RESTRICTED FEEDING AND THE FUNCTIONAL

EFFICIENCIES OF THE LAYING HEN

By

P.C. GLATZ, B.Ag.Sc.(Hons.)

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DEPARTMENT OF ANIMAL PHYSIOLOGY

WAITE AGRICULTURAL RESEARCH INSTITUTE

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SUMMARY

This thesis is concerned with two aspects of functional efficiency in laying hens. The first is an investigation of the relationship between feed conversion efficiency (FCE) and physiological variables among several lines, generations and breeds of hen fed *ad libitum* or on restricted amounts of feed.

The second is an examination of the consequences to egg shell quality of restriction of food supplied to laying hens.

Metabolic rate, water turnover, carcass fat, plasma thyroxine, thyroxine secretion rate, FCE and body weight were measured at various ages in four generations and in four lines of laying hens allocated 33% less feed than *ad libitum*. The data collected were analysed by multiple linear regressions. The relationship between FCE (18-66 weeks) and physiological variables in hens on restricted and *ad libitum* feeding were quantitated in prediction equations. Efficient restricted hens were observed to have lower levels of plasma thyroxine and lower body weight than inefficient hens on restricted intake. The efficient hens fed *ad libitum* had higher water turnover rates than the inefficient hens.

Four lines of hens were inbred over four generations and subjected either to 33% feed restriction or to *ad libitum* feeding. Production parameters, physiological variables, body weight and shell quality measurements (shell weight, shell weight per surface area of egg, shell thickness, egg conformation and egg shell porosity) were treated by analysis of variance. The main points of interest arising

from this study were in summary:

1. FCE declined with inbreeding.

2. Large fluctuations in food intake and egg weight occurred between generations in some lines of birds as inbreeding progressed.

3. A 33% feed restriction in hens resulted in a marked reduction in FCE, egg production, egg weight and metabolic rate. There was, however, a small sub-group of individual hens that had exceptionally high FCE considering the level of feed restriction. These hens produced eggs of comparable number and quality to the fully fed birds. Development of birds with these characteristics opens up the possibility of genetic selection.

4. There was no difference between the lines of hens in rate of water turnover whether they were fed *ad libitum* or restricted.

5. The most efficient line of birds on the restricted feeding régime exhibited the lowest thyroxine secretion rate. The least efficient line had an elevated thyroxine secretion rate.

6. The third generation of birds were the least efficient of all generations and exhibited the highest thyroxine secretion rate and metabolic rate. Their body fat levels were also elevated.

7. There was a trend toward higher levels of plasma thyroxine as inbreeding progressed.

8. Significant differences in shell weight and egg conformation were observed among the various lines, but there were no

differences between lines in the other variables that were used to assess shell strength.

9. Body weight and egg weight of hens were correlated with shell thickness. Egg shell porosity was positively correlated with all production variables.

10. Shell weights of feed restricted birds were lower than those of hens fed *ad libitum*. There were no differences, however, between hens on restricted and *ad libitum* feed levels in their shell thickness or shell weight per surface area of egg.

11. Differences between lines of hens in body weight at 6 weeks of age were reflected in subsequent body weights at 18, 30, 42 and 66 weeks of age.

In the comparison of genetic lines, functional efficiencies of three breeds of hens were examined in relation to four feed intake levels ($80g. 24h^{-1}$, $90g. 24h^{-1}$, $100g. 24h^{-1}$ and *ad libitum*). Data collected were treated by analysis of variance.

There was a difference between breeds in FCE. Feed levels of $80g.24h^{-1}$ and $90g. 24h^{-1}$ resulted in a decline in FCE for all breeds. The least efficient breed of hen had the highest metabolic rate and thyroxine secretion rate. The most efficient breed of hen exhibited the highest water turnover rate and also lowest body weight at 42 and 66 weeks of age.

Feed restriction for the breeds did not cause any decline in egg shell strength.

DECLARATION

I hereby declare that the work presented in this thesis has been carried out by myself, and does not incorporate, without acknowledgement, any material previously submitted for a Degree or Diploma in any University. To the best of my knowledge and belief, it does not contain any material previously published except where due reference is made in the text.

PHILIP C. GLATZ

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INTRODUCTION

The egg poultry industry in western countries faces increasing pressures as the cost of egg production escalates. One of the few means available for reducing the cost of egg production and improving the financial return per bird is to lower the outlay on feed, which makes up about 60% of the total cost. This has been achieved in some instances by altering the composition of feed, and in others by restricting the amount of feed offered to laying hens. There has been considerable research into restricting the feed of laying hens. The levels of restriction have usually only been 5-10% below *ad libitum*. In some cases this degree of feed restriction has been successful, but in others egg production has been reduced. Because of the varying successes of restricted feeding experiments (Sykes, 1972), it has been difficult for the commercial egg farmer to use the practice of restricted feeding in the laying period because of uncertainty in the subsequent performance of hens.

For the future it seems clear that a 5-10% restriction of feed would have only a minor impact on the poultry industry. A much greater effect would result if strains of birds were developed that could produce eggs efficiently on feed levels 30-40% below *ad libitum*. Only scant information, however, exists on the production performance and efficiency of hens subject to this amount of feed restriction. Furthermore, physiological investigations of individual hens relating energy variables (oxygen consumption, thyroid activity, water turnover and carcass fat) to efficiency and egg shell quality have rarely been undertaken. Examination of the question of what makes one hen more efficient than another in physiological terms, at low feed levels, may give valuable information to geneticists and offer them an alternative basis for selection. It may be expected that a fuller understanding

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of the physiological basis of egg production characters will permit
measurements to be made at an earlier point in the series of physiological
characters culminating in high bird efficiency.

With these considerations, the questions proposed for investigation
using a limited number of birds on the same compound feed, were:

1) The relationships between feed conversion efficiency and
physiological variables (metabolic rate, water turnover, carcass
fat, plasma thyroxine, thyroxine secretion rate) for *ad libitum* and
restricted feed levels, among several lines, generations and breeds
of hen.

2) The consequences of severe feed restriction on egg shell quality
and feed conversion efficiency in the laying hen.

CHAPTER I LITERATURE REVIEW

A. INTRODUCTION

This review discusses the metabolic efficiencies of adult hens. Their performance and characteristics range widely and many methods have been used to measure their biological efficiency. Hence comparisons are difficult. The variety of experimental treatments and other environmental variables have also contributed to the problems of trying to make comparisons. It would have been fortunate for poultry research if one universal measure of efficiency had been adopted. In this review only biological efficiency is considered. Definitions of biological efficiency are given along with some discussion on their methods of measurement and of assessing the energy and protein requirements of poultry. The relationships between biological efficiency, production parameters, physiological parameters and egg shell quality, are reviewed. The measurements singled out for attention include feed conversion efficiency (FCE) in relation to feed level, feed intake, egg number and egg weight. Metabolic rate, water turnover, total body water as a percentage of body weight (carcass fat estimate), thyroxine secretion rate and plasma thyroxine are examined in relation to egg production. Egg shell quality parameters, shell weight, shell weight per unit of surface area of egg, shell thickness, egg conformation and egg shell porosity are assessed in relation to production variables in hens.

B. EFFICIENCY OF THE LAYING HEN

Efficiency of the laying hen may be estimated by two main methods, the first using gross efficiency, and second the net efficiency.

1. Gross Efficiency

Gross efficiency is defined as the ratio of output in the form of eggs to input of a stated nutrient. For instance, gross energetic efficiency is defined as that fraction of energy that a hen converts to egg energy (dry matter only) and gross protein efficiency as that fraction of protein that a hen converts to egg protein. Kleiber (1961) states that gross protein efficiency is about 28% for the Leghorn adult, producing at the rate of 70% lay, while consuming a feed containing 16% protein and 3% fat. Gross energetic efficiency was given as 13.3%. Routine measurement of gross energetic efficiency and gross protein efficiency is extremely difficult at the commercial level and also at the experimental level due to the amount of equipment, facilities, time and labour needed. However, one measure of gross efficiency which is simple to obtain is feed conversion efficiency.

(a) Feed Conversion Efficiency (FCE)

Protein efficiency has been stated to be about 84% of the FCE value and energetic efficiency about 40% of the FCE value (Nordskog, et al. 1972). FCE measurement is the egg producer's method of expressing efficiency and this can be determined either directly or indirectly. Indirect measures depend on information on egg number, egg mass and body weight, but direct measures derive from egg number, egg mass, body weight and feed consumption. Nordskog, et al. (1969) indicated that the experimental error of direct measures of feed conversion is higher than that of indirect measures. The point is made however, that individual feed records are a valuable asset when a total assessment of efficiency is made.

(b)   <u>Direct Measures of Feed Conversion Efficiency</u>

The most commonly used criterion of efficiency has been F/P

or its reciprocal, where F is the weight of feed input and P

is the weight of resultant product.   The ratio is commonly

called feed conversion.   Because of the high correlations

between produce output and feed conversion some breeders

consider that only produce output is worth measuring.   Balloun

and Speers (1969) bred a line of Leghorn birds which produced

0.42 g of egg mass per gram of feed consumed, measured over a

250-day test period.   They concluded that this measure of

feed conversion enabled them to distinguish between lines of

birds of different efficiency.   The birds showing highest

efficiency were of lower body weight and required less daily

protein.   Similarly French(1971,   reported by Nordskog, *et al.*

1972)   used FCE as the basis for his comparison   when

examining the influence of the sex-linked dwarf gene on

efficiency.

The practical poultry husbandry measure of efficiency has been

pounds of food per dozen eggs, or kilograms of food per dozen

eggs, and many research workers have also used this measure.

It is normally referred to as the feed conversion ratio and

is simple to measure at the farm level.

(c)   <u>Indirect Measures of Feed Conversion Efficiency</u>

Indirect measures of feed conversion efficiency have been less

popular.   The feed efficiency index, defined as the ratio of

wet egg mass produced per unit of body weight has been used

as an indirect measure (Nordskog and Festing, 1962; Casey and

Norkskog, 1971). Interestingly, this measure of efficiency was used as the basis for their comparison between different lines of birds.

2. Net Efficiency

Two methods are available for estimation of net efficiency, the first of which is suitable only for determining the use of energy. This involves the collection of data from birds receiving the same diet but showing variations in food intake, body weight and egg output, treated by multiple regression analysis. French (1969, see Nordskog, *et al*. 1972) used this method to compare net efficiencies of three Leghorn lines.

The second method of studying net efficiency involves the construction of a series of diets with various limiting levels of the nutrient under study. When these are eaten, the rate of response in output can be observed directly and strains of birds compared. This approach has been reviewed by Morris (1972). A special case of the second method of measurement of net efficiency is the use of an animal calorimeter. This can be used to estimate maintenance requirements by observing heat output at various levels of energy input. For both measurements of net efficiency, extensive experimental facilities are required. Grimbergen (1974) reports on a number of calorimetery investigations of poultry, indicating that efficiency of utilization of metabolizable energy is 59.5%. Production of body energy from metabolizable energy had an efficiency of 83% and efficiency of use of body energy for egg production was 60%. Grimbergen (1974) also reports that another group of workers calculated the efficiency of egg fat production from metabolizable energy at 74%, and efficiency of egg protein production from metabolizable energy as 44%. For industry cheap

and simple methods for measuring gross or net efficiency are required; so research work should attempt to relate to these measures of efficiency.

C. METABOLIC RATE

The concept of basal metabolic rate refers to the heat production per unit time by an animal in a post-absorptive state, at rest and maintained in a thermally neutral environment (Kleiber, 1961). The heat produced by the laying hen derives from basal metabolism, feeding, digestion, egg production and activity. With birds it is difficult to measure BMR since they do not relax readily. Hence birds have been starved 24 hours before measuring heat production for metabolic rate. The procedures adopted in the measurement of energy exchange have been reviewed by Farrell (1974b). It must also be accepted that measurement of metabolic rate in hens severely interferes with normal behavioural patterns and this must be noted when interpreting results. A great deal of emphasis in recent years has been placed on determining the relative efficiencies of utilization of metabolizable energy by birds (Grimbergen, 1974).

Physiological relationships between metabolic rate, production parameters and efficiency have been very little studied but the changes of metabolic rate with size have been well investigated (Kleiber, 1965).

Comparisons between various research results in this area are difficult. The number of variables almost outnumber the number of research papers, but the emphasis is on finding whether differences in metabolic rate of hens are due to breed, individual production performance or physiological state.

1. Metabolic Rate of the Adult Hen

Mitchell, *et al.* (1927) indicate that the metabolic rate of the hen during adult life reaches an almost constant level. Barott and Pringle (1946) confirmed these observations. Leeson and Porter-Smith (1970) observed that the metabolic rate of starved laying hens was similar at point-of-lay and during peak-production. After this period there was a marked increase in starving heat production. Waring and Brown (1967) concluded that metabolic rate of hens aged 12 to 14 months was little different from hens 20 months of age. As reported by Balnave (1974), O'Neill (1971) measured starving heat production of White Leghorns between 12 and 25 months and found a yearly variation in metabolic rate, with maxima in the spring and autumn. These few examples indicate that more information on metabolic rate of birds over a full laying cycle and measured over a universally accepted set of conditions would be useful.

2. Metabolic Rate and Rate of Egg Production

As reported by Balnave (1974), Gerhartz (1914) was the first to note that the metabolic rate of egg-producing hens was 30% higher than that of non-laying hens. Waring and Brown (1965) reduced this figure to 19% from their data. However Tasaki and Sasa (1970) found that the starving heat production of the laying hens was 26% higher than that of non-laying hens. But Brody, *et al.* (1932) concluded that there was no marked difference in heat production between good and poor layers. Winchester (1940) presented evidence which can be interpreted as indicating an association between metabolic rate and rate of egg production, but Ota and McNally (1961) using regression analysis on the data they obtained from caged hens, failed to find any significant

relationship between egg production and metabolic rate.

3. Metabolic Rate and Plane of Nutrition

As reported by Freeman (1971a), Tasaki and Sakurai (1969) worked with two populations of hens, one of high metabolic rate and the other of low metabolic rate. The difference in metabolic rate between the low and high metabolic rate population disappeared when birds received a maintenance ration. From the data of Morrison and Leeson (1978) the metabolic rate of birds allowed *ad libitum* feed intake was higher than that of birds on restricted feed. However Balnave (1976) could detect no difference in metabolic rate between birds fed *ad libitum* and those on restricted intake.

4. Metabolic Rate and Breed Effects

Balnave (1974a) in a literature summary on breed effects and metabolic rate, reports that substantial variation occurs between laying birds of the same strain. The reasons proposed to explain this are experimental error, environmental variables, biological variation and differences in maintenance requirements. Bergman and Snapir (1965) observed that the starving metabolic rates of White Leghorn laying hens were considerably smaller than those of Plymouth Rock hens at temperaturesabove 28°C but these differences disappeared when environmental temperatures were reduced.

Lundy, Macleod and Jewitt (1978) reported that the metabolic rate of Babcock birds (a light-weight strain) was 13% higher than that of the heavier Warren strain.

5. Metabolic Rate and Feed Conversion Efficiency

Calverly, *et al.* (1946) selected rats for feed conversion efficiency. They found that a strain of low efficiency had significantly higher maintenance requirements and a slightly higher basal metabolic rate than that of the more efficient line.

Little attention, however, has been given to studies of the efficiency of feed use by the laying hen. Joshi, *et al.* (1948) found considerable variation of feed conversion efficiency among full sister families which raises the possibility of using genetic selection. Morrison and Leeson (1978) classified hens according to their feed conversion efficiency. Birds classified as efficient or inefficient had comparable body weight gains and did not differ significantly in protein or fat content of their carcasses. Inefficient birds had a significantly higher metabolic rate than efficient hens under conditions of *ad libitum* feeding or of starvation. Their data suggest that, for high-producing birds, factors other than carcass size and body composition are responsible for the observed differences in conversion efficiency. They observed that efficient birds were less active and spent more time resting and less time standing than inefficient birds.

In summary, then, it is apparent that individual differences in metabolic rate do exist between hens and breeds of hens, but the extent of variation and the precise reasons for variation in a flock of hens have not been elucidated.

6. Approaches to Energy Metabolism

There appear to be three types of approach by investigators in this field of metabolic and energy metabolism in the bird. The first group is interested in defining differences in performances of strains

of hen in relation to gross efficiency. A second group is concerned to
define net energy requirements for hens using calorimetric tests but
not to seek out the causes of differences between individual hens of
the one breed; and a third group of workers studies cellular energy
metabolism in birds but does not attempt to correlate this with efficiency.
A multi-disciplinary approach in this area of efficiency measurements
and energy metabolism would undoubtedly uncover useful information on
control and regulation of energetic efficiency in hens.

D. RESTRICTED FEEDING

Restricted feeding experiments with the laying hen have been a major
line of enquiry in poultry research over recent years. The incentive to
lower feed costs has increased as feed prices have risen with inflation.
There have been wide ranging approaches to restricted feeding
experiments with the general aim of defining optimum energy levels and
preventing the overconsumption of feed by the laying hen. The methods
and results of some of the more relevant restricted feeding experiments
are reviewed. Where possible analysis of food conversion efficiency in
relation to performance of birds is given.

1. Criteria for Defining Effectiveness of Restricted Feeding Trials

(a) Egg Production

Hen-day egg production and production per cent have been the
most common measures used. Many restricted feeding experiments
have aimed at reducing feed intake of layers without depressing
egg production. The work followed from the belief that laying
hens overconsumed feed and excess intake was diverted to fat
stores.

(b) <u>Egg Weight and Egg Grades</u>

Average egg weight and percentage of egg grades produced have been measured. This has shown the effect on egg weight and distribution of egg grades when restricting the feed of layers. This has been necessary in some experiments comparing the economics of restricted feeding versus *ad libitum* feeding.

(c) <u>Feed Conversion Efficiency</u>

Three measures of efficiency have been estimated in relation to restricted feeding versus *ad libitum* feeding. In commercial egg production and research, general measurement has been made of the number of kilograms of feed consumed per dozen eggs produced. Another measure has been feed conversion efficiency defined as F/P or its reciprocal where F is feed input in grams and P is produce output (eggs) in grams. Energetic efficiency defined by FE/PE or its reciprocal where FE is gross energy feed consumed and PE is gross energy eggs produced, has also been determined. Some workers have used this measure in experiments aimed to define maintenance energy requirements of laying hens.

2. <u>Restricted Feeding in Layers – Methods and Results</u>

The two main methods of feed restriction used have been qualitative feed restriction and quantitative feed restriction.

(a) <u>Qualitative Feed Restriction</u>

Four approaches have been made in this respect:

(i) Change in nutrient density

(ii) Use of inert fillers

(iii) Use of specific nutrient deficiency

(iv) Use of spectacles

(i) <u>Change in Nutrient Density</u>

In the past it has been assumed that a laying hen would adjust her voluntary food consumption to maintain a constant daily energy intake when offered diets of different energy density (Hill, 1962). However, Morris (1968) assessed, from data available in the literature and his own, that all strains tend to increase their energy intake as the energy density of the diet increases. Some strains do so to a greater extent than others. Those strains with a relatively large daily energy intake adjust their energy intake less precisely than do the smaller strains which consume less energy per day. In his assessment Morris (1968) demonstrated a biological association between the energy intake of a strain and a strain's tendency to increase its energy intake as the dietary ME concentration was raised. This was illustrated dramatically also, by the work of Dillon (1974) who showed that hens offered high energy diets of 12.96 - 13.79 $MJ.Kg^{-1}$ ME, consumed 8-15% more energy than those on diets containing 11.29 - 12.12 $MJ.Kg^{-1}$ ME.

(α) <u>Egg Number and Dietary ME Concentration</u>

Morris (1969) surveyed the literature relating egg production to energy density of the diet. He found in most of the experiments that there was no effect upon rate of lay of varying the energy density (excluding diets less than 10.05 $MJ.Kg^{-1}$ ME). De Groote (1972) also reports that increasing the dietary energy concentrations from 10.47 to 13.40 $MJ.Kg^{-1}$ ME had no significant effect on egg number.

(β) <u>Egg Weight and Dietary ME Concentration</u>

The effect of energy density *per se* on egg weight is
uncertain. Increases in egg weight of the order of
1-2%, associated with feeding high density diets, have
been reported by many workers. On the other hand there
are many reports in which dietary energy level had no
effect upon egg weight. Egg weight responses in many
instances may be confounded with the effect of
increasing concentration of essential fatty acids
(particularly linoleic) in the diet (Edwards and Morris,
1967; de Groote, 1972).

(γ) <u>Body Weight and Dietary ME Concentration</u>

In view of the data so far presented, it is not
surprising that body weight gain by hens fed high
energy diets is greater than among those fed low energy
diets. The response is illustrated for White Leghorn
hens by the data from de Groote (1972). He found that
most of the additional body weight increase was probably
fat tissue, as a period of energy restriction resulted
in a reduced proportion of body fat (Jalaludin, 1969 as
cited by Sykes, 1972; Hannagan and Wills, 1973).

In literature reviewed, there is little weighting given
to measures of efficiency in relation to variations in
energy density. One must expect gross and net energetic
efficiency to be higher for birds able to maintain
satisfactory egg weight and egg production levels on
lower energy intake.

