various grower rations, or pullets of different maturities, and egg output, grade distribution of eggs produced and feed consumption during lay have been quantified.

The first step of an economic analysis is specification of the income and cost components of net revenue from the production enterprise under study.

Income is derived from the sale of eggs during the production period and the value of the hen at the end of the production period. In New Zealand, the price received for eggs of different grades is set by a Price Tribunal following consultation with the Egg Marketing Authority. The income received from eggs then is a function of both egg weight and egg quality, though in this study we have assumed no quality differences between eggs produced from the various rations analysed. The price per dozen eggs within any given grade will usually fluctuate during the year.

Following Swan (1970) we can write an equation for egg revenue received during the t^{th} production period for hens receiving the j^{th} ration.

$$R_{jt} = \left(\left(\sum_{i=1}^{5} P_i \; G_{ij} \right) N_j \right)_t \qquad (6.1)$$

where, R_{jt} = revenue received from eggs (per hen) for the j^{th} ration during the t^{th} production period.

P_i = price received per egg for eggs in the i^{th} grade(1)

G_{ij} = the proportion of eggs laid for the j^{th} ration that are in the i^{th} grade.

N_j = the total number of eggs laid per hen on the j^{th} ration, (measured on a hen day basis).

---

(1)
i=1 : Large grade = 62+ grams
i=2 : Standard grade = 53-62 grams
i=3 : Medium grade = 44-53 grams
i=4 : Pullet grade = 35-44 grams
i=5 : Undersize grade = less than 35 grams.

Where the economic analysis involves a series of time periods, the egg revenue per hen from the jth ration is given by:

$$R_{jT} = \sum_{t}^{T} R_{jt} \qquad (6.2)$$

where R_{jt} is summed over the number of "price periods" and/or "production periods" (T) that make up the total production period. This equation could also be modified to allow for different rations to be fed during the total production period.

For the range of rations used in LN/32 it was found that, within strains of hen used, there were no differences in grade distribution between rations. This means that, within a strain, a weighted average egg price could be used for the total laying period. In addition, the ration treatments used in LN/32 were designed to be constant throughout the period of lay which began when the pullets were 22 weeks of age and ended 45 weeks later. For this study then we have a single production period: the total period of lay, so that T = t = 1. For this study then, equation (6.2) can be written:

$$R_j = \left(\sum_{i=1}^{5} \overline{P_i \ G_{ij}}\right) N_j$$

$$= P_e N_j \qquad (6.3)$$

where, $\sum_{i=1}^{5} \overline{P_i \ G_{ij}}$ = a weighted average egg price over all grades and over the total production period

$= P_e$

The value of the hen at the end of the production period in this study is assumed to be the value of a cull hen. Culled hen revenue is a function of the final liveweight of hens on the j^{th} ration and of the price per kilogram liveweight for cull hens.

$$V_j = P_b \, W'_j \qquad (6.4)$$

where, V_j = cull hen revenue per hen for the j^{th} ration
P_b = price per kilogram liveweight
W'_j = liveweight (kgrams) per hen at the end of the laying period for birds on the j^{th} ration.

In Chapter Five we estimated the production function for liveweight gain (ΔW_j) during the total production period. We have:

$$W'_j = W_j + \Delta W_j$$

so that equation (6.4) becomes:

$$V_j = W_j \, P_b + \Delta W_j \, P_b$$

$$= WP_b + \Delta W_j \, P_b \qquad (6.5)$$

where we assume that, within strains, the average initial liveweight of hens is the same for all rations.

In the context of this study the only cost component of net revenue is feed cost (F_j).

$$F_j = P_j \, I_j \qquad (6.6)$$

where, P_j = price per kgm of the j^{th} ration
I_j = total consumption (kgm) of the j^{th} ration per hen.

Equations (6.3), (6.5) and (6.6) can now be combined to express the net revenue per hen on the j^{th} ration for the total 45 week period of lay:

$$\begin{aligned} Z &= R_j + V_j - F_j \\ &= P_e N_j + WP_b + \Delta WP_b - P_j I_j \end{aligned} \qquad (6.7)$$

In equation (6.7) the control variables, levels of nutrients in the ration, will affect directly or indirectly:

N_j = the number of eggs produced per hen
ΔW_j = the liveweight gain (or loss) during lay
P_j = the price per kgm of ration
I_j = feed consumption per hen.

Having estimated the physical production functions for the variables $N, \Delta W, I$ and given that Linear Programming will be used to minimise P_j for any stated levels of the control variables, we can examine net revenue as a function of our economic control variables. The variables P_e, E, P_b and the price per kilogram of the various possible ration ingredients are taken as given by the producer seeking to maximise net revenue per hen over the period of lay. We will refer to this set of variables as exogenous as opposed to those whose value is affected by the levels of the control variables. We will refer to this latter set of variables as endogenous.

6.2 Method of analysis

Using production functions described in Chapter Five, and given values for the set of exogenous variables, it is possible to estimate the net revenue corresponding to any given ration, (specified in terms of the control variables: nutrient concentration combination). The aim of the economic analysis is to estimate the levels of the control variables that maximise net revenue and to examine the sensitivity of net revenue to changes in the values of the control variables, for any given values for the set of exogenous variables.

An examination of the net revenue equation (6.7) in conjunction with the estimated production functions, for the endogenous variables ($N_j, \Delta W_j, I_j$), that include various nutrient densities as independent (control) variables, leads to the conclusion that we have a non-linear programming problem. Given an appropriate computer programme it would be possible to solve the problem analytically. However, simpler and less costly, though approximate, methods of analysis are available. Candler and Cartwright (1969) describe a method whereby the variable of interest, (net revenue in this analysis), can be estimated as a function of the control variables; the estimated function can then be used to conduct the desired economic analysis.

We can adopt the procedure described by Candler and Cartwright as follows:

(1) Construct an appropriate experimental design in terms of various levels of the control variables. In our analysis this implies a set of nutrient levels (treatments), each corresponding to a ration.

(2) For the j^{th} experimental treatment:

  (a) Use Linear Programming to find the least-cost feed mix and hence P_j.
  (b) Choose the appropriate feed intake function and estimate total feed intake for the j^{th} experimental treatment, (I_j).
  (c) Estimate total feed cost: $P_j \; I_j$
  (d) Choose the appropriate egg number production function and estimate N_j, and hence estimate egg revenue $P_e \; N_j$.
  (e) Choose the appropriate liveweight gain function and estimate ΔW_j and hence $\Delta W_j \; P_b + WP_b = W'P_b$. Since we assume W is constant across all treatments within a strain, we could in fact ignore the term WP_b.)
  (f) Estimate net revenue per hen (Z_j) for the production period of interest, equation (6.7).

(3) Repeat this procedure for all of the experimental treatments specified in (1), so as to obtain an estimated value for Z_j corresponding to each set of nutrient levels (treatments).

(4) Use the estimated Z_j values to estimate an explicit function for net revenue in terms of the control variables, (nutrient levels). As mentioned above, this estimated function can then be used to conduct the desired economic analysis.

6.3 Experimental design

Examination of the functional relationships presented in Chapter Five leads to the following choice of control variables for this economic analysis:

X_1 = Dietary metabolisable energy concentration
X_2 = Dietary isoleucine concentration
X_3 = Dietary methionine concentration

We wish to estimate net revenue (Z) as a function of these control variables:

$$Z = f(X_1, X_2, X_3) \qquad (6.8)$$

The form of this function is not known but we can often make use of the properties of a Taylor series expansion to approximate a function in some small region, Allen (1938), Heady and Dillon (1961). The first-order Taylor series approximation is a linear function, the second-order approximation a quadratic function, and so on. In this study we have chosen to approximate equation (6.8) by a quadratic function:

$$\begin{aligned} Z = {} & b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_{11} X_1^2 \\ & + b_{22} X_2^2 + b_{33} X_3^2 + b_{12} X_1 X_2 \\ & + b_{13} X_1 X_3 + b_{23} X_2 X_3 \qquad (6.9) \end{aligned}$$

From equation (6.9) we need to estimate ten regression coefficients and hence the experimental design used will need to include at least ten treatments.

The experimental treatments used in this analysis were chosen after careful consideration of the range of dietary nutrient concentrations used in LN/32. Three energy density levels were used to estimate the production relationships presented in Chapter Five. The actual range of methionine and isoleucine concentrations varied between the three energy levels. For each energy level, (2756, 2976 and 3197 k. cal. M.E. per kg.), three methionine and three isoleucine levels were selected to give a (3 x 3) factorial arrangement of treatments that covered the actual methionine and isoleucine range for LN/32. The resulting 27 treatments, (combinations of values for X_1, X_2 and X_3), however do not exactly conform to a (3 x 3 x 3) factorial arrangement since the actual range of values for methionine (X_3) and isoleucine (X_2) varied between energy levels (X_1). Crude protein, calcium and phosphorus were also contained within the limits used in LN/32.

The experimental treatments chosen for our economic analysis are presented in Table 6.1.

The results presented in Chapter Five indicated differences between strains used for LN/32, for the feed intake, egg number and liveweight gain functions. This economic analysis considers only the results for White Base (b) layers and assumes that the initial liveweight of these birds in 1556 grams at start of lay, (22 weeks of age), i.e. W = 1556.

Table 6.1: Experimental treatments for the economic analysis

Treatment	Dietary M.E. (k.cal/kg) (X_1)	Dietary Isoleucine (%) (X_2)	Dietary Methionine (%) (X_3)	Dietary C.P. (%)	Dietary Calcium (%)
1	2756	0.47	0.22	14.45-16.26	2.85-3.35
2			0.24		
3			0.26		
4		0.50	0.22		
5			0.24		
6			0.26		
7		0.53	0.22		
8			0.24		
9			0.26		
10	2976	0.54	0.26	15.61-17.59	2.94-3.45
11			0.28		
12			0.30		
13		0.57	0.26		
14			0.28		
15			0.30		
16		0.60	0.26		
17			0.28		
18			0.30		

Table 6.1: <u>(Contd.)</u>:

Treatment	Dietary M.E. (k.cal/kg) (X_1)	Dietary Isoleucine (%) (X_2)	Dietary Methionine (%) (X_3)	Dietary C.P. (%)	Dietary Calcium (%)
19	3197	0.50	0.24	16.77-18.86	3.03-3.56
20			0.26		
21			0.28		
22		0.52	0.24		
23			0.26		
24			0.28		
25		0.54	0.24		
26			0.26		
27			0.28		

6.4 Ration formulation

Rations were formulated to least-cost for each of the experimental treatments presented in Table 6.1. A number of the ingredients used to formulate rations for LN/32 were not available and these were not considered. As methionine is one of the experimental variables, synthetic methionine was considered in ration formulation as it was suspected that rations may have become artificially expensive had the methionine concentration only been met by the original ingredients.

The ingredients considered in ration formulation, with their cost(1), are presented in Table 6.2.

6.5 Egg and culled hen prices

Egg and culled hen prices were those current in the Manawatu on 23 December, 1973.

(a) Eggs

Eggs were graded under the system used in 1971. The weight distribution per grade, then current was:

Grade	Weight
Large	+ 62 grams
Standard	53-62 grams
Medium	44-53 grams
Pullet	35-44 grams
Undersize	less than 35 grams

---

(1) The cost of ingredients used was the cost of ingredients to the P.R.C. as at 21.12.73.

Table 6.2: Ingredient cost for economic analysis

Ingredient	Cents per kilogram
Barleymeal	7.275
Wheatmeal	9.991
Pollard	6.938
Lucernemeal	10.138
Bloodmeal	39.397
Buttermilk	44.433
Boneflour	5.228
Bran	7.383
Maizemeal	5.431
Linseedmeal	12.503
Meat and bone meal (Borthwicks)	28.652
Tallow	28.652
Limestone	1.124
Dicalcium phosphate	66.120
Oystershell	4.634
Iodised salt	7.674
Premix	139.403
Synthetic methionine	180.728

The price schedule for eggs at the time of the economic analysis (December, 1973) was for the following grading system.

Grade	Minimum Weight	Cents per dozen
7	744 grams per dozen	51
6	636 grams per dozen	48
5	528 grams per dozen	41
4	420 grams per dozen	33
Undersize	Less than 420 grams per dozen	21
Commercial		41

The weights for the two systems of grading are almost identical. We can therefore use the December 1973 price schedule for the 1971 gradings.