(ii) Use of Inert Fillers

The addition of costly inert fillers to diets has improved feed conversion efficiency of hens, but has increased total feeding costs (Damron and Harms, as cited by Robinson 1976). These authors failed to point out however, that the improved efficiency compensated for increase in total feeding costs. Jackson (1972) compared the effects of quantitative feed restriction with the use of a wood dust diluent. He indicated that reducing the amount of food was the more effective method. Harms, *et al.* (1974) have found, however, that sand is an effective and cheap inert filler for poultry diets.

(iii) Use of Specific Nutrient Deficiency

There has been only a limited amount of work done with laying hens in this area. Since egg production is very sensitive to specific nutrient deficiencies, this offers little promise as a means of restricting feed intake of layers.

(iv) Use of Spectacles

Balnave (1976) reports on an experiment by Cumming where the field of view of birds was restricted by spectacles. By this procedure it was shown that food conversion efficiency of laying hens was substantially improved as well as egg output. How this occurs is not clearly understood.

(v) Limiting the Photoperiod

Bell (1974) reported that six equally spaced 10 - min light periods per 24 h reduced food consumption by 10-12% but did not significantly affect egg income minus food cost. Van Tienhoven and Ostrander (1976) observed no difference in egg production or feed efficiency between birds on normal light and those that received two short light periods every day.

(b) Quantitative Feed Restriction

There have been three main methods used to restrict the feed of layers quantitatively.

(i)   Feeding a fixed daily allowance

(ii) Limiting the time of feeding

(iii) Limiting the time of drinking

(i)   <u>Feeding a Fixed Daily Allowance</u>

There have been two approaches made in this context. One group of workers estimated the energy requirements of the laying hen for maximum egg production. Another group of workers concentrated on feeding varying degrees of restricted daily quantities of feed (rationing) and observing the effect on egg production.

(α)   <u>Energy Requirements of Laying Hens</u>

There is a discrepancy between estimates of the amount of energy that a laying hen should expend each day, based on calorimetric trials, and the amount of energy consumed on average by laying hens fed *ad libitum*. Grimbergen (1974) said this can be explained by differences in the methods used by workers in their calorimetric trials. However, after his work, Grimbergen (1974) comments that a complete explanation of this discrepancy cannot yet be given and further research work is required. Under experimental conditions actual energy consumed by laying hens to maintain maximum egg production has varied. Petersen (1971) using White Leghorn layers in a 40-week trial, fed weighed quantities of food daily and showed that the normal rate of lay could be maintained with daily inputs of 1,003 KJ ME at 26.7^0C and 1,087 KJ ME at 10^0C. Supramaniam (1970) as reported by Sykes

(1972) used medium hybrid layers over a 12-week period, and showed that the normal rate of egg production could be maintained on a daily intake of 1,129 KJ ME. He found that total energetic efficiency of hens was improved at a lower daily intake of 1,024 KJ ME even though egg numbers were slightly reduced. Jalaludin (1969) as reported by Sykes (1972) went even further in energy restriction, and claimed egg production was not reduced when daily intake was as low as 782 KJ ME. Jackson (1970) using the same diet formulation as Jalaludin (1969) could not achieve maximum egg production with this level of restriction. Thus an optimum ME daily intake to support maximum egg production in hens cannot yet be given in view of the above work.

(ii) Rationing

The second approach to restricted feeding has been the concept of rationing birds to a level of feed intake below that of *ad libitum* feed consumptiom. Usually this approach has commenced after birds have reached peak egg production.

Auckland and Wilson (1975) restricted intake of light-bodied and medium-bodied hybrid layers from 32-48 weeks of age, allowed *ad libitum* feed intake from 48-52 weeks of age, and then they reimposed restriction from 56-68 weeks of age. Using the data clearly presented by Auckland and Wilson (1975) feed conversion efficiency was calculated as defined below for the period 32-68 weeks of age.

feed conversion efficiency (expressed as %)

$$= (\frac{\text{Total Egg Weight Produced (g)}}{\text{Total Feed Consumed (g)}}) \times 100\%$$

For the light-weight strain (Hyline 935) maximum feed conversion efficiency and maximum egg production was achieved with birds consuming feed *ad libitum*. However, for this strain of bird, feed restriction from 124.8 g. $24h^{-1}$ to 111.7 g.$24h^{-1}$ feed conversion efficiency only declined by 0.4% even though production rate fell from 82.9% to 76.1% and average egg weight, 60.4 g. to 58.4 g.

Medium-bodied hybrids (Shaver 585), however, improved in feed conversion efficiency from 34.8% to 36.0% with restriction from 127.3 g.$24h^{-1}$ to 111.7 g.$24h^{-1}$. Production rate declined from 73.9% to 69.3% and egg weight from 59.9g. to 58.1g (Auckland and Wilson, 1975). In a similar experiment by Auckland and Fulton (1973) it was demonstrated that restricting a light-bodied hybrid (Shaver 288) from 122.1 g.$24h^{-1}$ to 105.4 g.$24h^{-1}$ reduced production more, from 80.6% to 76.5%, and an egg weight drop from 59.2 g to 57.7 g occurred. On the other hand food conversion efficiency for this level of restriction improved from 39.0% to 41.9%. Auckland and Fulton (1973) commented that restriction from 124.4 g. $24h^{-1}$ was not successful. Calculated feed conversion efficiency between these two feeding levels showed that with restriction, feed conversion efficiency was 35.0% compared to *ad libitum* level of 34.4%, but with an increased restriction to 102.3 g.$24h^{-1}$, feed conversion

efficiency improved from 34.4% to 36.1%. The results
of Auckland and Fulton (1973) and Auckland and Wilson
(1975) are presented in more detail to illustrate the
following points:

(1) There are strain differences in ability to cope
with restricted feeding.

(2) Feed conversion efficiency is sometimes superior
even when egg production is not at its maximum
rate.

Balnave (1975) restricted birds to 100 $g.24h^{-1}$ from 20,
30 and 40 weeks of age. Superior laying performance
was obtained from birds restricted from 20 weeks of age.
Production rates were unaffected with feed restriction
but average egg weight declined. Over the laying period
this method of restriction reduced total feed consumption
by 10%. Wells (1974) restricted hens from 40 weeks of
age to 76 weeks of age. Birds were restricted to the
38 to 40-week level of *ad libitum* feed intake. The data
presented by Wells (1974) enabled the kilograms of feed
consumed per dozen eggs produced, and feed conversion
efficiency (%) to be calculated. This method of feed
restriction reduced the amount of feed per dozen eggs
from 1.97 kg. to 1.89 kg. and feed conversion efficiency
improved marginally from 34.7% to 34.9%. Production per
cent declined from 72.7% to 69.9% and egg weight fell by
approximately 2 g.

Hannagan and Wills (1973) used a similar method of feed

restriction to that of Wells (1974). Egg production was not adversely affected, although percentage of large eggs was reduced by 15%. Feed conversion efficiency was improved however, by an estimated 10%. Snetsinger and Zimmerman (1974) conducted tests with hens from 42-70 weeks of age. They presented data showing improvement in feed conversion efficiency from 42.0% to 45.9% with feed restriction of 6-10%. Where the feed limitation was 10% or less, all strains of hens tested showed no significant depression in egg production; but, in most cases there was a slight reduction in egg size.

Some workers have restricted feed intake of layers from point of lay. Balnave (1974b) using medium-bodied and light-bodied strains of hen, restricted feed intake by 14% in the laying period. There was a 9.7% reduction in egg production and egg weight was reduced by 1.7%. Feed conversion efficiency was improved by nearly 1% with feed restriction. Similarly Walter and Aitken (1961) using Single Comb Leghorns and Red Cross Hylines demonstrated that a feed restriction of 12% in the laying period caused an 8% drop in egg production. The amount of feed consumed per dozen eggs was improved in the restricted hens.

Gerry and Muir (1972) restricted birds to 90% of the feed which had been eaten the previous week. Production rates declined but measured kilograms of feed consumed

per dozen eggs produced was improved with restriction. McMahon, *et al*. (1974) using cross-breed layers which were 6% restricted in the laying period, found that these hens produced a larger number of eggs of larger egg size. Feed conversion efficiency improved from 33.2% to 36.6%.

(iii)   Limiting the Time of Feeding

Burmester and Card (1939) and Cherry (1959) found that egg production fell if hens received less than 6-8 h of mash feeding-time per day. This was confirmed by McGinnis and Dronowatt (1967). Using single feeding periods of 4 and 6 h per day, they found that feed intake was reduced 10 and 15% respectively. Egg weight and egg production were also reduced. Bell (1972, as reported by Snetsinger and Zimmerman, 1974) found that allowing hens access to feed, for 10 min   in every 4 h, reduced feed consumption 20%, but egg production was only reduced by 5-9% between replicates. However Pope (1971, reported also by Snetsinger and Zimmerman, 1974) found an improvement of 6% in feed conversion efficiency with a 7.5% reduction in feed intake by restricting hens to 3 one-hour feeding periods per day. Egg production was reported to be unaffected, but egg weight was reduced. Polin and Wolford (1972, 1973) achieved an increase in net energetic efficiency with single or multiple feeding periods of 5 h or less per day, even though production rate fell 10% and average egg weight decreased.

Snetsinger and Zimmerman (1974) found that single feeding periods of 4h and 6h per day depressed egg production by 4.7% and egg weight by 3.2%. But when hens were given access to food for 8h per day they showed normal rates of egg production, even though feed intake was reduced by 10%. Balnave (1975) comments however, "It appears that feeding time has to be reduced to approximately 4h daily before a reduction of 10-15% in food intake occurs and with these short feeding periods, possible over-restriction is a constant problem."

In a field trial Snetsinger and Zimmerman (1974) showed that groups of hens which had their feeders covered for periods of 7h or 5h had approximately a 6% and 5% feed restriction respectively. Production was unaffected and there was only a small egg size loss.

Wells (1974) using birds 40 weeks of age reduced time available for feeding to two separate 2h periods over 20 weeks of lay. Feed intake was reduced by 13-15% and production fell by 6.2%. There was a marginal deterioration in amount of feed consumed per dozen eggs produced. In contrast, Swanson and Johnson (1975) found that hens limited to 3 one-hour feeding periods per day consumed 12.8% less feed and rate of lay declined only by 1-2%. Feed consumed per dozen eggs produced was considerably improved.

(iv)   Limiting the Time of Drinking

Maxwell and Lyle (1957), using 20-week old hens in a 6-week trial, restricted water to 3 periods of 15-min each day. With water restriction there was an improvement in egg production from 79.4% to 82.3%. The number of kilograms of feed consumed per dozen eggs produced was improved by an estimated 5%. Muir and Gerry (1976) found only marginal improvement in egg production when water was supplied in 4 periods of 15-min per day, compared with *ad libitum* water supply. Feed intake was slightly lower for the restricted group, but the feed consumption per dozen eggs produced was improved by 2.2%. Hill and Richards (1975) found that restricting birds to 5 periods of 25-min improved the feed consumed per dozen eggs, compared to groups of birds on unrestricted water. Spiller, *et al.* (1973) conducted a trial which showed that birds restricted to 5 periods of 15-min watering per day ate less but egg production was the same as among unrestricted controls. In a further trial Spiller, *et al.* (1976) observed a decrease in egg production per hen day and in feed consumption, when water was supplied in 2 periods of 1h and 3 periods of 15 min daily. No estimates of efficiency between restricted and unrestricted groups were given. In another group of experiments however, Spiller, *et al.* (1976), using birds of different ages, found that production %, average egg weight and feed conversion efficiency were superior in hens restricted

to 5 periods of 15 min , compared to birds on
unrestricted water, allowed 1h water per day, 15
min per day, and 3 periods of 15 min per day. Hill
and Richards (1975) also conducted a series of
experiments with hens of different ages. Water for
birds was limited to 25-min periods 5 times per day.
The results are conflicting. Nevertheless, the best
results were obtained from a group of hens on restricted
water, from 41 weeks of age to end of lay. Production
percent improved from 67.7% to 70.5% and feed conversion
efficiency rose from 33.6% to 35.6%. Birds on restricted
water from point-of-lay to 61 weeks of age layed fewer
eggs but feed conversion efficiency was the same as the
control group.

3. Physiology of Feed Restriction

It has been suggested by Gowe, *et al*. (1960) and Hollandsand Gowe
(1961) that when the feed of a bird is restricted before maturity, the
restriction acts as a mild stress which stimulates enlargement of
endocrine glands. After maturity when *ad libitum* feeding is allowed,
the stress is no longer present and the hens respond by achieving a
higher rate of egg production and greater resistance to environmental
stress. Fuller and Dunahoo (1962) reported a significantly lower metabolic
rate which was still evident up to 52 weeks of age in pullets reared on
limited food. This could be a form of acclimatization or habituation.
The most severe levels of restriction during rearing produced the lowest
metabolic rate. The point of this work is that restriction during pullet
growth produces a more responsive physiological and reproductive setting

in birds for superior performance as adults.   Those birds not
restricted as pullets and achieving superior performance with feed
restriction as adult hens may have unknowingly been restricted as
pullets.

4.   Interpretation of Restricted Feeding Trials

There are many difficulties when attempting to assess the
literature concerning restricted feeding in laying hens.   These can be
summarized as follows:

(a)   Assessment   Different production and efficiency variables have
been used to assess the performance of birds
subjected to restricted feeding.

(b)   Food Components In some experiments both energy and protein has
been restricted but in others only one of these
nutrients has been varied.

(c)   Food Quality   Rations formulated for restricted feeding trials
have varied in component type, and hence quality.
Different time periods over the hen's laying cycle
have been used to restrict the feed.

(d)   Methods of   Numerous methods have been used to restrict the
Restriction   feed of hens leading to difficulties in interpreting
results between methods.

(e)   Strains of   Many different strains of hens have been used in
Bird   restricted feeding experiments.   It is probable
that the genetic differences between these strains
in efficiency of protein and energy utilization has
lead to different performances.

It would appear that if protein and energy response curves were established for each of the major strains of hen over their laying cycle that restricted feeding experiments could be centred more closely around the established optimum levels of energy and protein for each strain.

E.   PROTEIN REQUIREMENTS OF HENS

In considering the protein requirements of laying hens it is clear that factors such as energy content of the diet, temperature and stress alter feed intake and influence the level of dietary protein required. Such factors also influence the level of food intake.

1.   Crude Protein Requirements

The protein requirements of laying hens has been one of the most widely studied subjects in poultry nutrition. Defining the optimal amount and quality of protein is difficult because it is affected by the size of the hen, rate of egg production, egg size, season and environment. Expressed as a percentage of the dry matter of the food the protein needs of the laying hen have variously been reported from as low as 11 to 12% of feed mass, to as high as 18 to 20%.

All of these estimates are valid for particular conditions. Milton and Ingram (1957) reported that 18% protein was superior to 14 or 16% for egg yield. Hochreich, *et al.* (1958) showed that a level of 17% protein in the diet was required to maintain maximum egg production. Frank and Waibel (1960) presented data showing 15% protein to be sufficient for laying hens. Thornton, *et al.* (1957) indicated that a 13% protein level might be sufficient to support egg production when hens were maintained in cages. In support of this, Miller, *et al.* (1957) obtained good egg production with diets containing 12.5 to 13% protein. However, Talley

and Sanford (1966) using levels of 14, 15, 16, 18% protein found the higher levels of protein enhanced performance in the presence of high air temperatures. Quisenberry (1965) presented evidence showing that reduced protein levels - as the egg production period advanced - caused a decrease in body weight, but an increased rate of laying. Bray and Gessel (1961) showed that when the daily protein intake of hens fell below 12 g, egg production decreased, either simultaneously or during the following period.

Fernandiz, *et al.* (1973) reported that a diet containing 13% protein and supplemented with lysine and methionine was as effective as levels of 15, 17 and 18% protein for supporting egg production. Hens consumed equal amounts of feed that were essentially isocaloric diets with different levels of protein.

From the available evidence it is very difficult to define the protein requirements for optimal egg production. A knowledge is required of the pattern of feed consumption, the relation between egg production rate and daily protein requirement, to formulate a diet to meet the requirements under varying conditions.

2. Protein Requirements of Strains

Little analysis of protein requirements of strains of birds or of individual variations have been undertaken. Summers (1967) comments however, that differences in protein requirements appearing in the literature can be explained by differences attributable to strains. Harms and Waldroup (1962) reported a significant strain x protein level interaction, on the other hand for egg production when two similar strains of White Leghorn pullets were fed 13, 15 or 17% crude protein.

The response to different protein intakes was identical for the strains, and interaction arose because of different responses in food intake. Sharpe and Morris (1965) compared responses in a Rhode Island Red x Light Sussex strain and a small White Leghorn-type hybrid. These strains differed in egg output and also in body weight. The heavier cross bred strain produced less output of egg for the same amount of protein and this was assumed to be due to their extra growth requirements. Moreng, *et al.* (1964) found that a high body weight strain made more efficient use of dietary protein for egg production than 3 lighter strains. A difference of protein requirements between different strains of White Leghorn hens was found by Speers and Balloun (1967) when one strain did well on a 13% diet, a second strain required 15% protein and a third strain required a 17% protein feed for maximum egg production.

The experiments of Lillie and Denton (1967) with Leghorn pullets fed three levels of protein 10, 12.5 and 15%, indicated that the higher the protein level, the greater the egg production and body weight gain. Hubbell, *et al.* (1968) studied individually caged Leghorn hens and found that significant differences in protein consumption were reflected in egg production. The laying studies of Hunt and Aitken (1970) with 3 commercial Leghorn laying strains fed 4 different protein levels (11, 13, 15, 17%) showed that egg production was adversely affected by feeding at 11% and 13% protein levels, while birds on 15% and 17% were comparable in egg production. It was evident that egg production results were affected by strain. Feed consumption was influenced by energy intake rather than strain. Adams, *et al.* (1970) carried out a laying experiment with Leghorn hens fed a constant protein level of 18% versus variable protein diets of 14%, 16% and 18%. There was no difference in feed conversion between the two different feeding programmes. Protein

consumption never dropped below 17 g. $24h^{-1}$.

Whether all observed breed difference can be accounted for in terms of different outputs is not clear. Most differences can be explained in this way although a notable exception was one of 4 strains studied by Moreng, *et al*. (1964) which showed a very high efficiency of protein utilization. Reasons for this high efficiency of protein utilization are not clear, however. Whether there is any residual genetic variation in net protein utilization is not clear from the existing evidence. Comparison of individual hens on limited protein intake, in egg production ability and net protein utilization has been investigated, but all information has been pooled for analysis.

F. WATER METABOLISM IN BIRDS

Water is by far the largest single constituent in the body of birds. Although by weight a bird is 60-75% water, the molar composition is even greater. By number there are 99% of water molecules in the body, and less than 1% of fats, carbohydrates, proteins and electrolytes. For this reason alone, water must stand as one of the most important nutrients.

There have been limited studies on water use by domestic poultry. Most of the work has been restricted to direct measurements of water intake. However, the metabolism and balance of body water in the hen has generally been disregarded as a factor for study in identifying relationships in the hen.

1. Water Use by Birds

The maintenance of body water equilibrium is dependant on water intake, metabolic water and dietary water on the positive side and excreta water, evaporative water and egg water on the negative side.

Homeostatic controls maintain a nearly constant level of body water. Changes in water balance may reflect a change in metabolic status of the bird.

(a) Metabolic Water

In the bird, water is produced from the oxidation of hydrogen in protein, carbohydrate and fat. Some water appears also during synthesis involving acids and bases. This water contributes approximately 20% to the body water pool (Leeson, *et al.* 1976).

(b) Dietary Water

Poultry rations contain about 5-15% water, while most complete diets comprise approximately 10% water. Birds in runs eating insects or worms obtain higher proportions of water from food (70 - 80% water). This water is present in both biologically active and structural forms (Karamas, 1973).

(c) Drinking Water

Water obtained through drinking contributes approximately 70% to the body water pool in birds (Leeson, *et al.* 1976).

For birds, water intake increases with age, but consumption per unit of body weight decreases with age (Medway and Kare, 1959). Anderson and Hill (1967) amongst others have shown that food and water intake are linearly related in birds. When the supply of food was restricted, however, the consumption of water intake was not correspondingly altered. In contrast, sheep reduce food intake if water is not available and drink less water if the food consumption is low (Clark and Quin, 1949). Drinking behaviour in the ruminant is mediated by the cortex, limbic area and ventral hypothalamus (Morgane, 1969) while in birds Wagner (1964) showed that drinking behaviour was associated with control centres in

the hypothalamus.

The ratio of water:food ingested by the hen increases with temperature. Budgell (1970) described three hypotheses to explain the relationship between water intake and environmental temperature.

(i) Stimulation of water intake at high temperatures due to the local dryness of oropharyngeal receptors.

(ii) Systemic dehydration

(iii) Alteration in temperature of hypothalamus due to temperature *per se*.

At cold environmental temperatures, water intake is reduced (Parker, *et al*. 1972).

2. Water Loss by Birds

The excreta of laying hens contains about 80% water (Anderson and Hill, 1967). The quantity of water excreted as urine is four times less than the water excreted in faeces (Dicker and Haslam, 1972). These authors presented results which indicate that considerable quantities of water are absorbed by the intestinal epithelium. Water is lost in birds through the body surface and by evaporation from the moist surface of the respiratory tract. The evaporative rate is proportional to the respiratory rate. In birds 50% of total heat loss (through evaporation) may occur at environmental temperatures around 35^0 C (Kerstens, 1964 see Leeson, *et al*. 1976).

3. Water Balance and Turnover Studies in Birds

Younger birds have a greater proportion of body water than fatter mature birds. Lopez, *et al*. (1973) recorded values of 57 and 76% (of

body weight) for 7-year-old hens and 5-month-old pullets. Farrell (1974) found that the mean water content of 8-week-old meat birds was 62.5% (of body weight) while Farrell and Balnave (1977) recorded a considerable range in body water content, from 40-59% (of body weight) for hens ranging in age from 6 months to 2 years.

As hens age there is an increase in their body weight, but a decrease in their TBW as % of body weight. Body water and body fat are negatively correlated (Farrell, 1974 and Farrell and Balnave, 1977) indicating that as birds age there is an increase in the proportion of body fat, indirectly indicated by TBW estimates.

There is increased fat deposition with age since body fat and body water are negatively correlated (Farrell, 1974 and Farrell and Balnave, 1977).

By use of tritiated water the rate of water turnover in the hen can be measured and this was used by Chapman and Mihai (1972) who showed that the laying hen had a greater water turnover than the non-laying bird. Also water turnover in the laying bird is greater than that recorded for the adult male bird (Chapman and Black, 1967). Chapman and Black (1967) indicated that water turnover in the hen was not correlated with egg production, but it is apparent that egg formation must affect water loss from the body.

The formation of an egg involves the synthesis and transportation of considerable quantities of proteins across the walls of the oviduct. In part at least, this material is derived from the increased food consumed during the egg-forming period (Morris and Taylor, 1967). The increased demand for raw materials requires additional measures for transportation and dictate that fluid ingestion should also be increased.

Howard (1975) found that water intake increased about 12 h before oviposition and rose steadily about 2 h before lay and then fell sharply. Alterations in the water content of the oviduct were not sufficient to

explain the increased water intake. Total body weight remained constant
inspite of the consumption of the additional water. In view of these
findings Howard (1975) suggested that water has a metabolic role, as it
was not retained as a net fluid surplus.

Macfarlane, *et al.* (1974) have found that the amounts of energy
and water passing through a mammal are linked, and their turnover rate
is influenced by genotype, food, environmental temperature and age.
Macfarlane, *et al.* (1966) and Graham (1968) showed that there was a
genetic relationship between yield of wool from selected sheep and
their water intake. Ten years of selection for higher wool yield
resulted in selected animals passing through 13% more water than
unselected controls. It has been proposed that laying hens should
also be selected on a water intake basis (Lifschitz, *et al.* 1967).
Macfarlane, *et al.* (1974) has reported that within a breed or species
of mammals there is a range of both polymorphism and polyfunctionalism.
The range of water turnover in sheep for instance is 20% above and
below the average turnover rate of a flock. Macfarlane, *et al.* (1974)
suggest that it may be possible to segregate families with low rates
of water use from those with high rates. It would appear that this
approach in hens would also be valuable.

4. *In Vivo* Body Fat Estimates in Birds

Various techniques have been used to estimate body composition
in vivo, but one of the most reliable methods has been the measurement
of the distribution space of water using tritiated water. Farrell
(1974) used tritiated water to predict body water space, enabling body
fat to be estimated in poultry. Comparison between determined body

water content and tritiated water space showed that the former was overestimated on average by 18%. Farrell and Balnave (1977) reduced this figure to 15%.

In cattle Macfarlane, *et al*. (1974) report, however, that tritiated water gives about a 4% greater estimate of total body water than is obtained by dehydration.

Farrell and Balnave (1977) used periods of 24 h and 21 h for withdrawal of food and water respectively before injection of tritiated water. However, Panaretto (1968) found in the comparatively much larger ruminant animals that a 24-h period without food or water was sufficient. Hence in poultry only a few hours without food or water would be necessary. Farrell and Balnave (1977) presented a regression equation predicting fat relative to determined fat – this equation was based on values derived from 16 hens which had been restricted in food intake during growth and either restricted or fed *ad libitum* during lay. As a result a wide range of body weight and fat contents was obtained. However, they did not seek to relate the predicted fat measurements to performance or efficiency of the hens.

5. Body Fat and Efficiency of Birds

Farrell (1974a) produced results with broiler chickens showing that the percentage of body fat increased with an increase in dietary energy content. Water content of chickens declined with increasing dietary energy concentration. The energy stored as fat also increased with increasing concentration of dietary energy as did energy content of the carcass. Food conversion ratio declined with increasing dietary energy concentration. Neill, *et al*. (1977) slaughtered hens for carcass

analyses after they had reached a specific stage of their physiological development. Birds with higher amounts of accumulated fat tended to consume more food prior to and subsequent to their first egg, with a consequent detrimental effect on efficiency of food utilization.

G. ROLE OF THYROID HORMONES IN BIRDS

The thyroid has two broad spheres of function - regulation of metabolism and anabolism.

1. Metabolic Effects of Thyroid Hormones

In the adult warm-blooded animal thyroid hormone regulates the level of metabolic activity. Administration of thyroid hormone increases oxygen consumption and heat production and accelerates the metabolism of carbohydrates, proteins and fats. Not all tissues respond to thyroid hormone by an increase in energy metabolism. The brain, gonads and certain accessory sex organs, lymph nodes, spleen, thymus and dermis are unresponsive (Barker and Klitgaard, 1952). This suggests that thyroid hormones have multiple and variable actions on tissues.

Thyroxine (T_4) and triiodothyronine (T_3) have been shown to increase rectal temperature when a chicken is maintained in a thermally neutral environment, and thyroid hormones reduce the hypothermia that develops during exposure to cold (Freeman, 1971b). Similarly, hypothermic chicks have an impaired thermogenic response (Freeman, 1971b). Very few data exist on the effects of thyroid activity on metabolic rate in birds. The injection of T_4 into chicks resulted in a rise of metabolic rate of only short duration, probably because of the rapid rate of destruction of thyroid hormones in the bird (Singh, *et al.* 1968). It would

appear likely, however, that birds and mammals are similar in their thyroid response to environmental temperature, a function which is part of the complex thermo-regulatory mechanism in endotherms.

Administration of T_3 to hens results in an increased rate of incorporation of both methionine and lysine into egg albumen in dwarf hens, whereas an increased rate for lysine only was noted in normal hens. Administration of T_4 to hens resulted in a decreased incorporation of both methionine and lysine in normal hens, but in dwarf hens the decrease in rate of incorporation was found only for methionine (Grandhi, *et al.* 1975).

In mammals carbohydrate, lipid, protein, vitamin, water metabolism and neural activity are influenced by the thyroid hormones but in birds, information on the role of the thyroid in these areas of metabolism is inadequate.

2. Anabolic Regulation

Regulation of anabolism involves growth and developmental differentiation in the bird. The thyroid is one of the earliest endocrine glands to develop in the chick embryo. The tissues of the embryo are sensitive to thyroid hormone since duration of incubation and time of hatching can be affected by injecting thyroid hormone (Romanoff and Laufer, 1956 as cited by Falconer, 1971).

Beyer (1952) showed that there was an increase in chicken weight after treatment of the egg with thyroxine. It appears that moderate increases in available thyroid hormone in chickens will accelerate growth. Thyroid hormone requirement for growth and development is

shown most dramatically in metamorphosing amphibians. Thyroid hormone stimulates protein synthesis, including formation of new proteins and inhibits synthesis of some previously produced proteins, in specific areas of the body (Frieden, 1967).

In mammals normal growth requires the combined action of both growth hormone and the thyroid hormones (Lostroh and Li, 1958; Pindborg, *et al*. 1957). This type of relationship is also probable in chickens, since goitrogen-treated chicks, with no hormone supplementation, have a very poor growth rate.

3. Hormones of the Thyroid Gland

The thyroid glands in birds produces two major hormones – tetraiodothyronine (thyroxine (T_4)) and triiodothyronine (T_3) which are both iodine containing amino acids. In 1914 Kendall first isolated thyroxine in mammals and Gross and Leblond (1951) detected iodide, thyroxine, monoiodotyrosine and diiodotyrosine in thyroid gland extracts, but they were unable to detect a substance designated as "compound number 1". Subsequently Gross and Pitt-Rivers (1952) established that the unknown "compound number 1" was triiodothyronine.

In mammalian systems approximately four-fifths of the extrathyroidal body pool of T_3 is derived from the peripheral monodeiodination of T_4 (Surks, *et al*. 1973).

This process of deiodination is finely regulated giving rise to either T_3 or reverse T_3. In man caloric restriction results in a reduction in serum T_3 and a reciprocal increase in reverse T_3 (Spaulding, *et al*. 1976). Since T_3 is more active than T_4 in man and reverse T_3 is

essentially inactive, feed restriction appears to shunt T_4 metabolism
from activating to inactivating pathways. In birds T_4 has the same
potency as T_3 and the conversion of T_4 to reverse T_3 may also be
favoured by dietary restriction. In birds plasma T_4 initially decreases
with removal of feed but then increases after 6 days of feed withdrawal.
T_3 levels remain constant throughout feed withdrawal period. Resumption
of feeding results in a decrease in T_4 and increase in T_3 (Brake, *et al.*
1979). Brake and Thaxton (1979b) observed that the increase in T_4 was
coincident with a loss of ovarian weight, and presumably function, adding
further evidence to the postulated inverse thyroid-gonad relationship
in domestic bird species (Burger, *et al.* 1962; Jallageas and Assenmacher,
1974).

Peripheral generation of T_3 may play a central role in the
mediation of the biologic activity of thyroid hormone. Some investigators
have concluded that T_4 does not have intrinsic hormonal activity and may
be considered as a pro-hormone (Oppenheimer, *et al.* 1972b; Ingbar and
Braverman, 1975). Other workers however, still support the argument for
a direct biological action of T_4 when using the pituitary as the guage
(Chopra, *et al.* 1975b, Fukuda, *et al.* 1975 and Refetoff, *et al.* 1976).

The hormones T_4 and T_3 in birds are bound to albumin
and pre-albumin-like components. The concentration of
circulating thyroid hormones in the bird expressed as protein bound
iodine dl^{-1} varies between 1 and 2 μg in untreated adult birds, which
is lower than the amount usually found in plasma of domestic mammals
or man (Singh, *et al.* 1967).

Mammalian plasma contains an α_2 globulin which selectively binds T_4 and T_3 and normally carries the major proportion of circulating thyroid hormones. This is absent in avian blood, which transports thyroid hormones free in solution and loosely bound to albumin and pre-albumin (Tata and Shellabarger, 1959). As a consequence of the reduced thyroid hormone binding in avian blood, T_4 and T_3 in birds have relatively shorter half lives ($t_{\frac{1}{2}}$) than in mammals. Heninger and Newcomer (1964) reported mean half lives of 4.9 and 3.9 h for T_4 and T_3 respectively in the cardiac tissue of chickens. These values are similar to the $t_{\frac{1}{2}}$ observed by Singh, *et al.* (1967). In contrast with these results, Tata and Shellabarger (1959) reported mean $t_{\frac{1}{2}}$ values for both T_3 and T_4 in chickens of 22.5h. In chickens exposed to a range of environmental conditions Hendrich and Turner (1967) reported $t_{\frac{1}{2}}$ values ranging from 7.0 to 14.8 h. Increased plasma radio-activity found in cardiac blood relative to venous blood probably accounts for the discrepancy observed in reports of the $t_{\frac{1}{2}}$ values of T_4 and T_3 (Singh, *et al.* 1967).

In contrast to mammals, the biological activity of T_3 is equal to that of T_4 in birds (Tata and Shellabarger, 1959) but reports about the proportions of T_3 and T_4 that are actually metabolized have been conflicting. Wentworth and Mellen (1961) found that the T_3:T_4 ratio was 40:60 in the blood of chickens, turkeys and ducks. Vlijm (1958 see Singh, *et al.* 1967) reported the ratio T_3:T_4 as 3:20, but Sadovsky and Bensadoun (1970) separated the plasma iodohormones by thin layer chromotography, and found that the T_3:T_4 ratio changed at various times of the day due to alterations of the T_3 level. T_3 at 1600 h accounted for 68% of the total iodohormones.

Grandhi and Brown (1975) observed changes in the proportions of
T_3 and T_4 ($T_3:T_4$) at different ages in both dwarf and normal hens. The
relative amounts of T_3 compared with T_4 indicated that there was a
marked decline in the relative amounts of T_4 present. As the birds
approached sexual maturity the synthesis of T_3 increased sharply so
that the ratio of $T_3:T_4$ became approximately 15:1. This was in contrast
to the $T_3:T_4$ ratio of younger birds which was 0.7:1.

As T_3 has a body distribution space which is significantly
higher than T_4, and a biological half life similar to T_4, these properties
probably make it the important component of the output of the chicken
thyroid gland.

4. Mechanism of Action of the Thyroid Hormones

Knowledge of thyroid hormone action at the cellular level in
the fowl is inadequate and few experimental data exist on the mode of
action of thyroid hormones in birds. Although thyroid hormone action
and metabolism in birds should be examined independently of mammals,
many of the principles of hormone action in mammals should apply in
birds.

(a) Cellular Transport

Thyroid hormone increases the uptake of some amino-acids
and carbohydrates by cells (Goldfine, *et al.* 1975, which may
directly alter metabolic processes. In their work with chickens Segal,
et al. (1975) showed that the first effect of thyroid hormones is
independent of protein synthesis and may have a direct effect on the
activity of specific carriers on the membrane. The second action of

the thyroid hormones probably results in an increased synthesis of membrane carriers.

(b) Enzyme Activity

Thyroid hormones inhibit the activity of a number of dehydrogenases e.g. 15' hydroxyprostaglandin dehydrogenase (Tai, *et al.* 1974) although the mechanism of this effect is not clearly understood. However, interference with coenzyme or substrate binding may be involved in the mechanism. The thyroid hormones may affect enzyme activity by directly binding to the enzyme molecule (Hoch, 1974). There is also synthesis of the enzymes active in oxidative phosphorylation.

(c) Calorigenesis

It was in the 1950's considered that thryoid hormones increase BMR by influencing 'uncoupling' of oxidative phosphorylation, decreasing the yield of oxidative phosphorylation and giving rise to an increase in oxygen consumption. On the other hand, thyroid hormone can increase oxidation in the presence of normal phosphorylation. This has been called 'loose coupling' and represents a high respiration rate independent of the availability in ADP (Hoch, 1962, 1974). Several theories have been proposed to explain the increase in metabolic rate brought about by thyroid hormones.

(i) Effects on Mitochondria

There is evidence that thyroid hormones interact directly with mitochondria and that subsequent changes at the tissue level include alterations in oxygen consumption, and enzyme activity. The main effect is the modification of the turnover of mitochondrial DNA and proteins (Buchanan, *et al.*

1971). Herd, *et al.* (1974) proposed that T_4 induces the synthesis of a cytoplasmic protein which acts on the mitochondria.

(ii)   Stimulation of Regulatory Enzymes

The calorigenic action of thyroid hormones has also been explained on the basis of induction of specific enzymes with a regulatory role on key points of intermediary metabolism. One of these enzymes which is stimulated in this way is the mitochondrial cytochrome-linked α - glycerophosphate dehydrogenase (Hoch, 1974).

(iii)   Interaction with Catecholamines

T_4 is known to increase the response of animals to noradrenaline, but hypothyroidism produces the opposite effect. Van Inwegen, *et al.* (1975) suggested that modulation of cyclic AMP phosphodiesterase by thyroid hormones is one mechanism for the regulation of the responsiveness of rat adipose tissue to lipolytic agents such as adrenaline and glucagon.

(iv)   Stimulation of the Sodium Pump

Edelman and Ismail-Beigi (1974) found that sodium transport was stimulated by thyroid hormone and that the increase in available ATP secondarily served to stimulate the oxygen consumption and heat production. They also suggested that thyroid hormones exert their activity primarily by stimulating the activity of the Na^+-K^+-ATPase rather than secondarily as the result of changes in membrane permeability to sodium.

(d)   Protein Synthesis

There is evidence that thyroid hormones influence enzyme activity by inducing protein synthesis (Weis and Sokoloff, 1963; Lee and Miller, 1967).   Furthermore, thyroid hormones have been shown to influence increases in the amounts of some enzymes and proteins (Li, et al. 1975; Hervas, et al. 1975).

(i)   Effects on Transcription

Tata, et al. (1963) and Frieden (1967) observed increased RNA synthesis after the administration of thyroid hormone. This effect appeared to be the result of increase in activity of RNA polymerase probably due to elevation of template activity.   Kim and Cohen (1966) observed an increase in template efficiency after administration of T_4.   The hormonal effect could be mediated by an increase in r RNA or modulation of m RNA coding for a specific protein.

(ii)   Effects on Translation

Thyroid hormones may also affect the rate of protein synthesis at the translational level.   Cohen (1970) showed a higher rate of incorporation of t RNA in ribosomal preparations treated with T_4 than untreated preparations.   In rats, incorporation of labelled amino acids into proteins was increased after treatment with T_4 (Sokoloff and Kaufman, 1961) while T_3 injections to a euthyroid animal increased in vitro protein synthesis (Sokoloff, et al. 1968) in the presence of mitochondria.   Hence, it was suggested that the interaction of thyroid hormone with mitochondria releases a factor which stimulates protein synthesis of the ribosomal

level. However, the requirement for mitochondria has been questioned (Carter, *et al.* 1975).

Thus the mechanism of thyroid hormone action at the cellular level is complex. Thyroid hormones have a specific effect on synthesis of proteins (especially enzymes). The mechanism of action appears to be at the chromosomal level involving interaction with receptors which stimulate protein synthesis. Some of the metabolic effects of the thyroid hormones could be mediated by interaction with mitochondria, cell membranes and with some enzymatic systems.

5. Control of Thyroid Function

(a) The Pituitary - Thyroid Axis

The thyroid gland of the fowl is under pituitary control through secretion of thyroid stimulating hormone (TSH). The long term effects of TSH on thyroid function include increased iodine uptake, increased hormone synthesis and increased gland size. Secretion is controlled by the blood concentration of free thyroid hormone, which, when increased, inhibits TSH secretion from the thyrotroph cells. This interrelationship forms the basis of the negative feedback mechanism of thyroid control. When the blood level of free thyroid hormone is decreased, the thyrotrophs are stimulated to secrete TSH. Increased blood TSH concentrations in turn promote thyroid hormone production. The reverse mechanism operates when the free thyroid hormone level of the blood is increased (Falconer, 1971).

(b) Neural Control

Other factors which control TSH secretion are not completely understood. The central nervous system exerts regulation through the hypothalamic neurosecretion thyrotropin - releasing hormone (TRH). This together, with other releasing factors, is liberated into the blood vessels of the hypophysial portal system, and passes in the portal blood to the anterior pituitary. The area of the hypothalamus which appears to control the secretion of TRF is in the region above and behind the optic chiasma. Lesions in this area between the anterior commissure, posterior commissure and optic chiasma, suppress thyroid activity in fowls, and lesions in the supraoptico-hypophysial tract reduce thyroid activity in mammals (Brown - Grant, 1966). It appears that this neural control of TSH secretion is important in the response of the animal to stresses such as cold and emotion, which affect thyroid activity. It is also likely that the thyroid changes which are associated with reproduction are mediated through the hypothalamic regulation of pituitary TSH release (Brown - Grant, 1966).

6. Thyroid Response to the Environment

Investigations of thyroid gland function and metabolism have largely been limited to short term experiments with limited numbers of birds. Where possible thyroid function is assessed in relation to production performance of hens and environmental factors.

(a)   Temperature

The variation in thyroid secretion with season of the
year was first investigated in the chick by Reineke and Turner
(1945). Maximum secretion was shown to occur during winter
months, with lowest levels during summer. Thyroxine secretion
rate and levels of TSH in adult birds increase during exposure
to cold. When birds are shifted suddenly from a warm
environment to a cold environment, TSR increases very slowly
over a period of few weeks, while a return of birds from a
cold environment to a warm environment contrastingly results
in a very rapid reduction in TSR (Stahl and Turner, 1961). High
environmental temperatures (30 to 35^0 C) have a depressing effect
on thyroid secretion; only under extreme conditions of heat
(45 to 45^0 C) has an activation of the thyroid in birds been
observed (Chaudhuri and Sadhu, 1961). The speed of response of
the mammalian thyroid to elevations of body temperature is
almost immediate, indicating that a mechanism other than the
normal negative feedback regulation of the thyroid is involved.

Héroux and Brauer (1965) and Good, et al. (1974) have found
that an increment in the use of thyroxine is brought about by
increases of food intake. Heat and cold as such have little
effect on TSR.

However, Andersson, et al. (1962) has shown that cooling
mammals (goats) results initially in a fall in body temperature,
followed by a rise in temperature, with a parallel rise in
circulating thyroid hormone. By warming the preoptic area of

the brain during cooling of the body, the increase in thyroid hormone secretion was prevented. It was clear then, that a temperature-regulating centre in the hypothalamus was initiating the response, presumably through the secretion of hypothalamic TSH releasing factor (TRF) but in birds this aspect of control is not understood.