For the economic analysis all undersize, commercial and pullet eggs are grouped (price = 33 cents per dozen).

The average grade distribution of eggs for White Base (b) layers was used in the economic analysis:

Grade	Percent eggs per grade
7	20.78
6	58.20
5	17.49
4 (plus others)	3.53
Total	100.00

Thus the weighted average egg price (P_e) used in this analysis is:

$$P_e = 51\ (.2078) + 48\ (.5820) + 41\ (.1749) + 33\ (.0353)$$
$$= 46.9 \text{ cents per dozen.}$$

6.6 Experimental results

The experimental results for each treatment (Table 6.1) in the economic analysis are presented in Tables 6.3-6.6.

Endogenous variables I_j, N_j and ΔW_j are predicted from the estimated functions for White Base (b) layers presented in Chapter Five. Where daily metabolisable energy, methionine or isoleucine intakes are variables in these equations, predicted values are obtained from the relationship:

Table 6.3: Feed consumption and cost

Treatment	Feed consumption (gms./hen/day) (I_j)	Cost per kg. (cents) (P_j)	Total cost/ hen/315 days ($) ($F_j$)
1	119.34	8.97	3.37
2		9.01	3.39
3		9.05	3.40
4		8.93	3.36
5		8.88	3.34
6		8.91	3.35
7		8.89	3.34
8		8.74	3.29
9		8.78	3.30
10	115.80	10.00	3.65
11		10.04	3.66
12		10.08	3.68
13		10.01	3.65
14		10.05	3.67
15		10.09	3.68
16		10.39	3.79
17		10.43	3.80
18		10.47	3.81
19	112.24	13.07	4.62
20		12.84	4.54
21		12.89	4.56
22		13.56	4.79
23		11.91	4.21
24		11.95	4.23
25		INFEASIBLE	RATION
26		11.99	4.24
27		12.03	4.26

Table 6.4: Egg number and revenue

Treatment	Eggs per hen per 315 days (N_j)	Eggs per grade Grade				Egg revenue per hen per 315 days ($) ($R_j$)
		7	6	5	4	
1	189	39	110	33	7	7.38
2	194	40	113	34	7	7.58
3	199	41	116	35	7	7.77
4	189	39	110	33	7	7.38
5	194	40	113	34	7	7.58
6	199	41	116	35	7	7.77
7	189	39	110	33	7	7.38
8	194	40	113	34	7	7.58
9	119	41	116	35	7	7.77
10	202	42	118	35	7	7.89
11	207	43	121	36	7	8.09
12	212	44	124	37	7	8.29
13	202	42	118	35	7	7.89
14	207	43	121	36	7	8.09
15	212	44	124	37	7	8.29
16	202	42	118	35	7	7.89
17	207	43	121	36	7	8.09
18	212	44	124	37	7	8.29
19	198	41	115	35	7	7.73
20	203	42	118	36	7	7.93
21	208	43	122	36	7	8.13
22	198	41	115	35	7	7.73
23	203	42	118	36	7	7.93
24	208	43	122	36	7	8.13
25	INFEASIBLE RATION					
26	203	42	118	36	7	7.93
27	208	43	122	36	7	8.13

Table 6.5: Body weight gain and culled hen revenue

Treatment	Weight gain (gms/hen/ 315 days) (ΔW_j)	Final liveweight (gms/hen) (W'_j)	Culled hen revenue ($ per hen) (V_j)
1	658	2214	0.78
2	595	2151	0.76
3	528	2084	0.74
4	673	2229	0.79
5	610	2166	0.76
6	543	2099	0.74
7	719	2275	0.80
8	656	2212	0.78
9	589	2145	0.76
10	716	2272	0.80
11	652	2208	0.78
12	588	2144	0.76
13	746	2302	0.81
14	682	2238	0.79
15	618	2174	0.77
16	776	2332	0.82
17	712	2269	0.80
18	648	2204	0.78
19	847	2403	0.85
20	783	2339	0.83
21	722	2278	0.80
22	866	2422	0.85
23	802	2358	0.83
24	741	2297	0.81
25	INFEASIBLE RATION		
26	821	2377	0.84
27	760	2316	0.82

Table 6.6: Income, cost and net revenue ($ per hen for the total laying period, 315 days)

Treatment	Egg revenue (R_j)	Culled hen revenue (V_j)	Feed cost (F_j)	Net revenue (Z_j)
1	7.38	0.78	3.37	4.79
2	7.58	0.76	3.39	4.95
3	7.77	0.74	3.40	5.11
4	7.38	0.79	3.36	4.81
5	7.58	0.76	3.34	5.00
6	7.77	0.74	3.35	5.16
7	7.38	0.80	3.34	4.84
8	7.58	0.78	3.29	5.07
9	7.77	0.76	3.30	5.23
10	7.89	0.80	3.65	5.04
11	8.09	0.78	3.60	5.21
12	8.29	0.76	3.68	5.37
13	7.89	0.81	3.65	5.05
14	8.09	0.79	3.67	5.21
15	8.29	0.77	3.68	5.38
16	7.89	0.82	3.79	4.92
17	8.09	0.80	3.80	5.09
18	8.29	0.78	3.81	5.26
19	7.73	0.85	4.62	3.96
20	7.93	0.83	4.54	4.22
21	8.13	0.80	4.56	4.37
22	7.73	0.85	4.79	3.79
23	7.93	0.83	4.21	4.55
24	8.13	0.81	4.23	4.71
25		INFEASIBLE RATION		
26	7.93	0.84	4.24	4.53
27	8.13	0.82	4.26	4.69

$$\hat{x} = X.I \qquad (6.10)$$

where X is the percentage (density) of the nutrient in the ration and $\hat{I}$ is predicted ration intake.

6.7 Net Revenue Function

Least Squares regression was used to estimate equation (6.9) and hence express net revenue (Z) as a function of the control variables:

X_1 = metabolisable energy (k.cal. per kg. of ration)
X_2 = isoleucine (percent of ration)
X_3 = methionine (percent of ration).

The estimated equation is presented in Table 6.7.

Table 6.7: Estimated net revenue equation

Variable	Regression coefficient
CONSTANT	$b_0 = 30.613$
X_1	$b_1 = -16.045$
X_2	$b_2 = 2.188$
X_3	$b_3 = -17.375$
X_1	b_{11} = -(1)
X_2	$b_{22} = -55.387$
X_3	$b_{33} = -83.601$
X_1 X_2	$b_{12} = 17.482$
X_1 X_3	$b_{13} = 18.871$
X_2 X_3	$b_{23} = 32.031$

$R^2 = .957$

---

(1) Variable X_1^2 was "expelled" from the regression due to a near linear relationship between this variable and the other variables in the equation. Given the "good fit" of this equation, as measured by the R^2 value we have assumed $b_{11} = 0$ in the subsequent analysis.

For convenience and ease of exposition we can write the estimated net revenue equation in terms of X_2 (isoleucine percent) and X_3 (methionine percent) for any level of metabolisable energy in the ration (X_1):

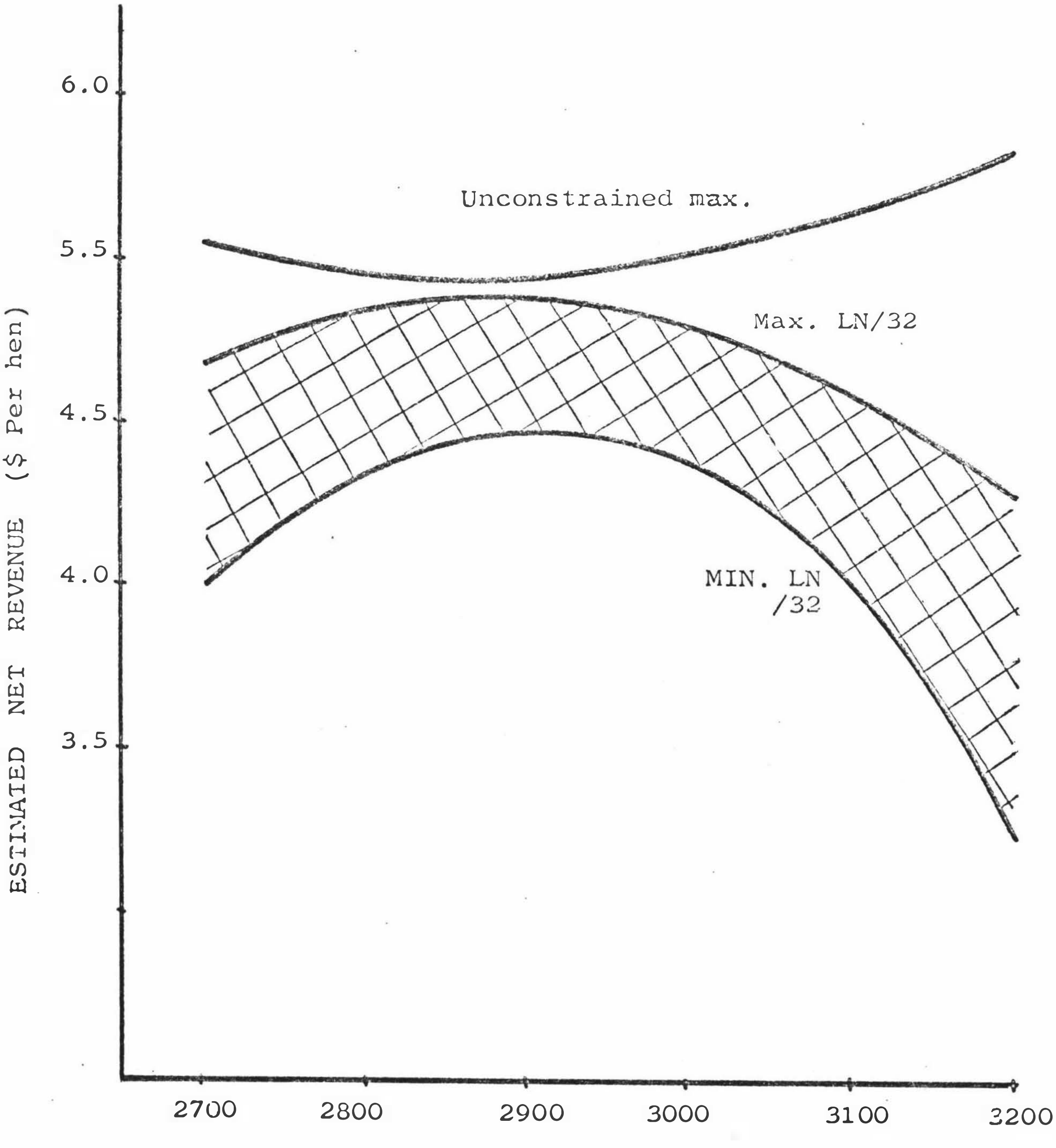
$$\begin{aligned} Z = & (30.613 - 16.045\,X_1) + X_2\,(2.188 + 17.482\,X_1) \\ & + X_3\,(-17.375 + 18.871\,X_1) - 55.387\,X_2^{\,2} \\ & - 83.601\,X_3^{\,2} + 32.031\,X_2\,X_3 \end{aligned} \qquad (6.11)$$

For values of metabolisable energy density (X_1) in the range used in LN/32 we can use calculus to calculate values for (X_2, X_3) that maximise estimated net revenue (Z). These values are tabulated for selected metabolisable energy values in Table 6.8, and the relationship between estimated net revenue (maximised) and metabolisable energy is graphed in Figure 6.1.