(b)   Metabolic Rate

Thyroxine has traditionally been looked on as a controller of metabolic rate. When a range of mammals was measured in the field, however, it was clear that thyroxine was produced to meet the need to metabolize food. Basal metabolic rates are genetically determined, with little influence from the thyroid (Macfarlane and Good,1976).

However, the injection of thyroxine into chickens results in a rise in metabolic rate of short duration (Singh, *et al*. 1968). Collins and Weiner (1968) showed that increasing environmental temperatures corresponded to a reduction of metabolic rate in mammals which reflected the observed reduction in thyroid activity, and reduced food intake.

The fowl shows pronounced diurnal rhythm in its metabolic rate, accompanied by a corresponding rhythm in the deep body temperature.

This rhythm was first described by Barott, *et al*. (1938) who found a difference of approximately 24% between the maximum and minimum BMR's during the first week of life and that

this variation declined with age. At 12 weeks of age the difference was 11% (Barott, *et al.* 1938) and in adults it was 9% (Deighton and Hutchinson, 1940). Barott, *et al.* (1938) and Tasaki and Sakurai (1969, reported by Freeman 1971) are agreed that the maximum metabolic rate of adults occurs at about 0800 h with the minimum rate occurring 12 h later.

The variation in diurnal rhythm is somewhat larger in the fully-fed adult and declines as starvation proceeds (Tasaki and Sakurai, 1969 reported by Freeman 1971).

7. <u>Thyroid Function and Growth</u>

Tanabe (1965) showed a linear decrease in TSR with age over the period of 2 weeks to 15 weeks in the chicken. This decline was similar to that seen in post-pubertal mammals. However, it is probably the reduction of food intake per unit of body mass with age as well as a decline in protein and water turnover rates with age rather than thyroxine which causes this decline in TSR. There is a trend towards a reduction in circulating T_4 with age recorded for both meat and egg type birds (Grandhi and Brown, 1975). As the T_4 levels with age declined, circulating T_3 levels increased, indicating that T_3 may have a growing importance over T_4 as the bird ages.

In an investigation of the relationship between thyroid secretion and growth rate in sheep, a curvilinear relationship was demonstrated, with marked decreases in growth rate in animals which were hyper - or hypothyroid (Draper, *et al.* 1968). This relationship is also probable in the growing chick since the results of Singh, *et al.* (1968) indicate that increases in growth rate occur with low

doses of thyroxine (birds given an antithyroid drug) whereas a higher dose results in lower growth rate.

Thyroidectomy has been shown to reduce the growth rate of female chicks (Winchester and Davis, 1952) by 30 to 50%. Hence thyroid function is essential for normal somatic growth and development, largely through the action of thyroxine on the somatotrophs of the pituitary.

8. Thyroid Function and Egg Production

In adult hens removal of the thyroid gland leads to a marked reduction in egg production (Taylor and Burmester, 1940). Winchester (1940) was able to increase egg production from 40 to 60% by administration of thyroxine. Turner, *et al.* (1945) as reported by Falconer (1971) conducted studies in an attempt to improve egg laying of hens during the summer months. It was observed that with high rates of hormone feeding, egg production and body weight decreased while mortality increased. With optimum feeding rates of thyroid hormone, however, improvement in egg production was achieved.

Booker and Sturkie (1950) showed that hens laying four-egg sequences had a higher thyroxine secretion rate than similar hens laying two-egg sequences, presumably a consequence of greater turnover of metabolites. Grandhi and Brown (1975) observed changes in proportions of T_3 and T_4 at different ages. Although T_3 is mainly produced by peripheral monodeiodination of T_4 they speculate on the existance of an adaptive mechanism in the thyroid glands which modifies the pattern of thyroid hormone synthesis in relation to physiological demands. While the exact significance of the $T_3:T_4$ ratio is obscure it is likely that T_3 and T_4 have separate functions. T_4 regulates energy metabolism and

T_3 is involved with mobilization of nutrients for the production of eggs. It could follow from this that hens with higher $T_3:T_4$ ratios have increased levels of egg production and efficiency.

H. CALCIUM AND EGG SHELL QUALITY

1. Introduction

The metabolic cost of producing an egg imposes a considerable nutritional load on the hen. A hen laying at the rate of about 80% produces about 45 g of egg mass per day, nearly 2% of the total body weight. Calcium drain is more severe, since it represents a daily turnover of 10% of the body pool. It is generally held by producers that an increase in incidence of cracked egg shells is the price inevitably paid, for an increase in rate of egg production. Studies relating efficiency of the hen to its egg shell quality are few for both *ad libitum* levels and fixed intake levels of calcium.

2. Role of Calcium in Egg Production

Gilbert (1969) has suggested that calcium is important in regulating ovarian function. It also seems that the hen has some mechanism of measuring her calcium depletion and which regulates the formation of ova accordingly. This reduced body calcium could stop laying through reduced ovarian function. Taylor (1972) suggested that if during the calcification of the egg shell, the ionic concentration of calcium in the plasma were to fall below a threshold level, the effect would be to reduce the secretion of gonadotrophins, which would in turn reduce the rate of follicular growth. This would reduce the rate of oestrogen secretion and with it the rate of synthesis of yolk material. The net result would be a reduction in egg production. The

need for the hen to secrete large amounts of calcium for the shell in some way limits the rate of ovulation and thus the rate of egg production.

3. Hormonal Control of Calcium Metabolism

    (a)   The parathyroid gland is located close, or even attached, to the posterior poles of the thyroid lobes in birds. In mammals it is generally accepted that there are two major effects of the parathyroid hormone. It increases the rate of bone reabsorption and the urinary excretion of phosphate. There are no reasons for supposing the physiological role of parathyroids in birds to be any different from that in mammals. It seems probable that soon after the period of rapid shell calcification begins, there is a fall in the plasma ionic calcium concentration which causes increased secretion of parathyroid hormone into the blood thus stimulating skeletal absorption (Taylor, 1971).

    (b) Calcitonin

       The ultimobranchial gland cells of birds contain high concentrations of calcitonin. The effect of calcitonin may normally be to prevent overshooting in the parathyroid regulation of the bird's plasma calcium level. It also has been suggested that calcitonin may protect the skeleton from excessive resorption (Simkiss and Dacke, 1971).

       The role of parathyroid hormone and calcitonin in maintaining calcium balance in the bird is not completely understood but their effects on egg shell quality cannot be

underestimated.

(c)   Thyroid Hormones

The shell strength of eggs (as measured by specific gravity) has been increased by feeding thyroxine to hens (Hoffman and Wheeler, 1948).

(d)   Oestrogens and Androgens

Oestrogens in conjunction with androgens play an important role in bone metabolism in laying hens, helping in the supply of calcium during laying (Taylor, 1966). Under the influence of these hormones secondary bone develops in cavities of the bones of the pullet in the final two weeks before the first egg is laid and persists throughout the laying season. This medullary bone acts as a reserve of calcium which is mobilized for egg shell formation when level of absorption from the gut is insufficient. Oestrogens in synergism with androgens enhances the absorption of calcium and phosphorus from the intestinal tract (Taylor, 1966).

Presumably these minerals are used for calcification of the medulla bone. Neither oestrogen nor androgen alone has an appreciable effect on calcium and phosphorus absorption (Taylor, 1966).

(e)   Pituitary and Hypothalmus

Birds placed on a low calcium diet continued producing eggs longer than expected when injected with a crude ovarian pituitary material (Taylor, *et al.* 1962). It was suggested that the amount of gonadotrophin released from the anterior pituitary is reduced during calcium deficiency and this mechanism may serve to protect the skeleton from excessive depletion. This effect is thought to be mediated by the

hypothalmus through a gonadotrophin releasing factor. There may be a critical level of ionic calcium in the plasma below which secretion of the releasing factor is inhibited. This inhibition reduces gonadotrophin secretion and hence rate of ovulation (Taylor, 1966).

4. Calcium Requirements of Laying Hens

The Agriculture Research Council (A R C) (1975) have estimated that the calcium requirement for hens to achieve maximum egg output is $3.0\,g. 24h^{-1}$. However, this is lower than requirement for maximum shell thickness. A R C (1975) analysed the literature and found that thickest shells were obtained with the highest intakes of calcium, this response being most marked with additional calcium where intakes were less than 3 g. The response to intakes above 3.8 g is marginal and above 5 g is negligible. There is some confusion when assessing shell strength in relation to restricted feeding. A R C realised this and calculated calcium intake of hens and related that to shell properties rather than the degree of feed restriction.

Increase in calcium content of the diet from 2 to 5% is associated with a thickening of the egg shell from 335 to 367μm (Foster and Neil, 1972). But Foster and Neill (1972) found that over this range of calcium intake variation in rate of egg production, body weight and egg weight had little consistent effect upon shell thickness.

In other experiments, Cipera and Grunder (1976) showed that birds which produced thicker shells had lower body weight than those which laid eggs of poor egg quality. They suggest that the consistent difference in body weight between hens of low and high egg shell

quality may indicate an underlying physiological difference. These results are opposite to those deriving from the mathematic theory of Foster and Neil (1972) in which heavier hens would tend to consume more calcium per egg.

High dietary levels of calcium tend to inhibit feed intake by hens (Hurwitz, *et al*. 1969) while a deficiency of calcium also reduces feed consumption (Roland, *et al*. 1973).

Phosphorus can influence shell quality presumably by influencing calcium absorption and/or bone resorption (Roland, 1976). Vitamin D stimulates intestinal calcium absorption and is the most potent substance known that influences bone resorption (Reynolds, *et al*. 1973).

(a) Restricted Feeding and Egg Shell Quality

Four examples may be cited where feed restriction was employed and some parameter reflecting shell strength was measured. Gerry and Muir (1976) found that restriction of feed by 15% did not effect any significant change in shell thickness. Similarly, Al-Khazraji, *et al*. (1972) did not observe any significant decline in specific gravity of eggs with 15% feed restriction. Also Kari, *et al*. (1977) imposed a 12% feed restriction and observed no significant change in shell thickness or shell weight of eggs assessed over a full laying year. Muir and Gerry (1976) imposed a 5% feed restriction to brown egg layers with no effect on shell thickness.

These results would indicate that the calcium intake of birds in the restricted feeding experiments was adequate to meet the requirements for satisfactory shell formation.

5. Factors Affecting Shell Strength

Peterson (1965) has reviewed the factors influencing the strength of egg shells. Genetic strains, rate of egg production, diet of the hen, age of bird and environmental temperature affect most measures of shell strength. Tyler and Geake (1964) observed that egg shells of individual birds differed greatly in shell strength.

6. Porosity

Not a great deal of information exists on egg shell porosity and bird efficiency. It is known, however that

(1) The age of birds does not influence shell porosity.

(2) The first egg of a clutch tends to have a lower porosity than other eggs in the same clutch (Wells, 1968).

CHAPTER II - EXPERIMENTAL

A. BIRDS

1. Project Development

The ensuing study was conducted in two phases.

(a) Phase 1

A group of 16 individual White Leghorn hens was allocated a range of feed from 80 g. $24h^{-1}$ to *ad libitum* over the period of 18-66 weeks of age. The following production, physiological and egg shell quality parameters were measured on these individual hens.

(i)

Production Parameters	Units	Age (weeks)
Feed Intake	$g.24h^{-1}$	18 – 66
Feed Intake	$g.24h^{-1}$	22 – 42
Feed Conversion Efficiency (FCE)	(%)	18 – 66
Feed Conversion Efficiency (FCE)	(%)	22 – 42
Egg Number		18 – 66
Egg Number		22 – 42
Average Egg Weight	g	18 – 66
Average Egg Weight	g	22 – 42

(ii)

Physiological Parameters		
Metabolic Rate	$KJ.kg^{0.75}.24h^{-1}$	25, 35, 45
Water Turnover	$ml.kg^{-1}.24h^{-1}$	25, 35, 45
Total Body Water as a percent of Body Wt.	(%)	25, 35, 45
Thyroxine Secretion Rate	$\mu g\ T_4.100g^{-1}.24h^{-1}$	25, 35, 45
Plasma Thyroxine	$\mu g\ T_4\ dl^{-1}$	25, 35, 45

(iii)

Shell Quality Parameters	Units	Age (weeks)
Shell Weight	g	45 – 55
Shell Weight per Surface Area of egg	mg. cm^{-2}	45 – 55
Shell Thickness	μm	45 – 55
Egg Conformation		45 – 55
Porosity	mg. cm^{-2}.24h^{-1}	45 – 55

(iv)

Body Weight Measurements	g	1, 2, 3, 4, 5, 6, 8, 10, 12, 14, 16, 18, 22, 26, 30, 34, 38, 42, 46, 50, 54, 58, 62, 66.

Four individual hens identified as A_1, A_3, A_4 and C_4 were selected on the basis of high F C E and bred into lines in a second, third and fourth generation. During the test period of 18 – 66 weeks of age birds were allocated feed either 80 g.24h^{-1} or *ad libitum* and above parameters measured at times indicated. F C E was determined over the period 22 – 42 weeks as this time period encompassed the period over which physiological measurements were made on birds.

(b) Phase 2

This phase observed performance of hens produced by line-crosses and outcrosses. Hens were fed *ad libitum* or allocated 80 g.24h^{-1}, 90 g.24h^{-1} or 100 g.24h^{-1}. As previously, production, physiological, egg shell quality and body weight parameters were measured on birds.

There have been variable reports on the daily ME intake required t maintain normal rates of lay. Jalaludin (1970) claimed that a daily ME intake of 782 KJ was sufficient, while Supramaniam (1970) reported tha

1129 KJ were required. Petersen (1971) found that rate of egg production could be maintained with a daily ME intake of 1 003 KJ.

For my work hens were restricted in feed by 33% over the period 18-66 weeks, which represented a daily ME intake of 883 KJ - intermediate to that reported by Jalaludin (1970) and Peterson (1971). The two other feed levels (90g. $24h^{-1}$ and 100g. $24h^{-1}$) were chosen so as to provide hens with ME intakes close to the optimum levels of reported ME requirements.

2. Birds

(a) F_1 Generation

Birds used were a White Leghorn strain, purchased from Anderson Chicks Pty. Ltd. at 18 weeks of age. Chickens were reared from day old to 6 weeks on litter and then grown in cages until 18 weeks of age.

(b) F_2 Generation

Selected hens from F_1 generation were mated with a related sire (White Leghorn) purchased from Anderson Chicks Pty. Ltd. Chickens were reared from day old to 6 weeks in a battery brooder and then grown in cages until 18 weeks of age.

(c) F_3 Generation

Selected hens from F_2 generation were mated with closely related sires. Chickens hatched were reared as described for F_2 generation.

(d) F_4, F_5 and Outcross Generation

Selected lines of hens were mated with a sire (White Leghorn) purchased from Anderson Chicks Pty. Ltd. to produce the outcross generation. Inbred lines (F_4 generation) were maintained into a fourth generation by mating of selected hens with closely related sires. Mating of selected hens of one line with selected sires from other lines produced the line-crosses (F_5 generation). Chickens were reared from day old to 6 weeks in a battery brooder and then grown in cages until 18 weeks of age.

Assessment periods were either 18-66 weeks of age, covering the entire productive life of the commercial laying hen or 22-42 weeks encompassing the peak period of laying of most hens. The 2 intervals from 22-42 weeks (i.e. periods 2-6) and 18-66 weeks (i.e. periods 1-12; 12 x 4 week intervals from the age of 18 weeks were designated as periods 1-12) are normally used in Random Sample Tests (Australia and overseas) to assess performance between strains of hens over these 2 intervals. Performance over the period 22-42 weeks measures the peak egg production ability of the hen. The stamina of the hen is guaged over the period 18-66 weeks.

The physiological parameters on birds were measured starting week 22 (ending week 25) and starting week 42 (and ending week 45). It was difficult for me to measure MR, WTOH and TSR on all hens in the one week. Therefore I spread the work over 2-3 weeks.

3. Housing and Environment

The poultry unit formed part of a general holding area at the Waite Agricultural Research Institute. The unit comprised a rearing shed and a layers shed. The rearing shed consisted of a group of growing cages arranged back to back with trough waterers. The layers shed was made up of A-frame cages with water made available *ad libitum* through nipple lines. The capacity of the layers shed was increased during the course of the study from 24 to 180 individual cages.

The rearing shed and the layers shed were cooled in the summer using evaporative cooling. In the winter convection and radiation heaters were used to raise environmental temperatures. Bird droppings were washed daily from cement floors in both rearing and layers shed. Layers shed lighting was held constant at 16:8 = L:D.

4. Feeding

Over the course of the study, feed was purchased from Noske Flour Mills Pty. Ltd. It was a standard layers crumble. Routine determination of metabolizable energy, protein and amino-acid composition were made. For individual bird studies, feed troughs were divided with masonite partitions. The division in the feed troughs were made the same height as the cages to prevent steal feeding by individuals. In each generation birds were randomly allotted to treatment and to cages. Restricted birds were fed daily. *Ad libitum* birds were fed twice weekly. Feed was weighed to nearest 0.1 g.

Feed intake was calculated on a weekly basis (expressed as a daily intake) for each bird and averaged for the two periods already indicated.

Table 1. Poultry Ration – Ingredients and Major Components

Mix	%	Major Components	%
Wheat (10.2% Protein)	52.0	Fat	2.7
Pollard	18.2	Fibre	8.2
Meat Meal (35.8% Protein)	19.0	Calcium	3.7
Blood Meal	1.0	Phosphorus	1.1
Cotton Seed Meal	3.8	Crude Protein	16.2 ± 0.3
Lucerne Meal	6.5	Moisture	10.4 ± 0.1
Salt	0.2		
Lime	8.9	ME 11045 ± 190 KJ.Kg^{-1}	
D.L. Methionine	0.1		
Vitamin & Mineral Mix	0.3		

Over the period of the project, 17 batches of feed were analysed for ME, protein and essential amino-acid content.

Table 1(a)   Percentage of Essential Amino-acids in Dried Layer Crumble

	%(±SEM)
Methionine	0.33±0.01
Cystine	0.28±0.01
Lysine	0.73±0.01
Glycine	1.44±0.09
Tryptophan	0.26±0.02
Arginine	1.11±0.02
Threonine	0.55±0.01
Isoleucine	0.50±0.01
Leucine	1.19±0.02
Histidine	0.35±0.01
Valine	0.81±0.01
Phenylalanine	0.66±0.02
Tyrosine	0.46±0.02
Serine	0.68±0.01

5. Bird Weighing

Birds were weighed to nearest gram at ages already indicated.

6. Egg Records

Egg production for each bird was recorded for the age period 18-66 weeks. Eggs were collected daily and weighed to nearest 0.1 g.

B. TURNOVER STUDIES, SAMPLE COLLECTION AND STORAGE

1. Injection

During the work, use was made of tritiated water (TOH) and iodine-labelled thyroxine (^{125}I-T$_4$). Both isotopes in 140mM NaCl were injected into the birds intramuscularly.

The muscle injected was the *peronaeus longus*. Birds were appropriately positioned and then the needle was plunged into the tissue quickly. The syringe was attached and the volume of the isotope was blown out through the needle into the tissue of the bird by a small bubble in the syringe to obtain quantitative injection. The needle was left *in situ* for a few seconds and digital pressure applied to the surface of the skin surrounding the injected region. This procedure was performed with the bird lying on its side and firmly held by hand, so that any movement of body and legs of the bird was prevented.

2. Blood Sampling

All blood samples obtained from the birds were taken peripherally from the wing vein (brachial). When blood samples were required, the bird was taken from the cage and placed on a table, on its back with the wing extended from the body. A dilute solution of Zephiran was applied to inner portion of the wing to clean the skin. Feathers located in the vicinity of the brachial vein were removed with scissors to show the line of the vein from the abdomen to wing extremeties. A small desk lamp was used to provide adequate light.

To hold the bird in place, one hand was positioned on the abdomen and the wing was fully extended at the same time. The index finger of that hand was placed firmly on the brachial vein proximal to the position of needle insertion. This caused filling of the brachial vein with blood.

The hypodermic needle was then inserted through the outer layers of skin into the vessel at an angle of 15^0 to the line of the wing and vessel. Depending on the experimental requirements a 5 ml or 10 ml syringe was used to withdraw blood samples. Syringes were all previously heparinized.

All blood collected was transferred to 10 ml plastic heparinized centrifuge tubes or 5 ml plastic vials.

3. Faeces Collection

Small tin trays of the same length and breadth as the individual cages were used for collection of faeces. Wire hooks attached to each corner of the tray were used to suspend the tray approximately 15cm below the individual cages. The bases of the trays were lined with a plastic sheet before faeces collections were made.

4. Storage

(a) Blood

Blood was transferred from the syringe into a heparinized 5 ml vial. The vial was capped and then shaken to mix the sampled blood with the heparin. The vial was then stored in a freezer and used when required for TOH determinations.

(b) Plasma

Sampled blood was transferred from the syringe into a 10 ml centrifuge tube which had been previously heparinized. Blood which had been placed in these tubes was centrifuged at 2000 r p m for 20 min

Plasma samples were transferred to a 5 ml container and stored in a freezer.