It is important to note that, for each of the energy levels used in LN/32, the estimated isoleucine and methionine ration levels that maximise net revenue (Table 6.8) are outside the range of isoleucine and methionine ration levels actually used in LN/32, (Table 6.1). It is likely that the energy, isoleucine and methionine levels in Table 6.8 would not in practice be feasible in a ration; or that ration cost would be greatly increased; or that predicted production response from the implied nutrient intakes would not eventuate in practice. For example, in Chapter Five, the response in egg number to increasing methionine intake was estimated as a linear relationship. As methionine intake increased, egg numbers were predicted to increase linearly. Since ration intake was predicted as a function of dietary

Figure 6.1

RELATION BETWEEN ESTIMATED NET REVENUE AND ENERGY DENSITY OF LAYER RATIONS



DIETARY ENERGY (k. cal. M.E. per Kg.)

energy concentration, an increase in methionine concentration at any given energy concentration will result in increased methionine intake. Predicted methionine intake for a ration containing 2756 k. cal. M.E. per kg. and 0.30 percent methionine is 0.358 grams per hen per day. This level is higher than actually achieved on any ration in LN/32. Fisher and Morris (1970) have demonstrated that for high levels of methionine intake, the egg response is non-linear. In this situation further research would be required before one could recommend layer rations based on the results presented in Table 6.8.

Table 6.8: Estimated isoleucine and methionine ration levels for maximum net revenue

M.E. (X_1) (k.cal/kg.)	Isoleucine (X_2) (%)	Methionine (X_3) (%)	Net revenue (Z) ($/hen)
2700	0.534	0.303	5.55
2756(1)	0.545	0.312	5.51
2800	0.554	0.318	5.48
2900	0.574	0.333	5.48
2976(1)	0.589	0.345	5.52
3100	0.614	0.364	5.66
3197(1)	0.621	0.378	5.83

(1) Energy levels used in LN/32

In order to overcome the problem of extrapolating beyond the experimental range of isoleucine and methionine levels (percent), the values for (X_2, X_3) that maximise and minimise estimated net revenue (Z) within the experimental range, for the metabolisable energy levels of LN/32, were calculated. These values are presented in Table 6.9 and graphed in Figure 6.1. The shaded area in Figure 6.1

represents the estimated net revenue range for the range of isoleucine and methionine levels corresponding to each energy level in LN/32.

Table 6.9: Maximum and minimum estimated net revenues for LN/32

Level	M.E. (X_1)	Isoleucine (X_2)	Methionine (X_3)	Net Revenue ($/hen)
max	2756	0.530	0.260	5.30
min	2756	0.470	0.220	4.72
max	2976	0.580	0.30	5.36
min	2976	0.540	0.26	4.92
max	3197	0.540	0.280	4.84
min	3197	0.500	0.240	3.85

Several features of Figure 6.1 are worthy of comment. Maximum estimated net revenue for LN/32 closely approximates the unconstrained maximum estimated net revenue over the lower energy density levels (2756, 2976 k. cal. M.E. per kg.) but there is a wide discrepancy at the high energy level, (3197 k. cal. M.E. per kg.). There is little to choose between the best ration of each of the lower energy density levels but maximum estimated net revenue for LN/32 declines rapidly as energy density increases above 3000 k. cal. M.E. per kg. Also, there is greater variability in estimated net revenue of the high compared with the lower energy levels within the isoleucine and methionine ranges of LN/32.

The shape of the unconstrained maximum estimated net revenue curve in Figure 6.1 is not what one might have expected. However, as mentioned previously, we should have serious reservations about predicting net revenue much outside the bounds of an experimental region.

We can now turn our attention to the effect of variation in isoleucine and methionine levels, from LN/32, on estimated net revenue. We will initially limit this discussion to rations with energy densities of 2756 amd 2976 k. cal. M.E. per kg. Tables 6.10 and 6.11 have been constructed from Tables 6.1 and 6.6.

Table 6.10: Estimated net revenues ($/hen) for rations of 2756 k. cal. M.E./kg.

		Methionine level (%)			Range
		0.22	0.24	0.26	
Isoleucine level (%)	0.47	0.79	4.95	5.11	0.32
	0.50	4.81	5.00	5.16	0.35
	0.53	4.84	5.07	5.23	0.39
Range		0.05	0.12	0.12	

Table 6.11: Estimated net revenue ($/hen) for rations of 2976 k. cal. M.E./kg.

		Methionine level (%)			Range
		0.26	0.28	0.30	
Isoleucine level (%)	0.54	5.04	5.21	5.37	0.33
	0.57	5.05	5.21	5.38	0.33
	0.60	4.92	5.09	5.26	0.34
Range		0.12	0.12	0.11	

From Tables 6.10 and 6.11 it would appear that changes in dietary methionine level have a greater effect on net revenue than changes in dietary isoleucine level. Again however, this result should be treated with some caution. Isoleucine intake was not found to be a significant variable in the egg number production function whereas methionine intake was found to be significant. This result could well have been due to deficiencies in the design of experiment LN/32 since isoleucine and methionine levels were not subject to control. We can put forward the tentative hypothesis that net revenue is more sensitive to methionine level than isoleucine level but this hypothesis should be tested by further research.

The estimated functions can also be used to investigate the relationship between net income and daily intake levels of selected nutrients. For example, we may be interested in the estimated relationship between average daily methionine intake for rations containing 0.55 percent isoleucine and various energy density levels. Since we have estimated feed consumption for rations of different energy densities (Table 6.3), we can easily calculate corresponding methionine daily intake levels (gms per hen per day) and methionine ration levels (percent). These figures are presented in Table 6.12 for selected methionine intake values.

Substituting for $X_2 = 0.55$ (isoleucine), equation 6.11 becomes:

$$Z = (15.062-6.4299X_1) + X_3\ (0.26 + 18.871\ X_1) - 83.601\ X_3^2$$

This equation can then be used to relate estimated net revenue and energy density of different average daily methionine intake levels for the total period of lay.

These relationships are presented in Figure 6.2. We can note, that if our estimated functions were assumed to hold true for a daily methionine intake of 0.35 grams/bird/day, there would be little to choose, in terms of net revenue, between rations of different energy densities, formulated to meet this methionine intake. However, we can also note that this conclusion involves an extrapolation beyond the limits of LN/32 for the 2756 and 3197 k. cal. M.E. per kg rations.

Table 6.12: Methionine ration levels (%) corresponding to different methionine intake levels

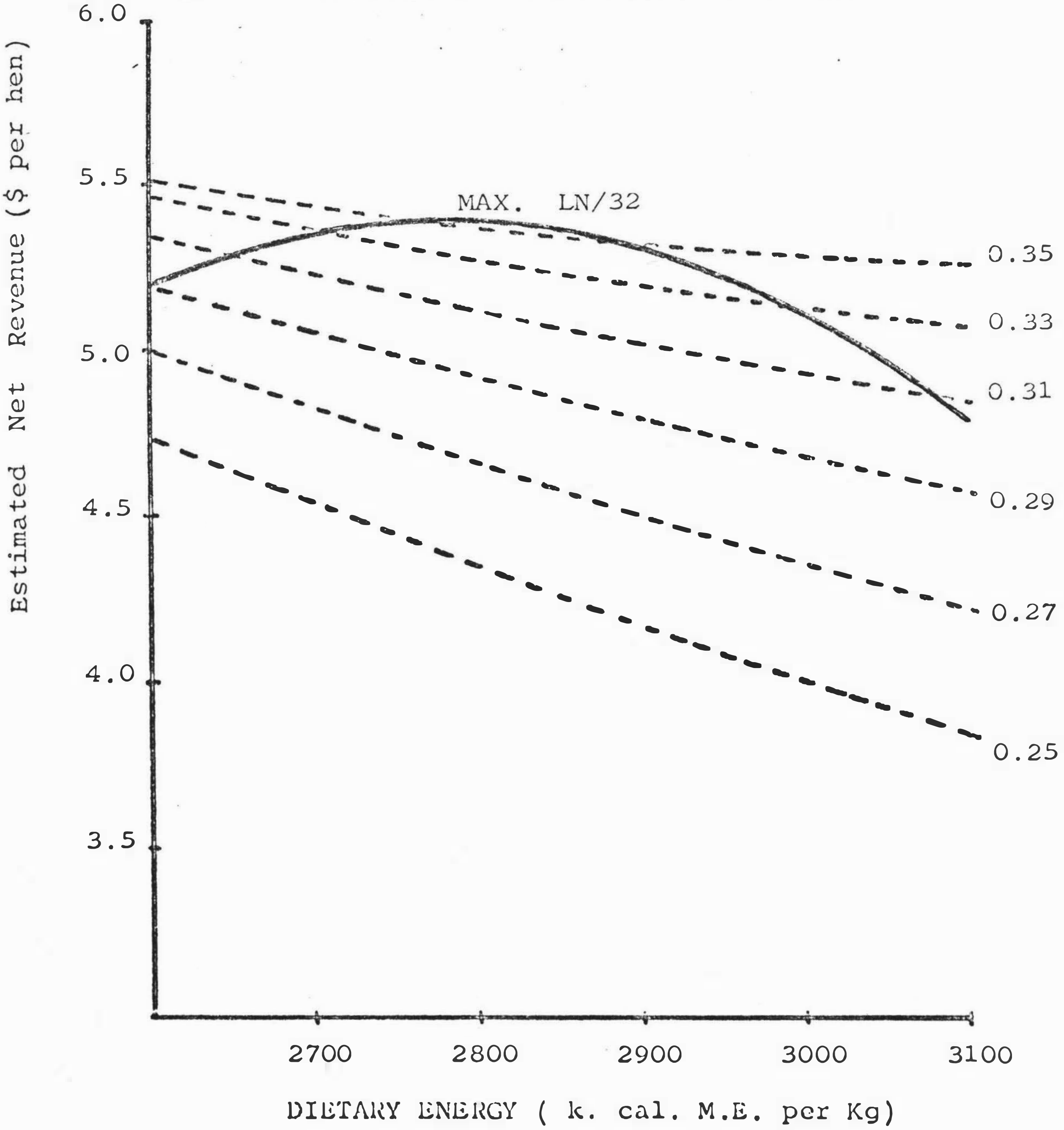
Methionine intake (gms/hen/day)	M.E. (k.cal/kg ration) (Feed intake, gms/hen/day) 2756 (119.34)	2976 (115.80)	3197 (112.24)
		(X_3)	
.25	0.2095	0.2159	0.2227
.27	0.2262	0.2332	0.2406
.29	0.2430	0.2504	0.2584
.31	0.2598	0.2677	0.2762
.33	0.2765	0.2850	0.2940
.35	0.2933	0.3022	0.3118

6.8 Conclusion

The economic analysis presented in this Chapter suggests that, for the nutrient densities used in LN/32, a ration formulated to contain: 2976 k. cal. M.E. per kg, 0.30 percent methionine and 0.58 percent isoleucine (Table 6.9) will maximise net revenue under the given price structure.

Figure 6.2

RELATIONSHIP BETWEEN ESTIMATED NET REVENUE AND ENERGY DENSITY AT DIFFERENT DAILY METHIONINE INTAKES (GMS); ISOLEUCINE AT 0.55 PERCENT.



We should stress that these results are dependent on the levels of the exogenous variables, especially product (eggs and culled hen) and feedstuff prices. The analysis presented applies to prices current in December, 1973. Should the price of high energy feedstuffs (maize, wheat) decrease in relation to the price of low energy feedstuffs (pollard, barley) then high energy density rations could result in maximum net revenue.

The economic analysis of values for the control variables, methionine level and isoleucine level in the ration, that fall outside the range of those used in LN/32 should be treated with a great deal of caution. At best this analysis can be used to estimate the potential benefit from further research using levels outside the range of those used in LN/32; but even here it is likely that ration cost or ration infeasibility should be investigated further before actual experimentation is contemplated (Townsley, 1971).

The economic analysis has been limited to the case where given rations are fed ad libitum during the entire period of lay. LN/32 was not designed to investigate the economics of phase feeding though some attention is given to this topic in Chapter Seven. Also, LN/32 was not designed specifically to estimate production responses to different isoleucine and methionine levels and future research results from P.R.C. should enable the estimation of these relationships with greater confidence. The primary aim of this Chapter has been to illustrate one approach to the economic [illegible] analysis of layer rations incorporating response functions for the endogenous variables of the production system under study.

CHAPTER SEVEN

ASPECTS OF LAYER RESPONSES

7.1 Introduction

LN/32 was originally designed to obtain quantitative estimates of layer responses that were of economic significance. This analysis was the basis of Chapter Five. LN/32 however provided information on other aspects of layer responses.

Included in LN/32 was treatment 17 to study the effects of protein source on layer responses. Treatments 16 and 18 were designed to study the effects of restricted feeding on layer responses.