(c) Faeces

Faeces which had been dried were finely ground and stored in bottles in the freezer.

(d) Feed

Feed which had been finely ground was stored in bottles in the freezer.

C. ANALYTICAL PROCEDURES

1. Crude Protein Analyses

Crude protein of feed was determined using the micro-Kjeldahl method. The nitrogen of protein was transformed into ammonium sulphate by acid digestion with boiling sulphuric acid. The acid digest was cooled, diluted with water and made strongly basic with sodium hydroxide. The ammonia released was distilled with a boric acid solution. The ammonia in the boric acid solution was titrated with a standardized potassium bi-iodate solution. A blank digestion was carried out with each batch of protein determinations. The variation between duplicate samples was 3%.

2. Amino-Acid Analyses

Amino-acid content of feed was determined using the method of Spackman, Stein and Moore (1958). Tryptophan was estimated by the method of Miller (1967) and methionine and cystine were estimated on samples oxidized with performic acid (Moore, 1960). Hydrolysis of the crude protein of the feed released free amino-acids by breakage of the peptide linkages. A solution containing the free amino-acids was applied to the column of a Beckman amino-acid analyzer. The sample amino-acids were referred to standard amino-acids. Individual amino-acids were determined with an accuracy of $\pm 2\,\mu\,\text{mol}$.

3. Estimation of Metabolizable Energy

The metabolizable energy (ME) of the compounded feed was evaluated directly from measurements of the heats of combustion of representative samples of feed and excreta (Shannon and Brown, 1969). The excreta output relative to food intake was determined using the procedure given by Vohra (1972).

Gross energy (GE) of feed and excreta was determined in a ballistic bomb calorimeter. A known weight of dried feed or excreta was ignited electrically and combusted in an excess of oxygen in the bomb. The maximum temperature rise of the top of the bomb was measured with a thermocouple and galvanometer system. Temperature rise of the test sample was compared with that obtained with a standard sample (benzoic acid) of known calorific value. The variation in GE between standard samples of benzoic acid was calculated to be 2.7%.

4. Determination of Plasma Thyroxine

Determination of the plasma thyroxine level was performed using the competitive protein-binding analysis of Murphy and Jachan (1965). After a single ethanolic extraction from plasma, the thyroxine of the unknown sample was quantitated according to its competition with a fixed amount of $^{125}I-T_4$ for binding sites on a constant amount of TBG. To separate the TBG-bound $^{125}I-T_4$ from the unbound $^{125}I-T_4$, an anion exchange resin was used. The standards were prepared according to Nobel and Barnhart (1969). When human plasma was used, these methods used 0.3 ml of ethanol extract which yielded sufficient thyroxine for accurate analysis.

However, measurement of pool samples of hen plasma, using 0.3 ml ethanol extract, gave low thyroxine concentrations.

To obtain greater accuracy of estimation, 0.6 ml of the ethanol extract was used, to provide twice the amount of thyroxine. These levels of thyroxine then fitted onto the more sensitive region of the standard curve. A pooled plasma sample stored frozen was assayed with each total thyroxine estimation. A mean value of $1.34\mu g.dl^{-1}$ (SEM = 0.14) was obtained for 20 separate determinations.

5. Determination of Thyroxine Secretion Rate

The method of Ingbar and Frienkel (1955) was used as the basis of the determination of thyroxine secretion rate (TSR). The method involved intramuscular injection of a tracer quantity of $^{125}I-T_4$ into the bird. It was assumed that in the steady state, the rate of hormone secretion equalled the rate of hormone loss. The injected $^{125}I-T_4$

reached equilibrium with the thyroxine distribution space and then disappeared from the circulation at an exponential rate. A change in this rate resulted from the secretion of endogenous ^{125}I-T_4 which followed thyroid gland uptake of ^{125}I-iodine derived from tracer metabolized by the tissues.

For routine TSR determinations blood samples were drawn 4h, 7h and 10h after injection of the ^{125}I-T_4. The radioactivity was measured in a aliquot of plasma. Plasma $PB^{125}I$ was then determined in this sample by precipitation of the plasma proteins. A standard sample of the injected ^{125}I-T_4 was counted with the experimental samples. The variation between standard sample counts was calculated to be 3% . The biological half-time ($t_{\frac{1}{2}}$) was estimated from the plasma $PB^{125}I$ degradation curve enabling the rate constant for loss to be calculated. The distribution volume of the hormone was then calculated. Finally the daily secretion of thyroxine was calculated using plasma thryoxine concentration, rate constant and distribution volume.

6. Determination of Water Turnover, Total Body Water and Carcass Fat

Total body water and water turnover were estimated by adaptation of the method of Morris, Howard and Macfarlane (1962). Tritiated water was injected intramuscularly as a 0.9% sodium chloride solution with a specific activity of $50\mu Ci.ml^{-1}$. Blood samples were taken at 4h, 1d, 4d and 7d. The total body water was estimated from the concentration of tritium at the time of injection, obtained by extrapolation of the disappearance curve. Water was obtained by freeze-drying blood and collecting the sublimed water in a cold trap (Cooper, Radin and Borden, 1958). Tritium concentration was determined on aliquots brought into

solution in a dioxane scintillation fluid and counted in a Packard scintillation spectrometer. The variation in standard sample counts was estimated at 3.2%. Total body water as a % of body weight was calculated to give an estimate of carcass fat.

7. Determination of Metabolic Rate

The closed-circuit method for measurement of heat production by oxygen consumption was used. The same air was held in an air tight chamber connected to a volume meter (300 volumeter, Med-Science Electronics, St. Louis). Moisture and carbon dioxide produced by the bird was removed by chemical absorbents. The decrease in volume of the chamber was compensated for by the volume meter, recorded as the oxygen uptake by the bird. Heat production was calculated from the thermal equivalent of oxygen, assuming a respiratory quotient of 1. The volume meter was found to measure volume with an accuracy of 1.5%. Due to the number of assumptions made, computed metabolic rate determinations were estimated to have an accuracy of only 8%.

8. Determination of Shell Quality Variables

Egg conformation, shell thickness and shell weight per surface area of the egg were determined using the procedures given by Tung, Staley and Richards (1968). The weight of eggs and shells were measured to nearest 0.01 g, egg width and length were determined with a precision of ±0.005 cm and shell thickness was measured to the nearest micron.

Shell porosity was determined using the incubation method given by Wells (1968). Eggs were weighed to the nearest 0.01 g. Temperature of the incubator was maintained at $38^0 \pm 1^0C$ and relative humidity at $80 \pm 2\%$.

CHAPTER III - RESULTS AND DISCUSSION

A. ANALYSES OF RELATIONSHIPS BETWEEN FCE AND OTHER VARIABLES

1. Preliminary Analyses

Before any analyses were commenced the collected data were screened and all data were omitted from the analyses of any bird which did not survive to 66 weeks. Some birds do not have the full complement of measurements since they were non-layers during egg quality measurements. The results for physiological parameters were averages of the 3 readings made on each bird. Egg shell quality estimates were averages of the eggs measured from each bird over the specified time period.

2. Correlation Coefficients between Independent Variables from Purebred Flock

The CORR procedure from the Statistical Analysis System (SAS) program was used to compute the product moment correlation coefficient between each pair of variables (Barr, *et al.* 1976). All production, physiological, metabolic and egg shell quality variables were fed to the computer, but only body weights at hatch, 6, 18, 42 and 66 weeks of age were included in the analysis.

The aim of this analysis was to identify those variables which were most closely linked to feed conversion efficiency. The data from restricted and *ad libitum* fed birds were considered together in the analyses.

The numbers of birds used from each breeding line for the 2 feed levels over the 4 generations in determining correlation coefficients, are shown in Table 2.

Table 2. Bird Numbers for each Line, Generation and Feed Level

Lines

Generation	A_1		A_3		A_4		C_4		
	80*	A	80	A	80	A	80	A	Subtotal
1	1	0	1	0	1	0	0	1	4
2	2	6	3	7	7	4	6	6	41
3	9	6	9	7	11	7	8	5	62
4	3	3	3	2	3	3	2	2	21
Subtotal	15	15	16	16	22	14	16	14	
Total	30		32		36		30		128

80^* represent a feeding level of 80 g.24h^{-1};

and A represents *ad libitum*

Key to Tables 3,3(a) 4, 5 and 6

X_1	=	FCE (18-66 weeks)
X_2	=	FCE (22-42 weeks)
X_3	=	Feed intake (g.24h^{-1}) 18-66 weeks
X_4	=	Feed intake (g.24h^{-1}) 22-42 weeks
X_5	=	Egg number (18-66 weeks)
X_6	=	Egg number (22-42 weeks)
X_7	=	Average egg weight (g) 18-66 weeks
X_8	=	Average egg weight (g) 22-42 weeks
X_9	=	Metabolic rate (KJ. kg$^{-0.75}$.24h^{-1})
X_{10}	=	Water turnover (ml.kg^{-1}.24h^{-1})
X_{11}	=	Total body water as a percentage of body weight (%)
X_{12}	=	Thyroxine secretion rate (μgT$_4$.100g^{-1}.24h^{-1})
X_{13}	=	Plasma thyroxine (μgT$_4$dl^{-1})
X_{14}	=	Shell weight (g)
X_{15}	=	Shell weight per surface area egg (mg. cm^{-2})
X_{16}	=	Shell thickness (μm)
X_{17}	=	Egg conformation
X_{18}	=	Porosity (mg. cm^{-2}.24h^{-1})
X_{19}	=	Body weight (g) - Hatch
X_{20}	=	Body weight (g) - 6 weeks
X_{21}	=	Body weight (g) - 18 weeks
X_{22}	=	Body weight (g) - 42 weeks
X_{23}	=	Body weight (g) - 66 weeks

Table 3. Simple Correlation Coefficients (r) - All Purebred Birds - Production Variables Versus Physiological, Egg Shell Quality and Body Weight Variables

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
X_1		0.906***	0.505***	0.510***	0.910***	0.860***	0.355***	0.276**
X_2			0.441***	0.463***	0.809***	0.895***	0.250**	0.225*
X_3				0.986***	0.789***	0.761***	0.423***	0.366***
X_4					0.785***	0.782***	0.437***	0.389***
X_5						0.945***	0.327***	0.243**
X_6							0.278**	0.230**
X_7								0.939***
X_8								
X_9	0.123^{ns}	0.113^{ns}	0.393***	0.381***	0.280**	-0.278**	-0.014^{ns}	-0.021^{ns}
X_{10}	0.240*	0.230*	0.058^{ns}	0.021^{ns}	0.211*	0.181*	-0.119^{ns}	-0.110^{ns}
X_{11}	0.089^{ns}	-0.139^{ns}	-0.487^{***}	-0.518***	-0.269**	-0.326***	-0.302***	-0.320***
X_{12}	-0.271**	-0.284**	-0.038^{ns}	-0.048^{ns}	-0.191*	-0.200*	-0.073^{ns}	-0.041^{ns}
X_{13}	-0.414***	-0.456***	-0.177*	-0.191*	-0.356***	-0.399***	-0.060^{ns}	-0.019^{ns}
X_{14}	0.222*	0.191*	0.301***	0.331***	0.203*	0.218*	0.653***	0.572***
X_{15}	-0.039^{ns}	-0.049^{ns}	0.114^{ns}	0.125^{ns}	0.003^{ns}	0.012^{ns}	0.201^{*}	0.130^{ns}
X_{16}	0.140^{ns}	0.112^{ns}	0.207*	0.219*	0.157^{ns}	0.156^{ns}	0.307***	0.225*

Table 3(a). <u>Simple Correlation Coefficients (r) - Purebred Birds - Production Variables Versus</u>
<u>Physiological, Egg Shell Quality and Body Weight Variables</u>

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
X_{17}	0.009^{ns}	0.040^{ns}	-0.006^{ns}	-0.001^{ns}	-0.030^{ns}	0.012^{ns}	0.098^{ns}	0.110^{ns}
X_{18}	0.309***	0.257**	0.294***	0.314***	0.358***	0.343***	0.193*	0.165^{ns}
X_{19}	0.170^{ns}	0.122^{ns}	0.087^{ns}	0.094^{ns}	0.113^{ns}	0.097^{ns}	0.314***	0.283**
X_{20}	-0.173^{ns}	-0.110^{ns}	-0.165^{ns}	$-0.181*$	$-0.194*$	-0.174^{ns}	-0.083	0.000^{ns}
X_{21}	-0.164^{ns}	-0.116^{ns}	0.065^{ns}	0.049^{ns}	-0.116^{ns}	-0.103^{ns}	0.124^{ns}	0.149^{ns}
X_{22}	0.231**	0.199*	0.709***	0.739***	0.437***	0.447***	0.544***	0.508***
X_{23}	0.254**	0.300***	0.704***	0.744***	0.442***	0.516***	0.529***	0.519***

* $p < 0.05$

** $p < 0.01$

*** $p < 0.001$

ns   not significant

n = 128 except

X_1 to X_7 with X_8,	n = 127	X_{20} with X_7,	n = 123
X_9 to X_{17} with X_8,	n = 127	X_{21} to X_{23} with X_7,	n = 127
X_{18} with X_1 to X_7,	n = 126		
X_{19} with X_1 to X_6,	n = 124		
X_{19} with X_7,	n = 123		
X_{20} with X_1 to X_7,	n = 124		

Table 4. Simple Correlation Coefficients (r) – All Purebred Birds –
Physiological Variables Versus Egg Shell Quality
and Body Weight Variables

	X_9	X_{10}	X_{11}	X_{12}	X_{13}
X_9					
X_{10}	0.155^{ns}				
X_{11}	$-0.246**$	0.163^{ns}			
X_{12}	$0.270**$	-0.076^{ns}	-0.129^{ns}		
X_{13}	0.044^{ns}	-0.099^{ns}	-0.075^{ns}	$0.560***$	
X_{14}	-0.114^{ns}	-0.098^{ns}	$-0.215*$	-0.173^{ns}	-0.055^{ns}
X_{15}	-0.107^{ns}	-0.036^{ns}	$-0.178*$	-0.133^{ns}	0.057^{ns}
X_{16}	-0.155^{ns}	-0.030^{ns}	-0.128^{ns}	$-0.304***$	-0.046^{ns}
X_{17}	0.144^{ns}	-0.054^{ns}	-0.023^{ns}	$0.176*$	0.018^{ns}
X_{18}	0.108^{ns}	0.011^{ns}	$-0.231**$	-0.043^{ns}	-0.019^{ns}
X_{19}	$-0.222*$	-0.147^{ns}	0.105^{ns}	$-0.218*$	$-0.230*$
X_{20}	-0.108^{ns}	$0.185*$	-0.042^{ns}	$-0.219*$	-0.035^{ns}
X_{21}	0.126^{ns}	-0.014^{ns}	$-0.205*$	-0.163^{ns}	0.075^{ns}
X_{22}	0.107^{ns}	$-0.214*$	$-0.524***$	$0.176*$	-0.126^{ns}
X_{23}	0.113^{ns}	$-0.205*$	$-0.525***$	$0.178*$	-0.134^{ns}

* $p < 0.05$ $n = 128$

** $p < 0.01$ except X_{14} to X_{17} with X_9 to X_{13}

*** $p < 0.001$ $n = 127$

ns   not significant X_{18} with X_9 to X_{13}

                                   $n = 126$

                     X_{19} and X_{20} with X_9 to X_{13}

                                   $n = 124$

Table 5. Simple Correlation Coefficients (r) – All Purebred Birds –
Egg Shell Quality Variables Versus Body Weight Variables

	X_{14}	X_{15}	X_{16}	X_{17}	X_{18}
X_{14}					
X_{15}	0.782***				
X_{16}	0.815***	0.907***			
X_{17}	0.120^{ns}	0.035^{ns}	0.015^{ns}		
X_{18}	0.039^{ns}	-0.081^{ns}	0.016^{ns}	-0.079^{ns}	
X_{19}	0.205**	-0.070^{ns}	-0.064^{ns}	-0.168^{ns}	0.139^{ns}
X_{20}	-0.086^{ns}	-0.001^{ns}	-0.029^{ns}	-0.122^{ns}	-0.026^{ns}
X_{21}	0.106^{ns}	0.021^{ns}	0.033^{ns}	-0.045^{ns}	0.034^{ns}
X_{22}	0.439***	0.137^{ns}	0.257**	-0.059^{ns}	0.364***
X_{23}	0.453***	0.146^{ns}	0.273**	-0.025^{ns}	0.326***

*	$p < 0.05$	
**	$p < 0.01$	
***	$p < 0.001$	
ns	not significant	

n = 127 except

X_{18} with X_{14} to X_{17},	n = 126
X_{21} to X_{23} with X_{18},	n = 126
X_{19} with X_{14} to X_{17},	n = 123
X_{19} with X_{18},	n = 122
X_{20} with X_{14} to X_{17},	n = 123
X_{20}, 21 with X_{18},	n = 122

Table 6.   Simple Correlation Coefficients (r) –
All Purebred Birds – Body Weight Variables

	X_{19}	X_{20}	X_{21}	X_{22}
X_{20}	0.115^{ns}			
X_{21}	$0.209*$	$0.505***$		
X_{22}	$0.350***$	0.011^{ns}	$0.390***$	
X_{23}	$0.334***$	0.003^{ns}	$0.326***$	$0.914***$

* $p<0.05$

** $p<0.01$

*** $p<0.001$

ns   not significant

n = 124 except

X_{21} with X_{22}, X_{23},   n = 128

X_{22} with X_{23},   n = 128

From the results (Tables 3-6 inc.) it is apparent that FCE over the 2 specified age periods is significantly correlated with all other production parameters as well as some physiological, egg shell quality and body weight parameters. However this analysis only observes the variables in pairs. Relationships involving more than 2 variables are not considered.

3. The Stepwise Regression Procedure

As a result of the number of significant correlations found between FCE and other parameters it was decided to apply the Stepwise procedure (Barr, *et al.* 1976) to find which of the independent variables should be included in a regression model for FCE. This technique was used to gain insight into the relative strengths of the relationships between FCE and other parameters.

The Stepwise procedure first finds the single variable model which produces the largest R^2 statistic. For each of the other independent variables, Stepwise calculates an F statistic reflecting that variable's contribution to the model, were it to be included. The variable with the highest F value is added to the model provided that the probability associated with that F value is greater than 5%.

After a variable is added, Stepwise looks at all the variables already included in the model. Any variable not producing a partial F - statistic significant at the 5% significance level is then deleted from the model. Variables are added to the model until none produces an F value of the required probability or until the variable deleted is the last variable added.

The Stepwise regression procedure was used for the 2 dependent variables - FCE (18-66 weeks) and FCE (22-42 weeks).

(a) Stepwise Regression Procedure for Dependent
    Variable FCE (18-66 weeks)

All variables measured in this study except body weights already specified were included as independent variables for this analysis. Data from birds on both feed levels were included. The following variables were selected in order of importance for their association with dependent variable FCE (18-66 weeks) using the Stepwise procedure.

		Stepwise regression correlation with FCE
1.	Egg number (18-66 weeks)	+ve
2.	Feed intake (18-66 weeks)	-ve
3.	Average egg weight (18-66 weeks)	+ve
4.	Body weight (42 weeks)	-ve
5.	Shell weight	+ve
6.	Shell weight per surface area egg	-ve
7.	Plasma thyroxine	-ve

No other variables met the 5% significance level for entry.

(b) Stepwise Regression Procedure for Dependent Variable
    FCE (22-42 weeks)

The following variables were selected in order of importance for their association with dependent variable FCE (22-42 weeks). Data from birds on both feed levels were included.

Stepwise regression
correlation with FCE

1. Egg number (22-42 weeks)   +ve

2. Feed intake (22-42 weeks)   -ve

3. Average egg weight (18-66 weeks)   +ve

4. Porosity   -ve

5. Body weight (18 weeks)   +ve

6. Shell weight   +ve

7. Shell weight per surface area egg   -ve

No other variables met the 5% significance level for entry.

It is evident that the first 3 variables selected in the model (egg number, feed intake and average egg weight) are by definition an integral part of the FCE calculation. Also shell weight makes an approximately 10% contribution to egg weight and hence its selection as an element of the model. Shell weight per surface area of egg appears as a variable in the model presumably because of its high correlation ($r = 0.782***$) with shell weight (refer to Table 5). Interestingly, porosity is significantly correlated with all production parameters except average egg weight (22-42 weeks).

Subsequently it was decided to perform a Stepwise search using parameters not directly associated with shell weight or egg weight. Hence all egg shell quality parameters as well as feed intake, egg number and average egg weight were

excluded from the Stepwise regression analysis.

(c) <u>Stepwise Regression Procedure for Dependent Variables</u>
    <u>FCE (18-66) and FCE (22-42) and Independent Physiological</u>
    <u>and Body Weight Variables</u>

The following 2 variables were selected in order of
importance for their association with FCE (18-66 weeks). Data
from birds on both feed levels were included.

		Stepwise regression correlation with FCE
1.	Body weight (42 weeks)	-ve
2.	Water turnover	+ve

No other variables met the 5% significance level for
entry in the model.

The following 3 variables were selected in order
of importance for their association with FCE (22-42 weeks).
Data from birds on both feed levels were included.

		Stepwise regression correlation with FCE
1.	Body weight (42 weeks)	-ve
2.	Water turnover	+ve
3.	Thyroxine secretion rate	-ve

No other variables met the 5% significance level for
entry in the model.

4. General Linear Models Procedure

The stepwise regression procedure selected water turnover, thyroxine secretion rate and body weight (42 weeks) as being the variables most closely associated with FCE (18-66 weeks, 22-42 weeks) if the data from birds on both feed levels were considered. The general linear model procedure (Barr, *et al.* 1976) was used to provide tests of significance (F tests) for the effects of line, generation and feed level. These tests cannot easily be obtained from the Stepwise procedure as variables, line, generation and feed level were forced into the Stepwise analysis.

(a) General Linear Model Analysis - Both Feed Levels

Table 7. General Linear Model Analysis - Both Feed Levels -
Line, Generation, Feed Level, Water Turnover, TSR
and Body Weight (42 weeks)

Source	df	FCE (18-66 weeks)		FCE (22-42 weeks)	
		Sums of Squares	F Value	Sum of Squares	F Value
Line	3	77.3	1.1^{ns}	559.3	6.0***
Generation	3	1097.4	15.0***	1496.6	15.9***
Feed Level	1	2381.5	97.6***	2855.6	91.1***
Water Turnover	1	125.4	5.1*	168.7	5.4*
TSR	1	41.7	1.7^{ns}	162.9	5.2*
Body Weight (42 weeks)	1	494.2	20.3***	745.3	23.8***
Error Sum of Squares		2854.9		3667.7	
Error df	49				
		$R^2 = 0.61$		$R^2 = 0.61$	

* p<0.05

** p<0.01

*** p<0.001

ns not significant

From the above test it is seen that the effect of line is significant for FCE (22-42 weeks) but not for FCE (18-66 weeks). TSR is not significant for FCE (18-66 weeks). The question arising now is "Does the above relationship between FCE and water turnover, TSR and body weight (42 weeks) hold true for both feed levels?"

(b) General Linear Model Analysis - Separate Feed Levels

Table 8. General Linear Model Analysis - *Ad Libitum* Fed Birds - Line, Generation, Water Turnover, TSR and Body Weight (42 weeks)

Source	df	FCE (18-66 weeks)		FCE (22-42 weeks)	
		Sums of Squares	F Value	Sums of Squares	F Value
Line	3	27.2	0.3^{ns}	138.9	1.4^{ns}
Generation	3	523.5	5.2**	611.3	6.1**
Water Turnover	1	205.2	6.1**	155.6	4.6*
TSR	1	0.3	0.0^{ns}	16.9	0.5^{ns}
Body Weight (42 weeks)	1	103.9	3.1^{ns}	88.0	2.6^{ns}
Error Sum of Squares		1660.6		1642.5	
Error df	49				
		$R^2 = 0.36$		$R^2 = 0.36$	

* $p < 0.05$

** $p < 0.01$

*** $p < 0.001$

ns   not signficant

Table 9. General Linear Model Analysis - Feed Restricted Birds - Line, Generation, Water Turnover, TSR and Body Weight (42 weeks)

Source	df	FCE (18-66 weeks)		FCE (22-42 weeks)	
		Sums of Squares	F Value	Sums of Squares	F Value
Line	3	17.8	0.4^{ns}	384.5	4.4**
Generation	3	623.3	12.7***	975.3	11.2***
Water turnover	1	2.5	0.2^{ns}	37.7	1.3^{ns}
TSR	1	54.8	3.4^{ns}	67.2	2.3^{ns}
Body weight (42 weeks)	1	347.6	21.3***	798.8	27.5***
Error Sum of Squares		961.9		1715.7	
Error df	59				
		$R^2 = 0.58$		$R^2 = 0.60$	

* $p < 0.05$

** $p < 0.01$

*** $p < 0.001$

ns   not significant

      From the above analysis (Table 9) it is seen that there is a significant effect due to lines for FCE (22-42 weeks) for restricted feed level only. This has brought about the significant F ratio in the combined analysis (Table 7). Similarly TSR is significant for FCE (22-42 weeks) at *ad libitum* feed level only, which has resulted in this effect being found to be significant in the combined analysis.

As a result it was decided to use the general linear models procedure for FCE versus all other independent variables (as specified in Stepwise regression procedure) for each feed level separately. This would enable the relationships between FCE and the significant variables to be expressed in the form of prediction equations.

5. <u>Prediction Equations</u>

    (a)   <u>Prediction Equations – Purebred *Ad Libitum* Birds</u>

        The model fitted was:

$$Y_{ijk} = u + L_i + G_j + b \text{ (Water turnover } ijk) + e_{ijk}$$

where Y_{ijk} = FCE of the kth individual in the jth generation and the ith line

        u = overall mean for FCE

        L_i = effect due to the ith line $(i = 1, \ldots 4.)$

        G_j = effect due to the jth generation $(j = 1, \ldots 4.)$

        b = regression coefficient

Water turnover ijk = Water turnover of the ijk^{th} individual

        e_{ijk} = random error

Table 10. General Linear Model Analysis – *Ad Libitum* Fed Birds – Line,
Generation and Water Turnover

Source	df	FCE (18-66 weeks)		FCE (22-42 weeks)	
		Sums of Squares	F Value	Sums of Squares	F Value
Line	3	3.6	0.0	112.2	1.1
Generation	3	463.2	4.5**	550.5	5.3**
Water Turnover	1	402.2	11.6**	275.6	8.0**
Error Sums of Square		1764.5		1753.2	
Error df	51				
		$R^2 = 0.32$		$R^2 = 0.31$	

* $p < 0.05$

** $p < 0.01$

*** $p < 0.001$

ns   not significant

Since the effect of line is not significant the prediction

equations can be written:

FCE (18-66 weeks)   =   6.2 + Gj + 0.14 (Water turnover)

      where G_1 =   12.6

           G_2 =   5.9

           G_3 =   0.6

           G_4 =   0.0

FCE (22-42 weeks)   =   8.3 + Gj + 0.12 (Water turnover)

      where G_1 =   16.1

           G_2 =   7.8

           G_3 =   3.2

           G_4 =   0.0

(b)   Prediction Equations - Purebred Restricted Fed Birds

The model fitted was:

$$Y_{ijk} = u + L_i + G_j + b_1 \text{ (Body weight (42 weeks)}ijk) +$$

$$b_2 \text{ (Plasma thyroxine } ijk) + e_{ijk}$$

where Y_{ijk} = FCE of the kth individual in the jth

generation and the ith line

u = overall mean for FCE

L_i = effect due to the ith line $(i = 1, ...4)$

G_j = effect due to the jth generation $(i = 1, ...4)$

b_1, b_2 = regression coefficients

Body weight
(42 weeks) ijk = Body weight of the ijk^{th} individual

Plasma thyroxine ijk = Plasma thyroxine of the ijk^{th} individual

e_{ijk} = random error

Table 11.   General linear Model Analysis - Restricted Fed Birds - Line, Generation, Body Weight, and Plasma Thyroxine

Source	df	FCE (18-66 weeks)		FCE (22-42 weeks)	
		Sums of Squares	F Value	Sums of Squares	F Value
Line	3	24.8	0.6^{ns}	476.5	5.7**
Generation	3	595.9	13.3***	793.1	9.6***
Body Weight (42 weeks)	1	279.8	18.7***	689.7	25.0***
Plasma Thyroxine	1	123.4	8.3**	162.2	5.9*
Error Sums of Squares		896.5		1661.4	
Error df		68		60	
		$R^2 = 0.61$		$R^2 = 0.61$	

*	$p<0.05$
**	$p<0.01$
***	$p<0.001$
ns	not significant

Please note different degrees of freedom in error mean square.

The prediction equations are:-

$$\text{FCE (18-66 weeks)} = 47.7 + Li + Gj - 0.01 \text{ (Body weight -}$$
$$\text{42 weeks)} - 4.9 \text{ (Plasma thyroxine)}$$

where L_1 = Line A_1 = 1.3 and G_1 = 11.0

L_2 = Line A_3 = 1.8 G_2 = 4.1

L_3 = Line A_4 = 0.6 G_3 = -2.2

L_4 = Line C_4 = 0.0 G_4 = 0.0

$$\text{FCE (22-42 weeks)} = 59.3 + Li + Gj - 0.02 \text{ (Body weight -}$$
$$\text{42 weeks)} - 5.66 \text{ (Plasma thyroxine)}$$

where L_1 = Line A_1 = 5.4 G_1 = 13.4

L_2 = Line A_3 = 7.5 G_2 = 8.5

L_3 = Line A_4 = 1.5 G_3 = 0.0

L_4 = Line C_4 = 0.0 G_4 = 0.0

These prediction equations quantitate the relationship between FCE and other terms in the model.

There were no differences between lines with period of FCE determination for those birds feeding *ad libitum*. For the restricted lines, however, there was a difference. Line A_3 and A_1 had superior FCE over the period 22-42 weeks but these lines could not maintain their stamina for the remainder of the egg laying period. Their FCE declined to levels similar to those of A_4 and C_4 by 66 weeks of age.

6. <u>Physiology and the Prediction Equations</u>

Water turnover is the only physiological parameter of those measured which assumes significance in the hens which have no constraints on feed intake. It is surmised that hens allowed *ad libitum* food supply, do not require the fine levels of thyroid hormone control observed in the restricted hens, where absolute levels of circulating thyroxine enter the model.

The lower plasma T_4 values of the efficient restricted hens compared to inefficient birds could represent one of the following:

1. A decreased output of T_4 from the thyroid gland in efficient birds. Brake and Thaxton (1979) have observed that an increase in plasma T_4 was coincident with a loss of weight and presumably function of the ovaries. Birds with lower plasma T_4 are then probably more primed for processes associated with production of eggs.

2. There may be lower plasma T_4 values in efficient restricted birds, because greater amounts of T_4 are converted to T_3 by peripheral monodeiodination. Hence efficient restricted hens may have an increased extrathyroidal pool of T_3 compared to inefficient birds. Oppenheimer, *et al.* (1972b) and Ingbar and Braverman (1975) have suggested that T_4 is a pro-hormone, and only T_3 has intrinsic hormonal activity (though this is not well supported). Presuming that efficient restricted hens have higher levels of T_3, this may then account for the increased egg production rates of the efficient birds. Grandhi and Brown (1975) have speculated that T_3 has the direct role of mobilizing nutrients for egg production.

Grandhi and Brown (1975) have observed also that growing chickens have a higher $T_4 : T_3$ ratio than laying hens. The plasma levels of T_4 relative to T_3 may control the priorities of metabolic activities associated with growth, maintenance and egg production. Assuming that there is a nearly constant iodohormone synthesis in all hens, adult birds with higher plasma T_4 (and hence greater $T_4 : T_3$ ratio) may be more primed for growth processes. Such birds may continue to grow and deposit adipose tissue at the expense of egg production,

this being reflected in their higher body weight and lower FCE as predicted by the equation.

In the hens fed *ad libitum*, thyroxine probably assumes a minor role in determining efficiency. The efficient hens are those turning over more water, reflecting the role of water as a carrier of nutrients and energy for egg production. In cattle, Good (personal communication) has observed that plasma T_3 levels and water turnover are linked. T_3 may also be linked with water metabolism in hens fed *ad libitum*.

From the analysis it is clear that hens subjected to restricted feeding exhibit a greater range of functional efficiencies. The differences observed between the lines that have been on restricted feed are not apparent among lines of birds fed *ad libitum*. These observations indicate that there is potential for genetic studies in a wide range of characters of birds which have been exposed to stress situations such as restricted feeding.

B. Analysis of Variance for Purebred Birds

The analysis of variance (Barr, *et al.* 1976) and Least Significant Difference (LSD) were used in further tests of the effects of line, generation, feed level, line by generation interactions, line by feed level interactions and generation by feed level interactions on production, physiological, egg shell quality and body weight variables.

LSD's are based on the comparison of 2 means. Simultaneous pairwise comparison of 4 means (e.g. 4 lines or 4 generations) at the 5% significance level, underestimates the true probability level.

However if the 1% significance level is used to calculate the LSD then the probability of making joint inferences about all paired comparisons among the 4 means will be close to the required 5% significance level.

The formula used to calculate LSD was

$$LSD = t_{0.01, f} \sqrt{\frac{2\ EMS}{n}} \qquad \text{(Clarke, 1969)}$$

where f = error degrees of freedom

n = average number of observations

EMS = Error Means Square (from analysis of variance table)

$t_{0.01}$ = Students' t 1% probability value (two-tailed test) for comparison of 4 means

$t_{0.02}$ = Students' t 2% probability value (two-tailed test) for comparison of 3 means

$t_{0.05}$ = Students' t 5% probability value (two-tailed test) for comparison of 2 means

In the discussion that follows, results are discussed in the same order that they are presented in analysis of variance tables.

Table 12. Analysis of Variance for Purebred Production Data

Source	df	FCE (18-66 weeks)	FCE (22-42 weeks)	Feed Int. (18-66 weeks)	Feed Int. (22-42 weeks)	Egg No. (18-66 weeks)	Egg No. (22-42 weeks)	Ave. Egg Weight (18-66 weeks)	Ave. Egg Weight (22-42 weeks)
		F value	F value	F value	F value	F value	F value	F value	F value
Line	3	0.38^{ns}	$3.04*$	$4.74**$	$5.29**$	0.27^{ns}	1.84^{ns}	$5.43**$	$4.38**$
Generation	3	$13.73***$	$12.18***$	0.56^{ns}	1.01^{ns}	$6.64***$	$6.50**$	$4.93**$	$3.11*$
Feed Level	1	$60.83***$	$50.44***$	$658.33***$	$1000.79***$	$189.31***$	$203.34***$	$19.01***$	$16.72***$
Line by Gen	9	1.70^{ns}	1.79^{ns}	$2.43*$	$2.21*$	0.90^{ns}	1.28^{ns}	1.48^{ns}	$2.14*$
Line by Feed Level	3	0.93^{ns}	1.55^{ns}	0.94^{ns}	1.49^{ns}	0.73^{ns}	1.25^{ns}	0.03^{ns}	0.53^{ns}
Gen.by Feed Level	2	0.00^{ns}	0.01^{ns}	0.15^{ns}	0.41^{ns}	0.15^{ns}	0.06^{ns}	1.54^{ns}	1.12^{ns}
Error Mean Square		29.81	39.27	61.63	46.87	1244.27	280.45	10.77	10.48
Error df		106	106	106	106	106	106	105	105

Note: Line by generation interaction degrees of freedom are 8 for
average egg weight (18-66 weeks) and average egg weight (22-42 weeks)

* $p < 0.05$

** $p < 0.01$

*** $p < 0.001$ ns not significant

Table 13. The Mean Production Performance of Purebred Lines

Line	No.of birds	FCE (18-66 weeks)	FCE (22-42 weeks)	Feed Int. (18-66 weeks)	Feed Int. (22-42 weeks)	Egg No. (18-66 weeks)	Egg No. (22-42 weeks)	Ave.Egg Weight (18-66 weeks)	Ave.Egg Weight (22-42 weeks)
		(%)	(%)	$(g.24h^{-1})$	$(g.24h^{-1})$			(g)	(g)
A_1	30	23.1	24.6^{ab}	103.6^b	105.4^b	139.8	77.7	50.0^b	54.9^b
A_3	32	23.2	27.7^b	98.3^a	100.2^a	140.7	74.8	55.0^{ab}	52.7^{ac}
A_4	36	21.5	22.5^a	96.1^a	97.2^a	127.0	60.0	56.3^{ab}	53.7^{ac}
C_4	30	22.7	23.3^a	97.7^a	99.3^a	140.9	65.2	54.1^a (29)	51.3^a (29)
LSD (p = 0.01)		$^+$ns	4.1	5.2	4.5	ns	ns	2.2	2.1

abc Means in the same column differently superscripted are significantly different (p<0.01).

$^+$ns = non-significant in analysis of variance (Table 12). Numbers in brackets are different from the bird numbers indicated in the first column.

1. Analysis of Variance for Purebred Production Data

    (a) Lines

(i) Feed Conversion Efficiency (Table 13)

There was no significant difference between lines for
FCE when measured over the full laying period of 18-66 weeks.
Over the age period 22-42 weeks, however, line A_3 had significantly
higher FCE than 2 other lines and numerically higher FCE than
line A_1. It is difficult to see why line A_3 is more efficient
that lines A_1, A_4 and C_4 when considering feed intake, egg number
and average egg weight separately (see Table 13). However, in a
previous analysis (Stepwise regression procedure) individual
birds that produced high egg numbers and egg weights, but had
low feed consumption, were the most efficient. Line A_3 birds
probably had a better combination of these characteristics than
the other lines, which would contribute to its superior perform-
ance in this early laying phase.

(ii) Feed Intake and Average Egg Weight (Table 13)

Birds of line A_1 were shown to have significantly higher
feed intake over the 2 age periods than the 3 other lines.
This was reflected in the average egg weight of this line which
was significantly higher than all other lines in the early
laying phase (22-42 weeks). But these differences largely
disappeared when egg weight was assessed over the full laying
period (18-66 weeks). In the analysis of variance (Table 12) a
significant interaction for line by generation for feed intake
was observed over the 2 periods.

Tables 14 and 15 show that the overall higher feed intake
for line A_1 was primarily due to the unusually high feed intake
of its generation 2 birds, and partly to the generation 4 birds.

Table 14. Purebred Line by Generation for Feed Intake (18-66 weeks)

| Generation | Line | | | | |
	A_1 (g.24h^{-1})	A_3 (g.24h^{-1})	A_4 (g.24h^{-1})	C_4 (g.24h^{-1})	LSD (p=0.01)
1	80.0(1) [a]	80.0(1) [a]	80.0(1) [a]	104.0(1) [a]	29.1
2	119.2(8) [b]	99.8(10) [a]	95.0(11) [a]	99.4(12) [a]	9.2
3	95.1(15) [a]	100.6(16) [a]	96.3(18) [a]	94.9(13) [a]	7.3
4	107.7(6) [bc]	91.6(5) [a]	99.9(6) [ac]	100.3(4) [ac]	13.0

abc means in the same row differently superscripted are

significantly different (p<0.01).

Bird numbers are indicated in brackets.

Table 15. Purebred Line by Generation for Feed Intake (22-42 weeks)

| Generation | Line | | | | |
	A_1 (g.24h^{-1})	A_3 (g.24h^{-1})	A_4 (g.24h^{-1})	C_4 (g.24h^{-1})	LSD (p=0.01)
1	80.0(1) [a]	80.0(1) [a]	80.0(1) [a]	104.0(1) [a]	25.4
2	122.8(8) [b]	104.5(10) [a]	97.2(11) [a]	101.8(12) [a]	8.0
3	96.9(15) [a]	100.3(16) [a]	98.2(18) [a]	96.2(13) [a]	6.4
4	107.7(6) [bc]	95.0(5) [a]	97.0(6) [ac]	100.5(4) [ac]	11.4

abc means in the same row differently superscripted are

significantly different.

Bird numbers are indicated in brackets.

In the analysis of variance (Table 12) a significant interaction

for line by generation for average egg weight (22-42 weeks) was found.

The high feed intake of line A_1 birds in generation 2 (Table 15) was also reflected by the high average egg weight of this line of birds in generation 2 (Table 16.)

It is of interest that one generation of birds of a particular line should have marked increases in feed intake and egg weight. The inbreeding procedure used may have resulted in this unusual response. Also line C_4 birds in generation 3 (Table 16) produced eggs of lower weight than all other lines in generation 3.

Table 16. Purebred Line by Generation for Average Egg Weight (22-42 weeks)

Generation	Line				
	A_1	A_3	A_4	C_4	LSD (p=0.01)
	(g)	(g)	(g)	(g)	
1	51.0(1)[a]	53.6(1)[a]	53.4(1)[a]	56.4(1)[a]	12.0
2	59.3(8)[b]	52.6(10)[a]	54.6(11)[a]	53.7(12)[a]	3.8
3	54.4(15)[b]	52.6(16)[b]	52.6(18)[b]	48.6(12)[a]	3.0
4	50.8(6)[a]	53.3(5)[a]	55.2(6)[a]	50.7(4)[a]	5.4

[ab] means in the same row differently superscripted are significantly different (p<0.01). Bird numbers are indicated in brackets.

(iii) Egg Production (Table 13)

No significant differences in egg production were observed between lines over the 2 periods although numerical differences are obvious. As mentioned previously, however, it is birds with the better combinations of low feed intake, high egg production and high egg weight which are the most efficient.