Although LN/32 was not designed to study aspects of phase feeding of layers we can analyse the results for periods within the laying cycle in an endeavour to determine if responses are affected by different nutrients at difference periods in the laying cycle. We can choose two periods (1-140, 168-315 days) for this analysis as they correspond with changes in ration composition for treatments 1, 3-6. It must be stressed that this analysis does not take account of changes in the ration as is inferred by phase feeding.

In this Chapter we will analyse the following aspects of LN/32:

(1) Treatment 17.
(2) Treatments 16, 18.
(3) Periods 1-140, 168-315 days.

7.2 Treatment 17

Ration 17 was formulated to the same energy and protein density as ration 14 (3197 k. cal. M.E. per kg., 17 grams protein intake based on an intake of 305 k. cal. M.E. per day). In addition, ingredient constraints were imposed.

1. A minimum inclusion rate of 1.5 percent buttermilk powder.
2. A minimum inclusion rate of 10.0 percent pollard.

This ration was formulated to include protein sources of proven quality. It had been suspected that the high meatmeal inclusion rate in rations of 3197 k. cal. M.E. per kg. would reduce the range of protein sources to virtually meatmeal alone. Should the meatmeal have an imbalance of amino acids then it was suspected there may have been a reduced egg output. To test for any response to the ingredient inclusion we can compare treatments 17 and 14.

7.2.1 Feed intake

Treatment 17 (like treatment 14) was fed *ad libitum*. Feed intake for treatments 14 and 17 for the 315 days of the laying cycle are presented in Table 7.1.

Apart from White Base (a) layers the feed intake is similar for both treatments. An examination of the feed intake of White Base (a) layers for all treatments shows that intake for this strain was greater on treatment 14 than on treatments of a similar energy concentration (3197 k. cal. M.E. per kg.).

Table 7.1: H.D. feed intake. Treatments 14, 17 (grams/hen/day)

Treatment	Strain W.B.(a)	 W.B.(b)	 M.L.	Total
14	116.1	116.1	113.4	345.6
17	101.2	115.7	111.3	328.2

7.2.2 Egg number

Egg number for treatments 14, 17 for the total laying period are presented in Table 7.2.

Table 7.2: H.D. egg number. Treatments 14, 17 (eggs/hen/315 days)

Treatment	Strain W.B.(a)	 W.B.(b)	 M.L.	Total
14	216.6	207.4	216.9	640.9
17	200.0	206.3	214.7	621.0

Again, White Base (a) layers are the only strain where there are response differences. There is a positive correlation between feed intake (and hence nutrient intakes) and egg number for all strains of layers. Although White Base (a) layers on treatment 17 did not perform to the level of that strain on treatment 14 they did perform better than layers on treatment 13 and 15 (also 3197 k. cal. M.E. per kg.). We can only hypothesise that White Base (a) layers on treatment 14 responded to an increase in feed intake which resulted in an increased energy intake. We cannot explain why this difference in feed intake occurred.

In general, we can say that there was no difference in the response between treatments 14 and 17. As hens consumed in excess of 17 grams of protein (treatment 14 = 20.53 grams, treatment 17 = 19.51 grams) the hypothesis that protein quality may be suspect could not be tested in the light of overconsumption of protein.

7.3 Treatments 16, 18

It was suspected that hens fed a diet of 3197 k. cal. M.E. per kg. may consume in excess of 305 k. cal. M.E. per day. Should this occur, it was decided to restrict the energy intake of layers to 305 k. cal. M.E. per day to determine what effect restricted nutrient intake would have on layer production. Two treatments (16, 18) were assigned to a restricted feeding regime.

Treatments 16 and 18 were formulated to the same energy and protein density as ration 14 (3197 k. cal. M.E. per kg.; 17 grams protein intake based on an intake of 305 k. cal. M.E. per day). In addition the ingredient constraints for treatment 17 were imposed on treatment 18.

Treatments 16 and 18 were initially fed at the rate of 305 k. cal. M.E. per hen per day. Treatments 14 and 17 are used as the controls in the comparisons that follow.

7.3.1 Feed intake

It was originally intended to feed treatments 16, 18 such that hens would receive 305 k. cal. M.E. per kg. Egg number in the first three months of treatments 16, 18 showed that hens were not performing to the level of hens on treatments 14 and 17. The H.D. egg number for treatments 14, 16, 17, 18 for the third month of lay are presented in Table 7.3.

Table 7.3: H.D. egg number. Treatments 14, 16, 17, 18. Month 3. (Eggs per treatment strain)

Treatment	Strain W.B.(a)	W.B.(b)	M.L.	Total
14	607	644	604	1855
16	505	552	636	1693
17	615	599	649	1863
18	584	577	600	1761

Although M. Line layers were producing at the same level for all treatments for month 3 of the laying period, the White Base (a) and White Base (b) layers produced least eggs on treatments 16 and 18. It was decided to increase the energy intake for treatments 16 and 18. This resulted in the daily energy intakes for the total laying period as shown in Table 7.4. Treatments 14 and 17 are used as the comparison.

Table 7.4: Daily energy intake for the total laying period (k. cal. M.E. per hen per day)

Treatment	Strain W.B.(a)	W.B.(b)	M.L.
16	311	330	324
18	311	319	317
14	371	371	363
17	324	370	356

7.3.2 Egg number

H.D. egg number for the total laying period for treatments 14, 16-18 are presented in Table 7.5.

Table 7.5: H.D. egg number. Treatments 14, 16, 17, 18. (Eggs per hen per 315 days).

Treatment	Strain W.B.(a)	W.B.(b)	M.L.	Total
14	216.6	207.4	216.9	640.9
16	180.5	180.6	225.6	586.7
17	200.0	206.3	214.7	621.1
18	177.9	199.7	211.0	588.6

A comparison of the egg number results for treatments 14 and 16 shows that for White Base (a) and White Base (b) layers production is significantly higher for treatment 14. M. Line layers produced best on treatment 16. Thus, for two strains of layers the reduced nutrient intake resulted in a negative response in egg number.

For all strains, egg number was higher on treatment 17 than 18 although only marginally so for White Base (b) and M. Line layers. Again, there is a negative response in egg number to a reduced nutrient intake.

Although there are strain differences, treatments 16 and 18, in general, produced the same number of eggs. The ingredient constraints in the ration fed to treatment 18 had no effect on egg number.

Using the egg number function presented in Chapter Five (realising that it applied to treatments fed ad libitum) we can estimate the expected egg number for treatments 16 and 18 given the intake of energy and methionine. The predicted (and actual) egg number for treatments 16 and 18 are presented in Table 7.6.

Table 7.6: Predicted H.D. egg number. Treatments 16, 18 (Actual H.D. egg number in brackets). (Eggs per hen per 315 days).

Treatment	W.B.(a)	Strain W.B.(b)	M.L.	Total
16	190.5 (180.5)	188.8 (180.6)	215.7 (225.6)	595.0 (586.7)
18	190.8 (177.9)	185.5 (199.7)	213.6 (211.0)	589.9 (588.6

Although there are strain differences there is excellent agreement between the predicted and actual egg number totals.

7.4 Analysis of the periods 1-140, 168-315 days in the laying cycle

The laying period for LN/32 can be divided into two periods 1-140, 168-315 days, as a result of ration changes on five treatments (1, 3-6) after 140 days.

It has been shown (Chapter Three) that the reduced egg number for treatments 1-6 was due to ingredient factors in the rations. We cannot quantify layer responses in terms of the dietary nutrient concentration until ingredient factors are constrained such that they will not affect layer production. Rations 1-6 must therefore be excluded from any production function analysis for the first 140 days of the laying cycle.

There was improved layer production on treatments 1', 3'-6' following the ration changes after 140 days (see Appendix E). An attempt to constrain ingredient inclusion in the rations, such that layer production would not be affected, was successful. For any production function analysis for the final 147 days of the laying cycle we can include treatments 1', 3'-6'.

For each period (1-140, 168-315 days) we can analyse the feed intake and egg number results with the view of generating hypotheses about the factors affecting these layer responses in different periods during the laying cycle. Although this analysis may highlight factors which could be considered if phase feeding was practised, it is emphasised that LN/32 was not designed to study aspects of phase feeding. There is no information on the effects of a change in ration nutrient concentration which is the basis of phase feeding.

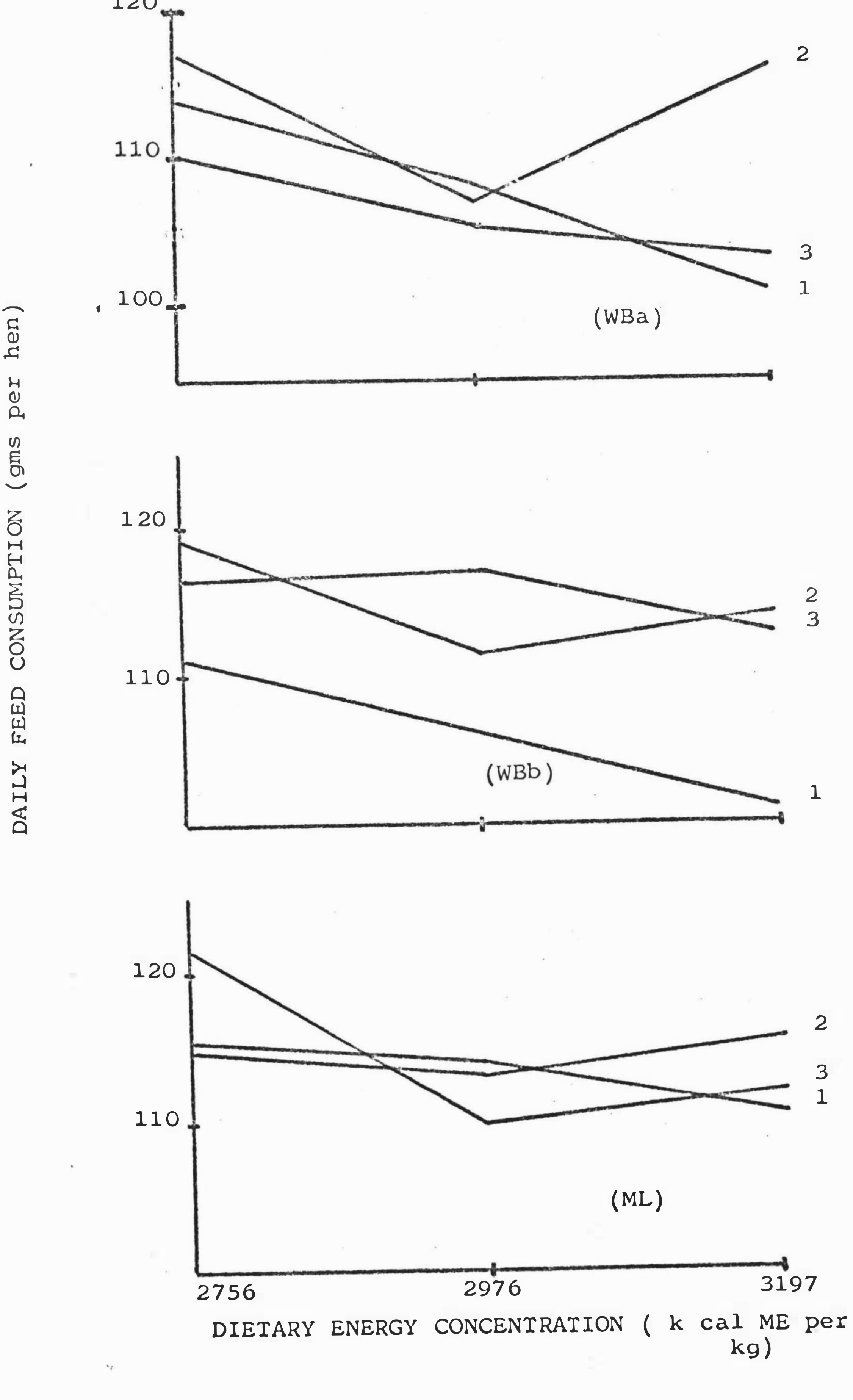
7.5 Feed consumption

7.5.1 1-140 days

Feed consumption for the first 140 days of the laying period for treatments 7-15 are graphed against the dietary energy concentration for each strain of laying hen in Figure 7.1. A distinction is made between the protein concentrations of the rations, where estimated intake of protein per day, based on an intake of 305 k. cal.s M.E. was 16(1), 17(2), 18(3) grams. There is a reduction in feed intake as the dietary energy concentration is increased. There is no obvious response to the dietary protein concentration.