(b) <u>Generation</u>

(i) <u>Feed Conversion Efficiency</u> (Table 17)

There was a general decline in FCE for both periods from generation 1 to generation 3, with the most marked decline occurring from generation 1 to generation 2. There was also a significant fall in FCE for both periods from generation 2 to generation 3. However, there was no significant decline between generation 3 and generation 4 in FCE for both periods. The trend of a decline in efficiency is considered to be due to the effects of inbreeding. The statistical validity, however, of comparing 4 birds in generation 1 to 41 birds in generation 2 in these analysis is questionable.
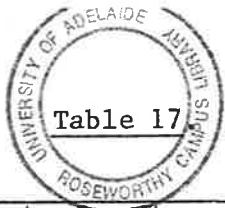
Table 17 The Mean Production Performance of Purebred Birds for Each Generation

Generation	No. of birds	FCE (18-66 weeks)	FCE (22-42 weeks)	Feed Int. (18-66 weeks)	Feed Int. (22-42 weeks)	Egg No. (18-66 weeks)	Egg No. (22-42 weeks)	Ave. Egg weight (18-66 weeks)	Ave. Egg weight (22-42 weeks)
		(%)	(%)	$(g.24h^{-1})$	$(g.24h^{-1})$			(g)	(g)
1	4	35.8^c	39.4^c	84.5	86.0	186.5^c	89.0^c	54.9^a	53.6^{ab}
2	41	24.7^{bd}	26.9^b	102.2	105.3	150.4^b	75.0^b	57.6^b	54.3^b
3	62	20.0^a	22.6^a	96.8	98.0	123.3^a	61.7^a	$54.7(61)^a$	$52.1(61)^a$
4	21	22.5^{ad}	22.4^a	100.2	100.2	140.0^a	62.4^a	55.4^{ab}	52.3^a
LSD (p = 0.01)		3.6	4.1	$^+$ns	ns	23.2	11.0	2.2	2.1

abcd means in the same column differently superscripted are significantly different (p<0.01).

$^+$ns = not significant in analysis of variance (Table 12).

Numbers in brackets are different bird numbers from those given in the second column.

(ii) Feed Intake

Although the numerical differences in feed intake with generation are obvious (Table 17) they are not significant. The interaction of line by generation for feed intake has previously been discussed.

(iii) Egg Production

As observed for FCE, egg production declined markedly from generation 1 to generation 3 with the most obvious decrease occurring from generation 1 to generation 2.

(iv) Average Egg Weight

No obvious trends are apparent with generation effects on egg weight. The interaction of line by generation for average weight (22-42 weeks) has previously been discussed.

(c) Feed Level

(i) Production Variables

With severe reduction in feed intake of approximately 33%, FCE, egg number and average egg weight were observed to fall markedly (Table 18). Jalaludin (1969 as reported by Sykes 1972) claimed that egg production was not reduced when daily intake was as low as 782 KJ of ME. In this study average daily intake was 884 KJ of ME.

Petersen (1971) and Supramaniam (1970 reported by Sykes 1972) indicate that daily inputs in excess of 1000 KJ of ME are required to maintain normal production levels. This daily intake of 13 g protein per bird in this present study is much lower than the daily intakes of 17 g protein which are known to support normal production levels (Adams, *et al.* 1970). However, Bray and Gessel (1964) have shown that egg

production decreases only when daily intake falls below 12 g.
Differences in protein quality of the diets and amino-acid
absorption may account for these differences. The decline in
egg weight with feed restriction, parallels the observations of
many other workers Auckland and Wilson, 1975a; Auckland and
Fulton, 1973b; Balnave, 1974; Snetsinger and Zimmerman, 1974 and
Wells 1974(a).   It is obvious from this present work that feed
restriction of 33% is too severe. As discussed previously there
are a small proportion of the severely restricted population which
had FCE superior to *ad libitum* fed birds. The inbreeding policy
used, however, did not result in any great proportion of birds
of each generation exhibiting high FCE.

Table 18. Effect of Feed Level on Production Variables for Purebred Birds

Variable		Restricted	*Ad libitum*	LSD (p=0.05)
Feed intake (18–66 weeks)	(g.24h⁻¹)	80.0^a	120.5^b	2.8
Feed intake (22–42 weeks)	(g.24h⁻¹)	80.0^a	124.1^b	2.4
FCE (18–66 weeks)	(%)	18.4^a	27.1^b	1.9
FCE (22–42 weeks)	(%)	20.3^a	29.4^b	2.2
Egg number (18–66 weeks)		92^a	189^b	12.0
Egg number (22–42 weeks)		44^a	93^b	5.9
Average egg weight (18–66 weeks)	(g)	55.6^a	57.6(58)^b	1.2
Average egg weight (22–42 weeks)	(g)	51.5^a	54.6(58)^b	1.1
KJ intake (18–66 weeks)	(KJ ME.24h⁻¹)	884	1331	
KJ intake (22–42 weeks)	(KJ ME.24h⁻¹)	884	1371	
Protein intake (18–66 weeks)	(g.24h⁻¹)	13.0	19.5	
Protein intake (22–42 weeks)	(g.24h⁻¹)	13.0	20.1	
Bird number		69	59	

^{ab} means in same row differently superscripted are significantly different (p<0.05).

Number in brackets are different bird numbers from those given in last row.

Table 19. Analysis of Variance for Purebred Physiological Data

Source	df	Metabolic Rate F value	Water Turnover F value	TBW% of Body Wt. F value	Thyroxine Secretion Rate F value	Plasma Thyroxine F value
Line	3	2.43^{ns}	0.02^{ns}	4.92^{**}	1.84^{ns}	1.28^{ns}
Generation	3	13.52^{***}	5.02^{**}	22.09^{***}	22.69^{***}	5.78^{**}
Feed Level	1	26.35^{***}	0.87^{ns}	51.01^{***}	0.01^{ns}	8.25^{**}
Line by Gen.	8	0.86^{ns}	0.74^{ns}	1.99^{ns}	0.40^{ns}	1.08^{ns}
Line by Feed Level	3	1.61^{ns}	3.07^{*}	0.69^{ns}	7.67^{***}	1.44^{ns}
Gen. by Feed Level	2	1.33^{ns}	2.57^{ns}	4.01^{*}	4.21^{*}	5.80^{**}
Error Mean Square		59.11	537.55	10.17	0.03	0.07
Error df		106	106	106	106	106

* $p<0.05$ TBW = Total body water

** $p<0.01$

*** $p<0.001$

ns   not significant

Note: Analysis of variance for metabolic rate used

K cal. $W^{-0.75}$. $24h^{-1}$ units to calculate Error Mean Square.

Conversion to $KJ.kg^{-0.75}$.$24h^{-1}$ occurs in any calculations

of LSD.

Table 20. The Mean of Physiological Variables of Purebred Lines

Line	No. of Birds	Metabolic Rate $(KJ.kg^{-0.75}.24h^{-1})$	Water Turnover $(ml.kg^{-1}.24h^{-1})$	TBW % Body Weight (%)	Thyroxine Secretion Rate $(\mu gT_4 100g^{-1}.24h^{-1})$	Plasma Thyroxine $(\mu gT_4 dl^{-1})$
A_1	30	341	124.3	56.9^a	0.653	1.229
A_3	32	341	124.4	57.1^a	0.603	1.133
A_4	36	343	121.9	60.2^b	0.720	1.290
C_4	30	355	127.8	59.8^b	0.628	1.173
LSD (p = 0.01)		^+ns	ns	2.1	ns	ns

[ab] means in the same column differently superscripted are significantly different (p<0.01).

[+]ns — not significant in analysis of variance (Table 19).

TBW = Total body water

2. Analysis of Variance for Purebred Physiological Data

   (a) Lines

      (i) Metabolic Rate and Water Turnover

There was no significant difference between lines in metabolic rate and water turnover. Line C_4 birds had a numerically higher metabolic rate which is reflected by the numerically higher water turnover value for this line. (The results in Table 20 are misleading as they comprise both the restricted and *ad libitum* birds, which were found to have different physiological relationships). In the analysis of variance for purebred physiological data, an interaction was found between line and feed level (Table 19). Measurements comparing restricted and *ad libitum* fed birds in rates of water turnover have not been reported in the literature. However, there are a number of reports which indicate that water intake is closely correlated with food intake (Anderson and Hill, 1967).

Table 21. Purebred Line by Feed Level for Water Turnover

| Line | Feed Level | | | | |
| | Restricted | | *Ad libitum* | | |
	No. of Birds	Water Turnover $(ml.kg^{-1}.24h^{-1})$	No. of Birds	Water Turnover $(ml.kg^{-1}.24h^{-1})$	LSD $(p = 0.05)$
A_1	15	125.8[a]	15	122.9[a]	16.8
A_3	16	129.0[a]	16	119.8[a]	16.3
A_4	22	113.1[a]	14	135.8[b]	15.4
C_4	16	132.3[a]	14	122.7[a]	16.8

[ab] means in same row differently superscripted are significantly different (p<0.05).

With the severe feed restriction of 33% it would be expected that water turnover of the restricted bird would be much lower than the

ad libitum fed bird, yet there was only one line of birds (A_4) which behaved as expected (Table 21). All the other lines (A_1, A_3 and C_4) showed no significant differences in water turnover between feed levels. It was observed that birds on restricted intake were able to consume their daily feed within 1 h. Subsequently these birds may have consumed more water than expected to reduce boredom or to achieve crop fill. No quantitive measurements of time spent drinking were made, however, between birds on the 2 feed levels. Line A_4 had the numerically lowest FCE (22-42 weeks) when water turnover measurements were made. In a previous analysis it was shown that FCE (22-42 weeks) was significantly correlated with water turnover ($r = 0.230^{**}$, Table 3). The lower water turnover and FCE of this line reflect the correlation between these variables. However, line C_4 also had a low FCE at 22-42 weeks (Table 13), similar to line A_4, but their water turnover was numerically higher than that of line A_4. This can be explained by the higher egg production of line C_4 (Table 13), compared to line A_4, reflecting the low but significant correlation between FCE (22-42 weeks) and egg production during weeks 22-42 ($r = 0.181^{*}$, Table 3).

(ii) Total Body Water as % of Body Weight

Two lines of birds (A_1 and A_3) were found to have a significantly higher body fat content than the other 2 lines (A_4 and C_4). These differences are discussed later in relation to generation and feed level.

(iii) Thyroxine Secretion Rate (TSR) and Plasma Thyroxine

There are no significant differences between lines in TSR and plasma thyroxine, but a significant interaction was found

between line and feed level for TSR (Table 19). Line A_3 birds
had significantly lower TSR with restricted feeding than the birds
fed *ad libitum* (Table 22), though lines A_1 and C_4 showed no
significant differences in TSR between *ad libitum* and restricted
feeding. Interestingly line A_4 had significantly higher TSR on
restricted feed than on *ad libitum* feeding. Line A_4 may not have
used the thyroxine as well as other lines. They produced fewer
eggs and had low FCE (Table 13).

Table 22. Purebred Line by Feed Level for TSR

| Line | Restricted | | Ad libitum | | |
	No. of Birds	TSR ($\mu gT_4.\ 100g^{-1}.24h^{-1}$)	No. of Birds	TSR ($\mu gT_4.\ 100g^{-1}.24h^{-1}$)	LSD (p = 0.05)
A_1	15	0.648^a	15	0.657^a	0.126
A_3	16	0.501^a	16	0.706^b	0.122
A_4	22	0.802^b	14	0.592^a	0.115
C_4	16	0.685^a	14	0.563^a	0.126

[ab] means in same row differently superscripted are significantly
different (p<0.05).

It is not likely that the severe feed restriction imposed on the
lines induced stress and raised thyroid gland activity, since
Brown - Grant (1966) showed an inhibition of thyroid activity with
stress in a number of species of animals. Nevertheless high TSR
probably contributed to a decrease in the hens ovarian function
and subsequent egg production. Only line A_3 was able to maintain
low TSR in the restricted phase this being reflected in its

significantly higher FCE (22-42 weeks).

A significant interaction was obtained for generation by feed level for TSR (Table 19)

Table 23. Generation by Feed Level for TSR for Purebred Lines

Generation	Restricted		Ad libitum	
	No. of birds	TSR (μg $T_4.100g^{-1}.24h^{-1}$)	No. of Birds	TSR (μg $T_4.100g^{-1}.24h^{-1}$)
1	3	0.507^a	1	0.380^a
2	18	0.462^a	23	0.586^b
3	37	0.827^b	25	0.745^c
4	11	0.537^a	10	0.486^{ab}
LSD (p = 0.01)		0.118		0.126

(spanning header: Feed Level)

[abc] means in same column differently superscripted are significantly different ($p<0.01$).

From Table 23 it is seen that restricted birds in generation 3 had a significantly higher TSR than all other generations. Birds on ad libitum feeding in generation 3 also had significantly higher TSR than birds in generations 1, 2 and 4. A significant interaction was obtained for generation by feed level for plasma thyroxine (Table 19).

Table 24. Generation by Feed Level for Plasma Thyroxine for Purebred Lines

Generation	Feed Level			
	Restricted		*Ad libitum*	
	No. of birds	Plasma Thyroxine	No. of birds	Plasma Thyroxine
		$(\mu g\ T_4\ dl^{-1})$		$(\mu g\ T_4\ dl^{-1})$
1	3	0.980^a	1	0.780^a
2	18	1.078^a	23	1.138^b
3	37	1.382^b	25	1.158^b
4	11	1.422^b	10	1.088^b
LSD (p = 0.05)		0.181		0.192

[ab] Means in same column differently superscripted are significantly different (p<0.05).

For restricted birds there was a trend toward higher levels of plasma thyroxine from generation 1 to 4 (Table 24) reflecting to a degree the decline in observed FCE (22-42 weeks). However in birds fed *ad libitum* this numerical trend is not as obvious as in generations 2, 3 and 4 inclusive which were not significantly different. This would partly explain why plasma thyroxine did not enter into the prediction equation for FCE with *ad libitum* birds.

Table 25. The Mean of Physiological Variables of Purebred Birds
over the 4 Generations

Generation	No. of Birds	Metabolic Rate $(KJ.kg^{-0.75} 24h^{-1})$	Water Turnover $(ml\ kg^{-1}. 24h^{-1})$	TBW% Body Weight $(\%)$	Thyroxine Secretion Rate $(\mu g\ T_4. 100g^{-1}. 24h^{-1})$	Plasma Thyroxine $(\mu g\ T_4\ dl^{-1})$
1	4	336^a	152.4^c	66.9^c	0.475^a	0.930^a
2	41	331^a	116.1^a	58.3^a	0.531^a	1.110^b
3	62	361^b	125.0^a	57.0^a	0.794^b	1.291^{bc}
4	21	326^a	134.0^b	61.9^b	0.512^a	1.262^c
LSD (p = 0.01)		21	15.2	2.1	0.114	0.174

^{abc} Means in the same column differently superscripted are significantly different (p<0.01).

(b) Generation

(i) Metabolic Rate

Generation 3 birds showed a significantly higher metabolic
rate than all other generations. This was probably caused by the
significantly higher TSR for this generation (Table 25). Metabolic
rate was significantly correlated with TSR (r = 0.270[***], Table 4).
In mammals the relationship between metabolic rate and thyroid
activity has been well established (Collins and Weiner, 1968). This
relationship in birds has not been fully investigated but evidence
available indicates birds have the same relationship (Falconer, 1971).
This relationship was observed when environmental temperatures were
varied and bird response in metabolic rate and TSR measured. All
TSR and metabolic rate measurements in this present study were taken
when shed temperatures could be maintained between 18^0C and 26^0C.
Generation 3 birds had one of the lowest numerical FCE's and TSR was
found to be negatively correlated with FCE (18-66 weeks and 22-42 weeks;
see Table 3) when all birds were considered.

(ii) Water Turnover and Total Body Water as a % of Body Weight
(Table 25)

Water content of the hens in this present study has been simply
calculated as $ml.kg^{-1}$ expressed as a %. The difference between the
water content and the body weight is the body solids content. In
the discussion that follows, a high body water % has been interpreted
as meaning a low body fat value. In the strict sense however, this
should be referred to as a low body solids content. However, Farrell
and Balnave (1977) have shown that determined body fat is negatively
correlated with tritiated water space of hens. Hence body water %
in hens has been interpreted . as being an indicator of body fat

content. However it must be made clear that all body solids are not fat.

Water turnover was significantly different for all generations except generation 2 and 3. It is interesting to note that water turnover of birds in each generation largely parallels their body fat measurements. There was, however, no significant correlation between water turnover and TBW as a % of body weight (r = 0.163, p = 0.065). A significant interaction was found between generation and feed level for TBW as a % of body weight (Table 19). Generation 3 birds on restricted feed had significantly higher body fat levels (Table 26) than all other generations. This generation of birds also secreted significantly more thyroxine although plasma thyroxine was not unusually high. FCE (22-42 and 18-66 weeks) for generation 3 birds was low indicating that birds were wasting food resources by laying down extra fat. Generation 1 birds had lower body fat than any other generation and this was reflected in their high FCE. For *ad libitum* fed birds the generation TSR levels (Table 26) almost mirror the generation body fat levels, but do not reflect the FCE levels. However the single bird of generation 1 had an exceptional FCE (refer appendices) and low carcass fat levels. The general trends seen here with FCE and carcass fat confirms the observations of Neill, *et al.* 1977.

Table 26. Generation by Feed Level for TBW as a % of Body Weight for Purebred Birds

	Feed Level			
	Restricted		Ad libitum	
Generation	No. of Birds	TBW as a % of Body Weight (%)	No. of Birds	TBW as a % of Body Weight (%)
1	3	66.7[c]	1	67.5[c]
2	18	62.3[b]	23	55.2[a]
3	37	58.7[a]	25	54.3[a]
4	11	62.7[b]	10	60.4[b]
LSD (p = 0.05)		2.2		2.3

[abc] Means in same column differently superscripted are significantly different (p<0.05).

(iii) Thyroxine Secretion Rate and Plasma Thyroxine

These results have been discussed previously in relation to line, generation and feed level.

(c) Feed Level

Table 27. Effect of Feed Level on Physiological Variables for Purebred Birds

Variable	Units	Restricted	Ad libitum	LSD (p = 0.05)
Metabolic Rate	$(KJ.kg^{-0.75}.24h^{-1})$	330[a]	362[b]	11
Water Turnover	$(ml.kg^{-1}.24h^{-1})$	124.0	125.0	$^{+}$ns
TBW as a % of Body Weight	(%)	60.7[a]	56.0[b]	1.1
Thyroxine Secretion Rate	$(\mu g\ T_4.100g^{-1}.24h^{-1})$	0.672	0.632	ns
Plasma Thyroxine	$(\mu g\ T_4.dl^{-1})$	1.373[a]	0.973[b]	0.093
No. of Birds		69	59	

[ab] Means in same row differently superscripted are significantly

different (p<0.05).

[+]ns not significant in analysis of variance (Table 19).

(i) Metabolic Rate

Metabolic rate of the restricted birds was significantly lower than *ad libitum* birds (Table 27). Balnave (1976) could detect no difference in metabolic rate between birds fed *ad libitum* and those on restricted intake. However Morrison and Leeson (1978) found that birds on restricted feeding had lower metabolic rate. Reference to Table 3 indicates that metabolic rate is significantly correlated with feed intake and egg number.

(ii) Water Turnover

The water turnover results have previously been discussed in relation to line, generation and feed level.

(iii) Total Body Water as a % of Body Fat

The carcass fat of the birds on restricted feed was significantly lower than *ad libitum* fed birds. Jalaludin (1969) as cited by Sykes (1972) and Hannagan and Wills (1973) have reported that energy restriction in hens results in a reduced proportion of body fat.

(iv) Thyroxine Secretion Rate

These results have previously been discussed in relation to line, generation and feed level.

(v) Plasma Thyroxine

These results have already been discussed. A further point of interest however, is that Turner *et al.* (1945) cited by Falconer

(1971) observed that with high rates of thyroxine feeding, egg production and body weight decreased. This parallels the observation in this work although the high plasma thyroxine values for the restricted birds was presumed to be a function of their poor feeding rate.

Table 28. Analysis of Variance for Purebred Egg Shell Quality Data

Source	df	Shell Weight	Shell Weight per Surface Area Egg	Shell Thickness	Egg Conform-ation	Porosity
		F Value	F Value	F Value	F Value	F Value
Line	3	3.96^{*}	1.92^{ns}	1.67^{ns}	12.49^{***}	2.74^{*}
Generation	3	14.80^{***}	11.75^{***}	23.34^{***}	5.30^{**}	0.95^{ns}
Feed Level	1	7.84^{**}	0.26^{ns}	1.50^{ns}	0.45^{ns}	13.28^{***}
Line by Gen.	8	1.35^{ns}	1.33^{ns}	1.88^{ns}	1.71^{ns}	0.97^{ns}
Line by Feed Level	3	1.18^{ns}	1.94^{ns}	0.73^{ns}	1.89^{ns}	1.89^{ns}
Gen. by Feed Level	2	3.05^{ns}	1.72^{ns}	2.95^{ns}	2.42^{ns}	0.82^{ns}
Error Mean Square		0.142	16.21	401.3	0.002	0.215
Error df		105	105	105	105	104

$*$ $p < 0.05$ $***$ $p < 0.001$

$**$ $p < 0.01$ ns not significant

Table 29. The Mean of Egg Shell Quality Variables of Purebred Lines

Line	No. of Birds	Shell Weight	Shell Weight per S A Egg	Shell Thickness	Egg Conformation	Porosity
		(g)	$(mg.cm^{-2})$	(μm)		$(mg.cm^{-2}.24h^{-1})$
A_1	30	5.73^b	80.5	355	1.33^a	4.63^a
A_3	32	5.60^{ab}	79.4	352	1.38^b	4.67^a(31)
A_4	36	5.73^b	79.9	352	1.39^b	4.43^a
C_4	29	5.39^a	77.0	339	1.33^a	4.45^a
LSD (p=0.01)		0.25	^+ns	ns	0.03	0.30

ab Means in the same column differently superscripted are significantly different (p<0.01).