Figure 7.1

DAILY FEED CONSUMPTION VS DIETARY ENERGY CONCENTRATION
(1- 140 DAYS)



An analysis of variance for feed intake for treatments 7-15 for the first 140 days of the laying period is presented in Table 7.7.

Table 7.7: Analysis of variance. Feed consumption

Source	d.f.	S.S.	M.S.	F.
Mean	1	3.22×10^4	3.22×10^4	36617
Energy	2	18.48	9.24	5.70 10%
Protein	2	10.09	5.05	3.11 NS
Whole plot error	4	6.48	1.62	
Strain	2	10.49	5.24	5.96 ^{x}
S x E	4	0.99	0.25	0.28 NS
S x P	4	12.34	3.09	3.51 10%
Split plot error	8	7.04	0.88	

The analysis of variance indicates significant between strain differences in feed consumption ($p < 0.05$) though this test is not valid (see Chapter 4.3). The Strain x Protein interaction is significant at the 10 percent level. This indicates that models for feed intake for the first 140 days of the laying period should contain protein (or perhaps amino acid) variables for each strain.

As with other analyses of variance for feed intake there is a significant response in feed intake for differences in the dietary energy concentration ($p < 0.10$).

The linear feed intake model used in Chapter Five was analysed for the period 1-140 days. This model had an error mean square of 15.23. The regression coefficients for this model are presented in Table 7.8.

Table 7.8: Regression coefficients. Linear feed intake model 1-140 days

Term	Regression coefficients	Students t-statistic	Px100	R^2 ($\bar{R}^2$)
M.L. CONSTANT	104.899			.570
W.B.a CONSTANT	99.818			.509
W.B.b. CONSTANT	101.722			
E	-0.128	.393	.050	
W	0.032	.320	.339	

Where I = feed consumption (grams per hen per hen day)
E = dietary energy concentration (k. cal. $x10^{-1}$ M.E. per kg.)
W = initial body weight (grams liveweight per hen)

7.5.2 168-315 days

Feed consumption for the period 168-315 days (the final 147 days of the laying period of LN/32) for treatments 3', 4', 6', 7-15 are graphed against the dietary energy concentration for each strain of layer in Figure 7.2. Consistent with the results for 1-140, 1-315 days there is a reduction in feed intake as the dietary energy concentration is increased.

An analysis of variance for feed intake for treatments 3', 4', 6', 7-15 for the final 147 days of the laying period is presented in Table 7.9.

There are significant differences in feed intake associated with differences in energy levels ($p < 0.01$) but the experiment is unable to detect significant differences associated with protein levels ($p > 0.10$).

Figure 7.2

DAILY FEED CONSUMPTION VS DIETARY ENERGY CONCENTRATION

(168 - 135 DAYS)

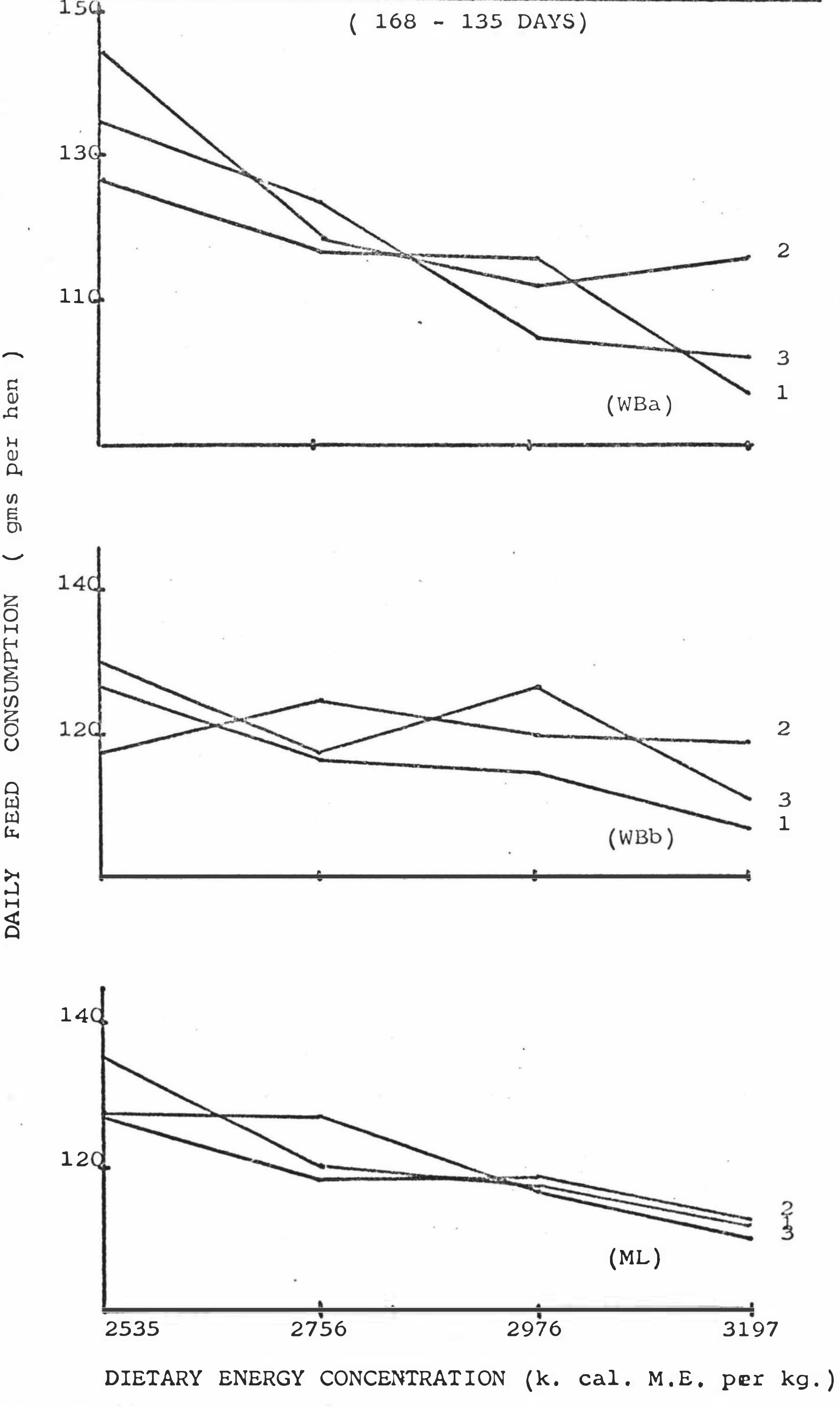


Table 7.9: Analysis of variance. Feed consumption

Source	d.f.	S.S.	M.S.	F.
Mean	1	5.38×10^4	5.38×10^4	11873
Energy	3	223.52	74.51	30.20 xx
Protein	2	7.53	3.76	1.62 N.S.
Whole plot error	6	13.93	2.32	
Strain	2	23.26	11.63	2.57 10%
S x E	6	9.43	1.57	0.35 N.S.
S x P	4	17.78	4.45	0.98 N.S.
Split plot error	12	54.41	4.53	

The analysis of variance indicates significant between strain differences in feed consumption ($p < 0.10$) though this test is not valid (see Chapter 4.3).

The linear feed intake model used in Chapter Five was analysed for the period 168-315 days. This model had an error mean square of 26.9. The regression coefficients for this model are presented in Table 7.10.

Table 7.10: Regression coefficients. Linear feed intake model 168-315 days

Term	Regression coefficients	Students t-statistic	Px100	R^2 ($\bar{R}^2$)
M.L. CONSTANT	131.662			.712
W.B.a CONSTANT	126.733			.686
W.B.b CONSTANT	129.277			
E	-0.255	8.22	0.000	
W	0.041	4.03	0.022	

Where I = feed consumption (grams per hen per hen day)

E = dietary energy concentration (k. cal. X 10^{-1} M.E. per kg.)

W = initial body weight (grams liveweight per hen).

7.5.3 Discussion

Features of the linear feed intake models for the periods 1-140, 168-315 days are:

(1) For both periods (as for 1-315 days) there is a decrease in feed intake as the dietary energy concentration is increased.

(2) There is a positive response in feed intake to an increase in the initial liveweight of the hen. It may be surprising to find that initial liveweight explains variation in feed intake in the final 147 days of the laying period (168 days after the initial weight was recorded). However, the liveweight gain models presented in Chapter Five show that liveweight gain is not affected by the initial liveweight of the hen and hence there is no compensatory growth. Heavy pullets maintain their weight advantage over lighter pullets throughout the laying period.

(3) The energy parameter for the linear feed intake models for 1-315, 1-140, 168-315 days are presented:

(a)	1-315 days	-0.161
(b)	1-140 days	-0.128
(c)	168-315 days	-0.255

Although the model for 168-315 days covers a greater energy range (2535-3197 k. cal. M.E. per kg.) the magnitude of the energy parameter is twice that for the model for 1-140 days. There is a greater decrease in feed intake for a given increase in the dietary energy concentration for the period 168-315 days than for the period 1-140 days of the laying cycle. This may be explained by an increase in feed consumption by those birds fed a dietary energy concentration of 2535 k. cal. M.E. per kg. This increase in feed intake may have been necessary to maintain an energy balance as a result of increased egg production for the period 168-315 days (see Chapter 7.6.2).

7.6 Egg number

7.6.1 1-140 days

Egg number for the first 140 days of LN/32 for treatments 7-15 are graphed against the dietary energy concentration for each strain of layer in Figure 7.3. There is no obvious trend in egg number with dietary energy concentration. As with egg number for the total laying period, there is a positive production response on a dietary energy concentration of 2976 k. cal. M.E. per kg. This corresponds with the maximum daily intake of isoleucine and methionine (as discussed in Chapter Five).

An analysis of variance for egg number for treatments 7-15 for the first 140 days of the laying period is presented in Table 7.11.

There are no significant differences in egg number associated with differences in energy levels ($p > 0.10$) or differences in protein levels ($p > 0.10$).

The analysis of variance indicates significant between strain differences in egg number ($p < 0.05$) though this test is not valid (see Chapter 4.3).

Table 7.11: Analysis of variance. Egg number

Source	d.f.	S.S.	M.S.	F.
Mean	1	2.43×10^5	2.43×10^5	7108
Energy	2	165.44	82.72	2.54 N.S.
Protein	2	109.25	54.63	1.68 N.S.
Whole plot error	4	130.47	32.61	
Strain	2	870.17	435.08	12.74 x
S x E	4	34.52	8.63	0.25 N.S.
S x P	4	176.17	44.04	1.29 N.S.
Split plot error	8	273.15	34.14	

The absence of significant responses in egg number to dietary nutrient concentration does not rule out the presence of significant responses to nutrient intake.

Two-Stage Least Squares was used to estimate production response models for egg number (see Chapter 5.3). Estimated nutrient intakes were obtained from the feed intake model presented in Table 7.8. The model with the lowest error mean square (26.45) contained an energy and calcium variable. As discussed in Chapter Five, the calcium intakes for LN/32 should have had no effect on egg number. The model with the second lowest error mean square (26.78) was of the form:

$$N = \alpha_j + \beta \hat{e}.$$

Regression coefficients for this model are presented in Table 7.12.

Figure 7.3

EGG NUMBER VS DIETARY ENERGY CONCENTRATION

1 - 140 DAYS

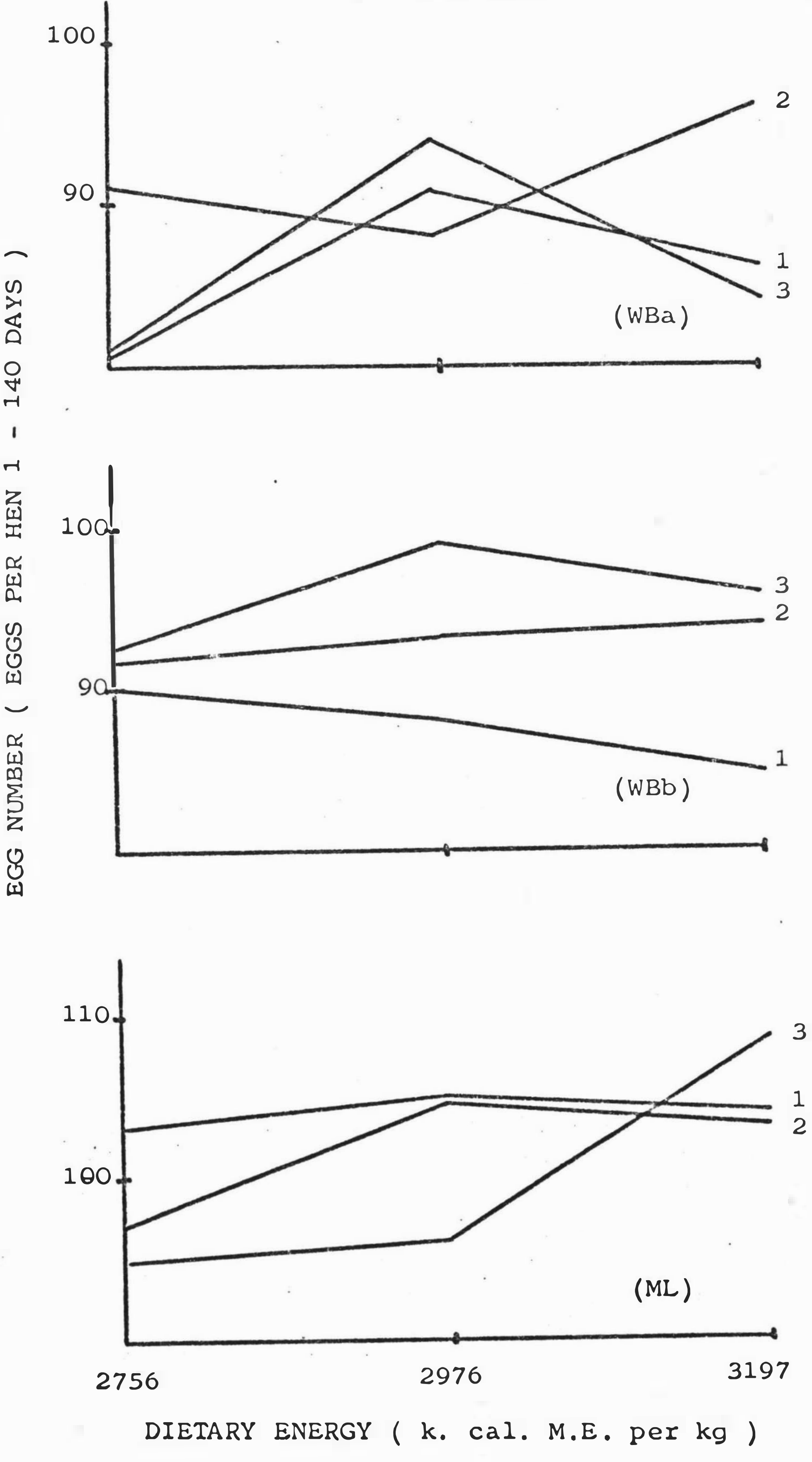


Table 7.12: Regression coefficients. Egg number 1-140 days

Term	Regression coefficients	Students t-statistic	Px100	R^2 ($\bar{R}^2$)
M.L. CONSTANT	64.987			.599
W.B.a CONSTANT	53.190			.557
W.B.b CONSTANT	57.294			
$\hat{e}$	0.110	2.20	3.586	

Where N = hen day egg number per hen for the first 140 days of the laying period

$\hat{e}$ = estimated energy consumption (k. cals. per hen per day).

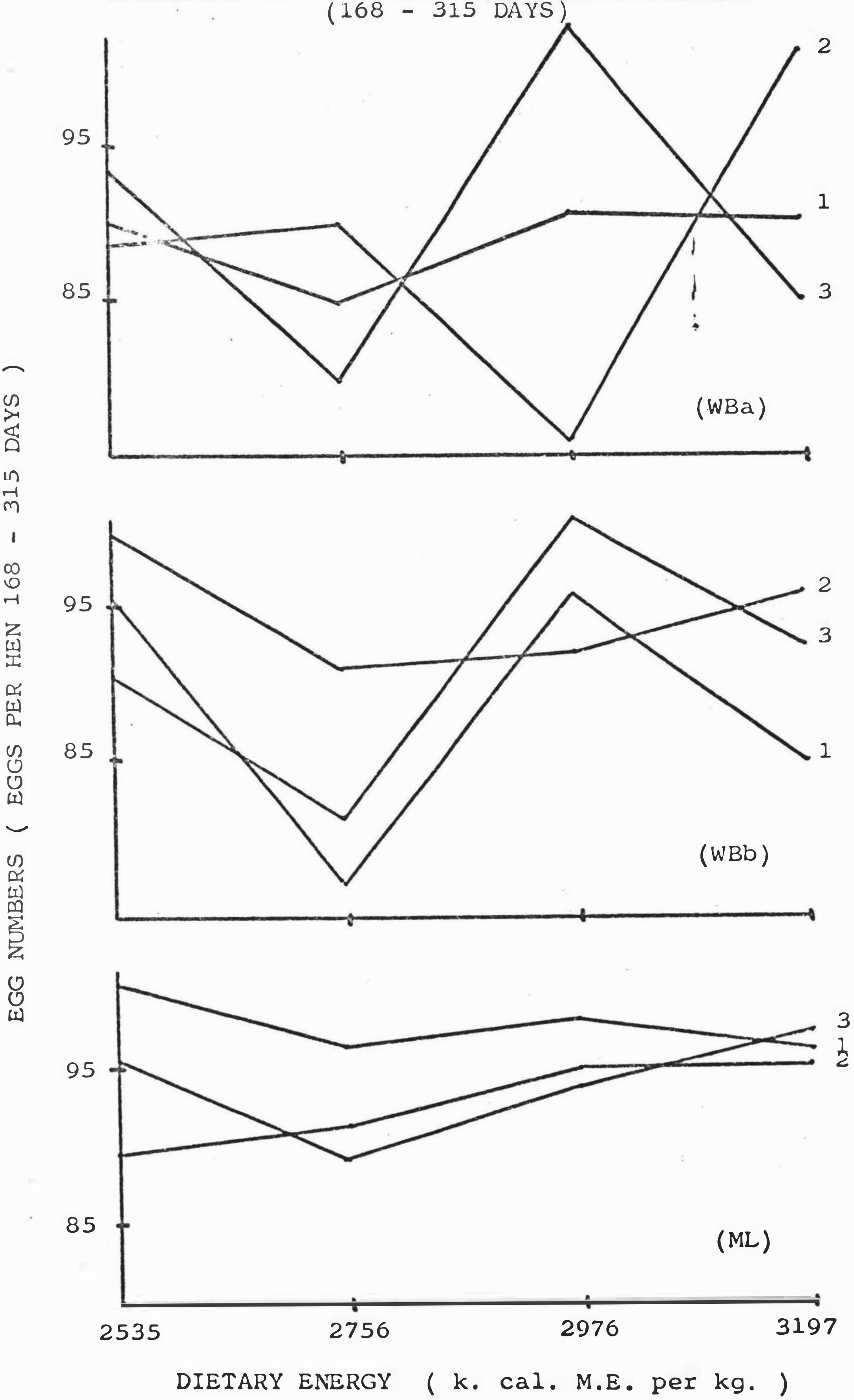
The model presented in Table 7.12 differs from the egg number model for the total laying period in that it does not contain methionine variables. White Base (b) layers did not respond to increased methionine intake for the initial 140 days of the laying period. This result may be surprising as it could be expected that any response to increased amino acid intake would occur during the peak of the laying period. LN/32 was not sensitive enough to detect this, had it in fact occurred.

7.6.2 168-315 days

Egg number for the final 147 days of the laying period (168-315 days) for treatments 3', 4', 6', 7-15 are graphed against the dietary energy concentration for each strain of layer in Figure 7.4. In general, there is an egg number maximum at an energy concentration of 2976 k. cal. M.E. per kg. Again this corresponds with the maximum daily intake of isoleucine and methionine (as discussed in Chapter Five).

Figure 7.4

EGG NUMBER VS DIETARY ENERGY CONCENTRATION
(168 - 315 DAYS)



An analysis of variance for egg number for treatments 3', 4', 6', 7-15 for the final 147 days of the laying period is presented in Table 7.13.

Table 7.13: Analysis of variance. Egg number

Source	d.f.	S.S.	M.S.	F.
Mean	1	3.01×10^5	3.01×10^5	8164
Energy	3	336.48	112.16	1.80 N.S.
Protein	2	2.98	1.49	0.02 N.S.
Whole plot error	6	395.70	65.95	
Strain	2	166.64	83.32	2.26 10%
S x E	6	115.75	19.29	0.52 N.S.
S x P	4	128.17	32.04	0.87 N.S.
Split plot error	12	442.05	36.84	

This analysis of variance detects significant between strain differences in egg number ($p < 0.10$) though this test is not valid (see Chapter 4.3). The significance of strain variation is reduced from the analysis of variance for 1-140 days. For the final 147 days of the laying period there is less variation in egg number between strains.

Two Stage Least Squares was used to estimate egg number models (see Chapter Five) where predicted nutrient intakes were obtained from the feed intake model presented in Table 7.10.

The model with the lowest error mean square (50.33) was of the form:

$$N = \alpha_j + \beta \hat{e} + \gamma \widehat{mth}.$$

The coefficient of the methionine parameter in this model is negative. An increase in the methionine intake results in a decrease in egg number. This is not consistent with the model presented by Fisher and Morris (see Chapter Two) for the levels of methionine intake in LN/32.

The model with the second lowest error mean square (50.81) was of the form:

$$N = \alpha_j + \beta \hat{e}.$$

Regression coefficients for this model are presented in Table 7.14.

Table 7.14: Regression coefficients. Egg number 168-315 days.

Term	Regression coefficients	Students t-statistic	Px100	R^2 ($\bar{R}^2$)
M.L. CONSTANT	47.625			.179
W.B.a CONSTANT	44.546			.122
W.B.b CONSTANT	41.193			
$\hat{e}$	0.136	1.75	8.72	

Where N = hen day egg number per hen for the final 147 days of the laying period

$\hat{e}$ = estimated energy consumption (k. cals. per hen per day).

Features of the model presented in Table 7.14 are:

(1) The reduced significance of the energy parameter, compared with the model for 1-140 days, as judged by the t-test.

(2) The "goodness of fit" as judged by the R^2 value shows that only 17.9 percent of the variation in egg number is explained by the model.

7.6.3 Discussion

Features of the models for egg production for the periods 1-140, 168-315 days are:

(1) For the period 1-140 days the inclusion of a methionine variable does not remove a significant sums of squares. This may be surprising as it could be expected that the amino acid intake would have a greater effect on egg production early in the laying period. LN/32 was not sensitive enough to detect this.

(2) The model presented in Table 7.14 for the period 168-315 days only accounts for 17.9 percent of the variation in egg number. Strain responses and responses in egg number to nutrient intake are not as marked in the later stages of the laying period.

(3) An examination of Figure 7.4 shows that egg number is greater on treatments of a dietary energy concentration of 2535 k. cal. M.E. per kg. than they are for a dietary energy concentration of 2756 k. cal. M.E. per kg. An explanation for this could be that there was "compensatory" egg production following the poor layer performance on treatments 1-6 during the initial 140 days of the laying period.

CHAPTER EIGHT

CONCLUSION

LN/32 was designed as part of a continuing investigation of the input/output relationships of layer production. The input/output relationships studied were those which were included in an economic model for laying hens under New Zealand production conditions.

An attempt was made to quantify the relationship between dietary energy concentration and *ad libitum* feed consumption. Nutritional theory had suggested that dietary energy concentration is the variable accounting for most of the variation in feed consumption. The results of LN/32 support this. Apart from dietary energy concentration other endogenous variables (dietary nutrient concentrations and physiological factors) were examined to determine what effect they had on *ad libitum* feed consumption. It was found that differences in the initial liveweight of the bird accounted for variation in feed consumption. The effect of initial live weight on feed consumption continued throughout the laying period. This was because relative differences between the birds initial liveweights were maintained throughout the laying period.

Under New Zealand layer production conditions the production responses from which income is derived are egg number, egg grade distribution and liveweight gain. As the controlled endogenous variables of LN/32 were dietary energy and protein concentration an attempt was made to quantify the relationships between energy and protein intakes and these layer responses.

Predicted nutrient intakes were used as the independent variables in the estimation of the egg number and liveweight gain functions as statistical problems were encountered when observed nutrient intakes were used. Two-stage Least Squares regression was used to obtain estimates of the production functions.

It was found that although energy intake accounted for differences in egg number, protein intake did not. The intake of other nutrients, not controlled in LN/32 were examined in an attempt to generate hypotheses about the relationships that should be examined in future studies. It was found that the intake of methionine affected a response in egg number, particularly for White Base (b) layers.

The nutrient intakes that affected a response in liveweight gain and hence the final weight of the culled hen were: energy, methionine and isoleucine intake.

There were no significant differences between average egg weight and hence the grade distribution of the eggs.

As LN/32 was not designed to estimate the production responses to amino acid levels, only tentative conclusions could be drawn as to the effect they had on layer production responses.

Three strains of laying hens were used to estimate the input/output responses in LN/32. It was found that there were significant strain differences in <u>ad libitum</u>

feed consumption, egg number, average egg weight and live-weight gain. As White Base (b) layers showed a positive response in egg number to methionine intake, an economic analysis was applied to this strain alone, to demonstrate an approach to the economic analysis of layer rations incorporating response functions.

A net revenue function was estimated in terms of the endogenous variables (dietary nutrient concentrations) which were included in the layer response functions. This function is of limited practical use due to:

(1) The estimates of the input/output relationships were obtained from an experiment which was not designed to study the variables which ultimately accounted for much of the variation in the production responses (amino acid intakes).

(2) Only one set of prices (the exogenous variable) was used. To obtain economic analyses under different price situations, using the method described in Chapter Six, would be expensive in terms of calculation time.

Before the procedure for the economic analysis outlined in this thesis can be adopted to the production situation, where the objective is to maximise net revenue under a dynamic price situation, the limitations of the data and the analysis must be overcome. That is:

(i) Future research must be aimed at obtaining quantified estimates of the input/output relationships of layer production. Although LN/32 only considered few controlled endogenous variables, over a limited range, the experiment identified a region for future research.

It is recognised that from an economic viewpoint, the ideal situation would be to have a complete understanding of all the physical input/output relationships of layer production. Idealistic as this may be, we can at least make some attempt to obtain knowledge of the relationships that are of major economic significance. Research has highlighted the relationship between feed consumption and dietary energy concentration. More research is required to determine what effect other nutrients have on feed consumption, particularly if they are limiting performance and hence have some affect on the energy balance of the layer.

Historically, many layer rations have been formulated such that hens received an excess intake of protein (this study was no exception) and hence amino acids. As protein becomes an expensive nutrient in layer rations it may be economically advisable to decrease the dietary protein concentration. To reduce the dietary protein concentration to a level that will maximise net revenue not only requires knowledge of layer response to total protein but also knowledge of the response to individual amino acids. The response to an individual amino acid will depend on the level of other nutrients. To obtain knowledge of layer response to all nutrients at different levels, in combination with all other nutrients, at different levels, requires a massive research programme. However, we do require this information should the choice of ration nutrient levels be an economic one. Nutrient level recommendations in the past have been made to maximise layer performance. These nutrient levels may not result in maximum net revenue.

To obtain knowledge of the physical input/output relationships of layers, cooperation is required between the production economist and the animal nutritionist in determining where the research effort should be placed. Once these relationships have been identified the correct form of the mathematical production function must be determined. This study was only preliminary in that LN/32 was not sensitive enough to determine what the correct mathematical form of the input/output relationships were.

(ii) A method must be obtained whereby the calculating cost can be reduced.

The method used for the economic analyses in this thesis was a systematic series of calculations incorporating linear programming and regression analysis. With the availability of computer facilities which can utilize several programmes simultaneously, it is possible to undertake the economic analysis using these facilities entirely. A programme could be written to analyse the economical model consistent with the analysis presented in Chapters Five and Six. Incorporated in such a programme would be the physical input/output relationships of layer production, a programme for the economic analysis, a linear programme to estimate ration cost, a regression programme to estimate the net revenue function and plotting facilities to draw price maps. The only exogenous variables are prices.

Utilizing such a computer programme, it would be possible to have immediate access to the ration which would maximise net revenue under any given price situation.

APPENDIX A

VARIABLES USED AND THEIR NOTATION

Variable	Notation
Feed consumption	I
Egg number	N
Liveweight gain	ΔW
Initial liveweight	W
Dietary energy concentration	E
Dietary crude protein concentration	P
Dietary calcium concentration	CA
Dietary methionine concentration	MTH
Dietary isoleucine concentration	ISO
Energy consumption	e
Crude protein consumption	p
Calcium consumption	ca
Methionine consumption	mth
Isoleucine consumption	iso
Constant correction for White Base a strain	WBa
Constant correction for White Base b strain	WBb
Predicted variable (x)	$\hat{x}$

Note: Units are not consistent between functions, and are presented after each function.

APPENDIX B

EXPERIMENTAL RESULTS 1-140, 168-315 DAYS

Table B.1: H.D. food consumption per bird per day for each treatment strain for the first 140 days of the laying period.

Treat-ment	Ration	M.E. (k.cal/kg)	C.P. (%)	Consumption (gms/day) strain		
				W.B.(a)	W.B.(b)	M.L.
1	1	2315	12.15	122.0	125.5	128.1
2	2	2315	12.90	124.3	125.5	122.5
3	3	2315	13.66	113.7	123.6	117.4
4	4	2535	13.30	117.1	117.1	121.1
5	5	2535	14.13	113.4	113.8	118.6
6	6	2535	14.96	132.1	124.7	128.3
7	7	2756	14.45	114.0	111.6	115.1
8	8	2756	15.36	117.2	119.2	115.2
9	9	2756	16.26	110.1	116.7	122.0
10	10	2976	15.61	108.0	106.7	114.0
11	11	2976	16.59	107.0	111.7	112.6
12	12	2976	17.59	105.5	117.3	110.0
13	13	3197	16.77	101.7	101.7	111.5
14	14	3197	17.81	116.0	114.1	115.7
15	15	3197	18.86	103.5	113.3	111.4
16	14R	3197	17.81	97.5	104.2	101.6
17	14I	3197	17.81	102.5	114.5	109.6
18	14IR	3197	17.81	94.3	97.3	97.9
19	19	2586	15.41	123.0	115.3	103.8

Table B.2: H.D. egg number per bird for each treatment strain for the first 140 days of the laying period.

Treatment	Ration	M.E. (k.cal/kg)	C.P. (%)	H.D. egg number strain		
				W.B.(a)	W.B.(b)	M.L.
1	1	2315	12.15	83.06	78.45	91.91
2	2	2315	12.90	80.39	88.58	92.71
3	3	2315	13.66	71.78	77.70	84.33
4	4	2535	13.30	70.76	70.43	92.11
5	5	2535	14.13	75.05	63.89	91.65
6	6	2535	14.96	77.15	73.57	84.58
7	7	2756	14.45	80.80	90.36	103.19
8	8	2756	15.36	90.79	92.04	97.43
9	9	2756	16.26	80.43	92.90	95.25
10	10	2976	15.61	91.25	88.26	105.10
11	11	2976	16.59	87.96	93.50	105.00
12	12	2976	17.59	93.93	99.10	96.10
13	13	3197	16.77	86.43	85.19	104.07
14	14	3197	17.81	96.36	94.25	102.80
15	15	3197	18.86	84.82	96.16	108.42
16	14R	3197	17.81	84.96	80.90	107.90
17	14I	3197	17.81	90.68	96.12	101.21
18	14IR	3197	17.81	80.30	89.00	97.80
19	19	2586	15.41	87.43	91.21	102.03

Table B.3: Average egg weight per strain per treatment for the first 140 days of the laying period (grams).

Treatment	Ration	Strain White Base (a)	White Base (b)	M. Line
1	1	49.29	50.10	50.56
2	2	49.31	51.11	51.22
3	3	48.09	50.24	47.71
4	4	52.81	50.39	50.60
5	5	49.36	50.02	50.27
6	6	52.59	54.52	49.64
7	7	52.27	51.45	49.98
8	8	50.91	51.97	49.76
9	9	50.21	52.02	49.76
10	10	51.73	53.40	51.57
11	11	50.25	53.30	49.97
12	12	50.49	50.35	51.09
13	13	49.07	51.67	51.98
14	14	51.43	55.08	50.44
15	15	53.95	52.30	50.49
16	14R	49.33	49.61	50.32
17	14I	50.34	53.24	50.14
18	14IR	50.65	52.08	47.98
19	19	52.83	52.67	50.06

Table B.4: Daily nutrient intake per hen for the first 140 days of the laying period.

Treatment	M.E. (k.cals)	C.P. (grams)	Methionine (mg)	Isoleucine (mg)	Lysine (mg)
1	290	15.23	171	474	578
2	288	16.03	177	451	607
3	273	16.15	192	461	557
4	300	15.75	214	473	572
5	292	16.29	226	491	602
6	325	19.21	271	586	719
7	313	16.41	253	533	606
8	323	18.02	281	588	675
9	320	18.89	298	619	717
10	324	17.01	288	585	635
11	329	18.34	313	633	694
12	323	19.11	328	660	729
13	336	17.62	248	519	679
14	367	20.48	292	583	848
15	349	20.66	313	601	892
16	323	18.33	256	513	745
17	348	19.40	285	627	845
18	309	17.17	252	556	749
19	295	17.59	232	629	800
Recommendation: Scott *et al.* (1969) (Phase One)			343	730	670

Table B.5: H.D. food consumption per bird per day for each treatment strain for the final 147 days of the laying period.

Treatment	Ration	M.E. (k.cal/kg)	C.P. (%)	Consumption (gms/day) strain		
				W.B.(a)	W.B.(b)	M.L.
1'	1'	2756	15.36	110.2	121.6	119.9
2	2	2315	12.90	129.0	136.9	130.5
3'	3'	2535	14.13	118.0	146.6	128.3
4'	4'	2535	13.30	127.1	130.2	135.0
5'	5'	2756	15.36	110.9	120.8	116.1
6'	6'	2535	14.96	135.4	127.3	128.3
7	7	2756	14.45	118.2	117.2	120.2
8	8	2756	15.36	118.7	125.2	119.0
9	9	2756	16.26	124.1	117.5	128.1
10	10	2976	15.61	115.6	114.1	116.6
11	11	2976	16.59	112.0	119.9	118.2
12	12	2976	17.59	105.6	126.0	116.7
13	13	3197	16.77	97.5	107.6	112.0
14	14	3197	17.81	116.3	118.5	112.1
15	15	3197	18.86	102.2	109.9	110.3
16	14R	3197	17.81	97.1	102.6	101.1
17	14I	3197	17.81	99.5	115.4	111.7
18	14IR	3197	17.81	99.9	103.1	101.2
19	19	2586	15.41	108.1	121.2	119.1

Table B.6: H.D. egg number per bird for each treatment strain for the final 147 days of the laying period.

Treatment	Ration	M.E. (k.cal/kg)	C.P. (%)	H.D. egg number strain W.B.(a)	H.D. egg number strain W.B.(b)	H.D. egg number strain M.L.
1'	1'	2756	15.36	76.15	69.96	90.19
2	2	2315	12.90	76.52	74.65	71.11
3'	3'	2535	14.13	87.70	98.67	89.21
4'	4'	2535	13.30	89.19	94.89	99.19
5'	5'	2756	15.36	94.85	79.27	87.79
6'	6'	2535	14.96	93.76	89.79	95.63
7	7	2756	14.45	84.39	76.15	95.71
8	8	2756	15.36	89.81	89.60	90.57
9	9	2756	16.26	79.07	81.54	88.27
10	10	2976	15.61	90.15	95.04	97.26
11	11	2976	16.59	74.50	92.10	94.82
12	12	2976	17.59	103.75	100.39	93.63
13	13	3197	16.77	89.67	84.98	95.36
14	14	3197	17.81	101.58	95.40	94.85
15	15	3197	18.86	84.78	92.75	96.37
16	14R	3197	17.81	79.14	83.27	95.93
17	14I	3197	17.81	90.01	91.08	93.37
18	14IR	3197	17.81	76.68	91.19	93.83
19	19	2586	15.41	84.29	74.57	96.53

Table B.7: Average egg weight per strain per treatment for the final 147 days of the laying period (grams)

			Strain	
Treatment	Ration	White Base (a)	White Base (b)	M. Line
1'	1'	58.31	61.22	59.49
2	2	57.48	61.15	59.20
3'	3'	57.30	58.17	58.00
4'	4'	59.96	60.18	58.38
5'	5'	57.59	60.16	59.11
6'	6'	57.46	61.27	58.59
7	7	59.98	60.11	57.36
8	8	57.34	61.54	55.58
9	9	59.77	58.88	58.45
10	10	59.63	60.68	59.28
11	11	57.83	61.30	57.92
12	12	57.35	59.54	56.47
13	13	56.48	65.10	58.42
14	14	58.82	62.12	58.49
15	15	60.90	59.04	55.36
16	14R	57.49	59.26	55.18
17	14I	57.78	63.11	58.79
18	14IR	58.66	60.57	56.65
19	19	58.62	60.16	59.11

APPENDIX C

AMINO ACID ANALYSES

Table C.1: Amino acid analysis of ingredients included in LN/32 rations. (% of air dry sample).

Ingredient	Lysine	Methionine	Isoleucine	Valine
Pollard	0.56	0.16	0.39	0.69
Barley	0.35	0.11	0.33	0.55
Maize	0.26	0.16	0.34	0.49
Wheat	0.27	0.14	0.38	0.53
Bran	0.53	0.19	0.39	0.58
B.M.P.	2.95	0.78	3.30	2.20
Wainaro meatmeal	2.83	1.15	2.20	2.99
Walkers meatmeal	2.85	0.76	1.49	2.40
Borthwicks meatmeal	2.16	0.57	1.22	1.49
Patea meatmeal	3.56	0.87	2.07	3.04
Bloodmeal	6.47	0.99	0.68	6.69
Bonemeal	0.27	0.10	0.20	0.40
Lucernemeal	0.62	0.14	0.72	0.81
Livermeal	8.10	1.20	3.30	4.20
Linseed		0.40	1.30	

Table C.2: Amino acid concentration of LN/32 rations (% of air dry sample).

Ration	Lysine	Methionine	Isoleucine	Valine
1	.4612	.1364	.3784	.5954
2	.4887	.1425	.3630	.6200
3	.4715	.1624	.3898	.6418
4	.4813	.1804	.3990	.6326
5	.5223	.1958	.4260	.6716
6	.5603	.2107	.4561	.7093
7	.5338	.2228	.4696	.7025
8	.5754	.2398	.5011	.7438
9	.6169	.2567	.5326	.7851
10	.5826	.2642	.5372	.7670
11	.6274	.2835	.5728	.8128
12	.6708	.3022	.6073	.8570
13	.6464	.2359	.4941	.7038
14	.7374	.2535	.5071	.8041
15	.8145	.2856	.5489	.9210
16	.7374	.2535	.5073	.8041
17	.7758	.2613	.5758	.7895
18	.7758	.2613	.5758	.7895
19	.7011	.2051	.5507	.8004
4'	.5374	.1698	.4116	.6625
3'	.5934	.1820	.4417	.7070
6'	.6496	.1943	.4719	.7518
1'	.5754	.2398	.5011	.7438
5'	.5754	.2398	.5011	.7438

APPENDIX D

ANALYSIS OF MINERAL AND VITAMIN ADDITIVE

Vitamin A	iu	5000
D_3		625
E		1.25
Riboflavin	mg	2.0
Vitamin B_{12}		.00025
Calcium Pantothenate		4.0
Nicotinic Acid		10.0
Folic Acid		0.25
Choline Chloride		80.0
Menadione Sodium Bisulphate		1.0
Selenium		0.068
Zinc Oxide		15.2
Ferrous Fumarate		10.0
Potassium Iodate		0.65
Copper Carbonate		2.25
Cobalt Carbonate		0.30
Manganese Sulphate		110.60

APPENDIX E

ANALYSIS OF TREATMENTS 1-6

Analysis of treatments 1-6 can be divided into three periods:

(i) The first 140 days of the laying period when rations 1-6 were fed.

(ii) The month when rations 7, 8, 9 were fed to treatments 1, 3-6.

(iii) The final 168 days of the laying period when rations 1', 2, 3'-6' were fed.

An analysis of nutrient intakes and ration ingredient inclusions for the first 140 days of the laying period for treatments 1-6 highlighted several factors:

(i) The daily intake of metabolisable energy ranged from 273 to 325 k. cals. (Treatment 2 = 228 k. cals.). For five treatments there was "under-consumption" of energy and hence protein.

(ii) The intake of crude protein ranged from 15.23 to 19.21 grams per day (Treatment 2 = 16.03 grams).

(iii) The intake of methionine ranged from 171 to 271 mg/ day. (Treatment 2 = 177 mg.).

(iv) The intake of isoleucine ranged from 451 to 586 mg per day. (Treatment 2 = 451 mg.).

(v) The level of animal protein sources in the rations was low (3.0 to 6.75 percent) hence there was a high reliance on plant protein sources, particularly pollard which had an inclusion rate of up to 50 percent of these rations.

(vi) Bran inclusion was lowest for treatment 2 (0.46 percent compared with a minimum of 1.38 percent of the other treatments).

(vii) Treatment 2 had an inclusion of 3.0 percent Walkers meat and bone meal (compared with 1.63 percent for treatment 1 and no inclusion in treatments 3-6).

It was concluded from these observations that if nutrient intakes were limiting performance then the performance of hens on treatment 2 should have been much lower. The fact that treatment 2 was performing best of treatments 1-6 could only be attributed to three factors:

(i) The low inclusion rate of bran in the ration.

(ii) The relatively lower dietary inclusion rate of pollard (compared with treatments 3-6).

(iii) The reliance on Walkers meat and bone meal as a protein source (although treatment 1 had this in conjunction with buttermilk powder, regarded as a high quality protein source).

It is also suspected that the intake of nutrients, particularly amino acids, may have been limiting performance, especially as treatment 2 was not performing to the level of some of the higher energy density treatments. Further evidence of this was that apart from treatment 2 the highest egg production in month 5 (Table F.1) was on treatment 6. This corresponded with treatment 6 having the highest intake of methionine and isoleucine for 1-140 days on treatments 1-6. Staff at the P.R.C. noted in the second month of LN/32 that hens on treatment 6 were consuming feed at such a rate that troughs were emptied prior to each feeding. To ensure ad libitum feeding these hens were fed four times per week. This resulted in an increase in feed intake and consequently an increase in nutrient consumptions. The increase in feed intake could be due to two factors:

(i) A nutrient deficiency in ration 6. An examination of the nutrient and ingredient content of the ration, relative to rations 1-9, did not establish this. Any feed intake response to low dietary methionine and isoleucine concentrations in ration 6 was not consistent with the intake pattern for other rations also low in these amino acids. That is, should the response in feed intake be to meet an amino acid requirement then treatments 1-5 should have also responded. This leads us to the next assumption.

(ii) Birds on low energy rations (2315-2535 k. cal. M.E. per kg.) could not respond to low dietary nutrient levels because they were not being fed an libitum. An increase in the amount of ration 6 fed to hens resulted in an increase in the daily feed intake. It is questioned whether a similar result would have occurred had hens on treatments 1-5 also been fed more liberally.

Month 6

As has been shown in Chapter Three, treatments 1, 3-6 were allocated rations 7, 8, 9 on September 22, 1971. These rations were chosen because of the then current stock situation.

Egg numbers for month 6 (beginning September 22) are presented for treatments 1-6 in Table 1. For treatments 1, 3-6 which underwent a ration change there is an increase in egg number. This occurred at a time when egg number should have been declining following maximum egg output (compare treatment 19). We can conclude that treatments 1, 3-6 responded to the nutrient and ingredient changes. Treatment 2 egg number however continued to decline and in fact was inferior to treatments 1, 3, 4, 6. Having demonstrated the ability of hens to respond to ration changes we are now interested in layer performance on the rations subsequently fed (October 20 until the end of the laying period).

Table E.1: Egg number per treatment. Treatments 1-6. Period 4-6 months

Treatment	Month 4	Month 5	Month 6
1	1493	1394	1451
2	1703	1562	1437
3	1335	1372	1500
4	1434	1245	1466
5	1319	1168	1418
6	1543	1455	1524
19 (Control)	1704	1695	1637

Months 7-12

The treatment allocation of rations from October 20, 1971 until the end of the laying period has been discussed in Chapter Three.

Egg number for the final 147 days of the laying period for treatments 1' - 6', 8, 19 are presented in Table E.2.

Table E.2: Egg number, period 168-315 days

Treatment	H.D. egg number		
	W.B.(a)	W.B.(b)	M.L.
1'	76.15	69.96	90.19
2	76.52	74.65	71.11
3'	87.70	98.89	89.21
4'	89.19	94.89	99.19
5'	94.85	79.27	87.79
6'	93.76	89.79	95.63
8	89.81	89.60	90.57
19 (Control)	84.29	74.57	96.53

Features of these figures are:

(i) Apart from strain differences (W.B.a, W.B.b on treatment 1) the increased production for all treatments when compared with treatment 2.

(ii) Treatments 1' and 5' were fed ration 8 to test the ability of hens fed rations of 2315 and 2535 k. cal. M.E. per kg. respectively, to respond to a proven ration. Treatment 5' shows a definite response and compares favourably with treatment 8. Treatment 1' in general, does not match the production level of treatment 8. Although treatment 1' did not perform to the level of treatment 8 for W.B.a and W.B.b, the performance of W.B.b may be considered satisfactory when compared with treatment 19.

(iii) Having shown that rations of 2535 k. cal. M.E. per kg. have the ability to respond to ration changes (Treatment 5' compared with treatment 8) we can examine treatments 4' and 6' to test for a response to ingredient variation for rations of 2535 k. cal. M.E. per kg. Disregarding strain differences both treatments 4' and 6' have greater production than treatments 5' and 8 indicating a positive response in egg number to ration ingredient changes.

(iv) Treatment 1' did not produce as high as treatment 8 when fed ration 8. Treatment 3' however produced on a par with treatment 8 when fed ration 8. This shows that at least treatments fed rations of 2315 k. cal. M.E. per kg. have the ability to respond to a ration change. The ability of treatment 1' to respond may have only been a random effect.

APPENDIX F

AN EXAMPLE OF THE RELATIONSHIP BETWEEN STRUCTURAL AND REDUCED FORM EQUATIONS

$$N = \alpha_j + \beta_1 e + \beta_2 \, iso + \beta_3 W \qquad (F.1)$$

$$I = a_j + b\,E + c\,W + d\,ISO \qquad (F.2)$$

$$e = I.E. \qquad (F.3)$$

$$iso = I.ISO \qquad (F.4)$$

where e = energy intake

iso = isoleucine intake

W = initial body weight

E = dietary energy concentration

ISO = dietary isoleucine concentration

I = feed consumption

N = egg number

Reduced form equation for egg number (N) is obtained by substituting for e and iso in equation (F.1)

$$\begin{aligned} N = {} & \alpha_j + \beta_1 a_j (E) + \beta_1 b(E^2) + \beta_1 c(W.E.) \\ & + \beta_1 d(ISO.E) + \beta_2 a_j (ISO) \\ & + \beta_2 b(E.ISO) + \beta_2 c(W.ISO) \\ & + \beta_2 d(ISO^2) + \beta_3 (W) \end{aligned} \qquad (F.5)$$

APPENDIX G

SIGNIFICANCE LEVELS

The significance levels used in this thesis are:

Significant at the 1 percent level: xx

Significant at the 5 percent level: x

Significant at the 10 percent level: 10%

Not significant at the 10 percent level: N.S.

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