$^+$ns = not significant in analysis of variance (Table 28).

Numbers in bracket is different bird number from that given in second column.

S A = Surface Area

3. <u>Analysis of Variance for Purebred Egg Shell Quality Data</u>

(a) <u>Lines</u>

(i) <u>Shell Weight</u>

Shell weight was found to be significantly correlated with average egg weight (18-66 and 22-42 weeks; $r = 0.653^{***}$ and $r = 0.572^{***}$ respectively). Line C_4 shell weight was significantly lower than that of line A_1 and A_4 but not of line A_3 (Table 29). The average egg weight (22-42 weeks) would closely reflect the weight of eggs during measurement of shell weight. Line A_3 and C_4 had similar average egg weight (22-42 weeks) during this period.

Shell weight was found to show significant positive correlation with all production variables (see Table 3a). Average egg weight and shell weight had the highest correlation coefficients followed by feed intake. Line A_1 had the highest feed intake and hence calcium intake (Table 13) of all lines during 22-42 weeks, but shell weight was similar to line A_4. However, line A_4 produced fewer eggs (numerically) which probably compensated for its lower calcium intake.

(ii) <u>Shell Weight per Surface Area of Egg and Shell Thickness</u>

Shell weight per surface area of egg and shell thickness were found to be highly correlated ($r = 0.907^{***}$), and shell weight was also correlated with these 2 variables (see Table 5). These findings confirm the observations of many workers (Wells, 1968). There was no significant difference between lines in shell weight per surface area of egg and shell thickness. Line C_4, however, is numerically lower for these 2 variables compared to other lines, this being reflected in the production of eggs of lower shell weight. There were small but significant positive correlations of average egg weight and feed intake with shell thickness. Also shell thickness

was positively correlated with body weight over 22-42 weeks
$(r = 0.439^{***})$. This opposes the findings of Foster and Neil
(1972) who found that variation in body weight and egg weight had
little consistent effect upon shell thickness. Cipera and Grunder
(1976) showed that birds which produced thicker shells had lower
body weight, the opposite to the correlation found in this study.

(iii) Egg Conformation

Two lines of birds (A_3 and A_4) had a significantly higher egg
conformation than lines A_1 and C_4. Interestingly egg shape or
conformation had a small but positive correlation with TSR
$(r = 0.176^{*})$, but shape was not correlated with any other variable.
No explanation can be given for this unusual relationship. The
studies of Carter (1968, 1970) indicate a possible relationship
between egg shape and shell strength; but the present study found
no significant correlation.

(iv) Porosity

Although porosity was significant in analysis of variance for
lines ($p < 0.05$) no difference could be found between lines using
LSD ($p < 0.01$). Interestingly, porosity was positively correlated
with all production variables except average egg weight (22-42
weeks). Porosity was negatively correlated with TBW as a % of
body weight of birds $(r = -0.231^{**}$ i.e. egg porosity increased as
carcass fat levels of birds increased) and positively correlated with
body weight 42 weeks and 66 weeks, $(r = 0.364^{***}$ and $r = 0.326^{***}$
respectively). Birds with high levels of carcass fat may be depositing
more lipids in the egg yolk. The supposed extra lipid could displace
some water to the egg white. This may lead to higher water content of
egg white and result in greater losses of water from the egg.

Table 30. The Mean of Egg Shell Quality Variables of Purebred Birds over 4 Generations

Generation	No. of Birds	Shell Weight	Shell Weight per S A Egg	Shell Thickness	Egg Conformation	Porosity
		(g)	$(mg.cm^{-2})$	(μm)		$(mg.cm.^{-2}.24h^{-1})$
1	4	5.06^a	69.0^a	305^a	1.42^b	4.3
2	41	5.91^c	79.8^{bc}	360^c	1.34^a	4.5 (40)
3	61	5.43^b	78.6^b	339^b	1.37^a	4.5
4	21	5.74^c	82.0^c	370^c	1.36^a	4.6
LSD (p=0.01)		0.25	2.6	13	0.03	^+ns

[abc] Means in the same column differently superscripted are significantly different (p<0.01).

^+ns = not significant in analysis of variance (Table 28). Number in brackets is different bird number from that given in second column.

S A = Surface Area

(b) Generation

(i) Shell Weight

Shell weight was observed to be positively correlated with FCE (18-66 weeks and 22-42 weeks, see Table 3). This correlation can be seen when observing generation 2, 3 and 4 (Table 30) but generation 1 birds negate this trend.

The 4 birds of generation 1 produced a large number of eggs, despite the reduced level of feed intake. Their rate of egg production was such that time for shell formation in the bird may have been reduced and this contributed to their poorer egg shell quality.

(ii) Shell Weight per Surface Area of Egg and Shell Thickness

Generation 1 birds had markedly lower levels of shell thickness and shell weight per surface area than all other generations. Generation 3 birds produced eggs which were significantly lower in shell thickness than generation 2 and 4. Previous discussion referred to the high TSR and metabolic rate of generation 3 birds. The stimulus which may have caused high TSR in these birds may have also changed parathyroid hormone and calcitonin balance and hence calcium balance in birds. This may have caused poorer shell quality.

(iii) Egg Conformation

Generation 1 birds had significantly higher egg conformation than 3 other generations. It is difficult to suggest why generation 1 birds would produce longer but thinner eggs than other birds, except that this shape of egg may facilitate more efficient movement of eggs through the vagina.

(iv) Porosity

There was no significant differences between generations in egg shell porosity.

(c) Feed Level

Table 31. Effect of Feed Level on Egg Shell Quality Variables for Purebred Birds

Variable	Units	Restricted	*Ad libitum*	LSD (p=0.05)
Shell Weight	(g)	5.47^a	5.70^b	0.13
Shell Weight per Surface Area Egg	$(mg.cm^{-2})$	78.7	79.9	$^+$ns
Shell Thickness	(μm)	344	357	ns
Egg Conformation		1.36	1.36	ns
Porosity	$(mg.cm^{-2}.24h^{-1})$	4.32^a	4.73^b	0.16
Calcium Intake (22-42 weeks)	$(g.24h^{-1})$	3.0	4.5	
No. of Birds		69	58	

[ab] Means in same row differently superscripted are significantly different (p<0.05).

[+]ns = not significant in analysis of variance (Table 28).

(i) Shell Weight, Shell Weight per Surface Area of Egg and Shell Thickness

ARC (1975) estimated that calcium requirement for maximum egg output is 3.0 $g.24h^{-1}$. Birds restricted in feed in this present study consumed an average of 3 g of calcium per day (Table 31). However, shell weight of restricted fed birds was significantly lower than *ad libitum* fed birds. Kari, *et al*. (1977) observed no

significant changes in shell weight of eggs with 12% feed restriction but in this study feed restriction was approximately 33%. It could be suggested that calcium intake of birds in this present work was not adequate to meet the requirements for satisfactory shell formation. However, there was no significant difference in the other shell quality variables, shell weight per surface area of egg or shell thickness between the 2 feed levels. Al-Khazraji, *et al.* (1972) and Gerry and Muir (1976) did not observe any significant decline in shell quality with 15% feed restriction.

(ii) Egg Conformation

There was no difference in shape of eggs between the 2 feed levels.

(iii) Porosity

Birds on restricted feeding had a significantly lower porosity than *ad libitum* fed birds. The restricted fed birds had a significant lower carcass fat level and (for reasons speculated earlier) this may have contributed towards the reduced rate of water loss from the egg.

Table 32. Analysis of Variance for Purebred Body Weight Data

Source	df	Body Weight (Hatch)	Body Weight (6 weeks)	df	Body Weight (18 weeks)	Body Weight (42 weeks)	Body Weight (66 weeks)
			(g) F value		(g) F value	(g) F value	(g) F value
Line	3	1.02^{ns}	5.57^{**}	3	4.82^{**}	8.39^{***}	6.77^{***}
Generation	2	39.39^{***}	1.09^{ns}	3	2.65^{ns}	23.38^{***}	20.20^{***}
Feed Level	1	0.55^{ns}	8.84^{**}	1	1.44^{ns}	111.65^{***}	110.11^{***}
Line by Gen.	6	2.64^{*}	5.33^{***}	8	2.21^{*}	2.42^{*}	1.69^{ns}
Line by Feed Level	3	0.39^{ns}	1.38^{ns}	3	2.13^{ns}	0.46^{ns}	0.19^{ns}
Gen. by Feed Level	2	6.80^{**}	2.78^{ns}	2	0.82^{ns}	0.08^{ns}	0.44^{ns}
Error Mean Square		11.26	2483.06		11439.64	30929.35	45895.13
Error df		106	106		106	106	106

* $p<0.05$ *** $p<0.001$

** $p<0.01$ ns   not significant

Table 33.   The Mean of Body Weight Data of Purebred Lines

Line	No. of Birds	Body Weight (Hatch)	Body Weight (6 weeks)	Body Weight (18 weeks)	Body Weight (42 weeks)	Body Weight (66 weeks)
		(g)	(g)	(g)	(g)	(g)
A_1	29	43.1	449^b	$1595^b(30)$	$2052^b(30)$	$2100^b(30)$
A_3	31	41.8	452^b	$1565^{ab}(32)$	$1940^{ab}(32)$	$2013^{bc}(32)$
A_4	35	43.1	414^a	$1520^a(36)$	$1897^a(36)$	$1901^a(36)$
C_4	29	42.6	405^a	$1511^a(30)$	$1853^a(30)$	$1863^a(30)$
LSD (p=0.01)		$^+$ns	33	71	117	143

abc Means in the same column differently superscripted are significantly different (p<0.01).

$^+$ns not significant in analysis of variance (Table 32).

Numbers in brackets are different bird numbers than those given in second column.

4. Analysis of Variance for Purebred Body Weight Data

   (a) Lines

     (i) Hatching Body Weight

There was no significant difference between lines in hatching body weight but there was a significant interaction between line and generation.

Table 34. Purebred Line by Generation for Hatching Body Weight

Line

Generation	A_1	A_3	A_4	C_4	LSD (p = 0.01)
	(g)	(g)	(g)	(g)	
1	-	-	-	-	
2	45.4 (8)[a]	46.0 (10)[a]	46.1 (11)[a]	48.3 (12)[a]	3.9
3	42.2 (15)[b]	40.0 (16)[ab]	41.7 (18)[b]	38.0 (13)[a]	3.2
4	42.2 (6)[a]	39.2 (5)[a]	42.2 (6)[a]	40.5 (4)[a]	5.6

[ab] Means in the same row differently superscripted are significantly different (p<0.01).

Bird numbers are indicated in brackets.

There was no significant difference between lines in generation 2 and 4 hatching weight, but line C_4 was significantly different from 2 other lines except line A_3 in generation 3 (Table 34). This difference can largely be attributed to lower egg weight of their mothers in generation 2 (Table 16). Hatching weight was positively correlated with egg weight (22-42 weeks), r = 0.314[***].

     (ii) Body Weight (6 weeks)

Lines A_1 and A_3 had significantly higher body weights than lines A_4 and C_4 at 6 weeks of age (Table 34). This difference is defined further in Table 35 which illustrates the significant

interaction between line and generation. Line A_1 and A_3 generally had higher 6-week body weights than line A_4 and C_4 for each generation.

Table 35. Purebred Line by Generation for Body Weight (6 weeks)

Generation	Line A_1	A_3	A_4	C_4	LSD (p = 0.01)
	(g)	(g)	(g)	(g)	
1	-	-	-	-	
2	409 (8)^{ab}	389(10)^a	451(11)^b	423(12)^{ab}	59
3	461(15)^b	483(16)^b	397(18)^a	381(12)^a	48
4	473 (6)^{ab}	481 (5)^b	393 (6)^a	432 (4)^{ab}	83

^{ab} Means in the same row differently superscripted are significantly different (p<0.01).

Bird numbers are indicated in brackets.

(iii) Body Weight (18 weeks Table 36)

The difference seen between lines in body weight at 6 weeks is reflected in the 18-week body weight, although line A_3 weight is not significantly different from lines A_4 and C_4. Deaton, *et al.* (1978) found that if initial chicken weight was low, then average body weight of the egg-type pullets at 12 and 18 weeks of age was also low. These findings are similar to those in this study where a significant positive correlation was found between hatching body weight and 18-week body weight ($r = 0.209^*$). The correlation coefficient improved to $r = 0.505^{***}$ for the relationship between 6-week and 18-week body weight. There was a significant line by generation interaction for 18-week body weight (Table 36).

Table 36. Purebred Line by Generation for Body Weight (18 weeks)

| Generation | Line | | | | |
	A_1	A_3	A_4	C_4	LSD (p = 0.01)
	(g)	(g)	(g)	(g)	
1	1340 (1)^a	1660 (1)^a	1490 (1)^a	1352 (1)^a	397
2	1638 (8)^b	1506(10)^a	1606(11)^{ab}	1558(12)^{ab}	126
3	1587(15)^b	1585(16)^b	1504(18)^{ab}	1467(12)^a	103
4	1598 (6)^b	1599 (5)^b	1415 (6)^a	1552 (4)^{ab}	178

^{ab} Means in the same row differently superscripted are significantly

different (p<0.01).

Bird numbers are indicated in brackets.

It is interesting to note that A_4 and C_4 are the only lines not significantly different for each generation.

(iv) Body Weight (42 weeks)

The difference observed between lines at 18 weeks are the same differences occurring at 42 weeks. This is demonstrated also by the significant positive correlation between 18-week and 42-week body weight (r = 0.390***). A significant interaction was found between line and generation for 42-week body weight and this illustrates the trend seen in the interaction for 18-week body weight. For this reason a table of values is not presented.

(v) Body Weight (66 weeks)

Body weight at 66 weeks of age was highly correlated with body weight at 42 weeks of age (r = 0.914***), resulting in the same differences between lines, as observed for 42-week body weight.

Of interest are the significant correlations found between hatching
body weight and subsequent body weight at 18, 42 and 66 weeks of age
(Table 6). This result could enable groups of birds of high and
low hatching weight to be segregated and different feeding treatments
applied to reduce the tendency of higher body weight birds to
accumulate fat. This procedure could also be adopted during the
laying phase of birds.

(b)   Generation

Table 37.   The Mean Body Weight of Purebred Lines for Each Generation

Generation	No. of Birds	Body Weight				
		Hatch	6 weeks	18 weeks	42 weeks	66 weeks
		(g)	(g)	(g)	(g)	(g)
1	4	-	-	1461	1627[a]	1626[a]
2	41	46.6[b]	419	1574	2154[c]	2221[c]
3	62	40.6[a]	431	1537	1825[b]	1848[b]
4	21	41.1[a]	444	1537	1884[b]	1886[b]
LSD (p = 0.01)		1.9	+ns	ns	116	141

[abc] Means in same column differently superscripted are significantly
different (p<0.01).

[+]ns = not significant in analysis of variance (Table 32).

(i)   Hatching Body Weight (Table 37)

There are 2 factors which may have contributed toward a
significantly higher hatching weight of chickens in generation 2.
Mothers of chickens were 4 weeks older in generation 1 than in
generations 2 and 3, and may have been producing eggs of greater

weight. Also, generation 1 eggs tended toward a numerically
lower egg shell porosity (Table 30) and this may have allowed
developing embryos to grow into a larger volume of egg materials.

Table 38. Purebred Generation by Feed Level for Hatching Body Weight

Generation	Restricted		Ad libitum	
	No. of Birds	Hatch Body Weight (g)	No. of Birds	Hatch Body Weight (g)
1		-		-
2	18	48.2[b]	23	45.2[b]
3	37	40.5[a]	25	40.8[a]
4	11	39.2[a]	10	43.3[ab]
LSD (p = 0.05)		2.7		2.9

[abc] Means in same column differently superscripted are significantly
different ($p < 0.05$).

(ii) Body Weight (6 and 18 weeks, Table 37)

    There were no significant differences between generations for
6 and 18-week body weight despite the hatching weight difference.
This result is discussed later in relation to feed level.

(iii) Body Weight (42 and 66 weeks, Table 37)

    Generation 2 birds had the highest body weight of all
generations. Previous discussion had pointed out the correlations
between hatching weight and 42-week body weight and the data in
Table 37 illustrate this clearly. The prediction equation for birds
on restricted feed indicates the importance of body weight at 42

weeks in relation to FCE. As indicated previously groups of chickens of low and high hatching weight could be segregated and fed different diets when restricted feeding is practised in the laying phase.

(c) Feed Level

Table 39. Effect of Feed Level on Body Weight of Purebred Birds

Body Weight (Age)	Restricted	Ad libitum	LSD (p = 0.05)
Hatch (g)	42.4 (65)	42.8 (58)	$^{+}$ns
6 Weeks (g)	450 (65)	414 (58)	18
18 Weeks (g)	1555	1536	ns
42 Weeks (g)	1745^a	2155^b	62
66 Weeks (g)	1730^a	2243^b	75
No. of Birds	69	59	

^{ab} Means in same row differently superscripted are significantly different (p<0.05).

Number in brackets are different from those bird numbers given in last row.

$^{+}$ns = not significant in analysis of variance (Table 32)

(i) Hatching Body Weight (Table 39)

There was no significant difference between hatching weight of chickens from mothers restricted or fed *ad libitum*. However, there was generation by feed level interaction discussed previously.

(ii) Body Weight (6 weeks and 18 weeks, Table 39)

A significant difference was found between 6-week and 18-week body weight of birds, even though all chickens were reared together and were allowed to feed *ad libitum* (Table 39). By the time birds

reached 18 weeks of age this difference was no longer significant although numerically different. The reason why chickens from dams (restricted in the laying phase) have higher growth rate cannot be explained. An investigation of this finding in meat-type birds may be useful where high growth rates are required.

(iii) Body Weight (42 and 66 weeks, Table 39)

The significantly lower body weight observed with feed restriction at 42 to 66 weeks of age confirms the observations of many restricted feeding experiments (Sykes, 1972).

5. <u>Summary of the Functional Differences Between Purebred Hens</u>

(a) <u>Summary of the Functional Differences Between Purebred Hens</u>
<u>on Restricted and *Ad Libitum* Feeding over the Production</u>
<u>Period 18-66 Weeks (Table 40, Figures 1 and 2)</u>

The FCE, egg production and average egg weight were
significantly lower for restricted birds than for birds fed
ad libitum.   Metabolic rate was also significantly lower for
the restricted birds, but their TSR was elevated. Body fat
content of the birds fed *ad libitum* was higher despite both
groups of birds turning over water at the same rate. The
lower body fat content of the restricted birds was reflected
in their lower body weight at 42 and 66 weeks of age.

The food restricted birds produced eggs of lower shell
weight, but there was no difference between the 2 groups of
hens in the other measures of shell strength. However, rate
of water loss from eggs (porosity) of birds fed *ad libitum*
was higher.

(b) <u>Summary of the Functional Differences Between Purebred Lines</u>
<u>over the Production Period 22-42 weeks (Mean of *Ad Libitum*)</u>
<u>and Restricted Fed Birds (Table 41, Figures 3 and 4)</u>

Only small differences were noted between lines when they
were assessed over the period 22-42 weeks. Line A_3 had superior
FCE, but its egg weight was low compared to the other lines.
The high body fat content of the most efficient line is unusual
although its body weight was higher at 42 and 66 weeks of age.
It is considered this lines function is an example of the
polyfunctionalism that is known to exist in other breeds of

animals. Line A_3 produced eggs with similar shell weight and shell strength compared to other lines, but birds of line A_3 produced eggs which had higher porosity.

(c) Summary of the Functional Differences Between Generations of the Purebred Birds over the Production Period 22-42 weeks (Mean of *Ad Libitum* and Restricted Fed Birds – Table 42, Figures 5 and 6).

From generation 1 to 4 there was a general decline in FCE and egg production rate as inbreeding progressed. Egg weight increased in the second generation but then declined in generation 3 and 4 to a level similar to generation 1. Hens of generation 3 were interesting. They were the least efficient hens and exhibited the highest TSR and metabolic rate of all generations. Their body fat level was also elevated. From generation 1 to generation 4, plasma thyroxine levels increased as inbreeding proceeded.

Shell weight and shell strength were significantly lower in generation 1 than in any other generation. This is an example of the decline in egg shell quality seen with improvement in egg production rate and FCE of hens. Body weight of generation 1 birds at 42 and 66 weeks of age was much lower than all other generations also being reflected in their lower body fat content.

Table 40. Summary of the Functional Differences Between Purebred Hens on Restricted and *Ad Libitum* Feeding over the Production Period 18-66 weeks

Variable	Units	Restricted	*Ad libitum*	LSD (p=0.05)
Feed intake	$g.24h^{-1}$	80.0	120.5	2.8
FCE	%	18.4	27.1	1.9
Egg number		92	18.9	12
Average egg weight	g	55.6	57.6	1.2
Metabolic rate	$KJ\ W^{-0.75}.24h^{-1}$	330	362	11
Water turnover	$ml.kg^{-1}.24h^{-1}$	124	125	ns
TBW% body weight	%	60.7	56.0	1.1
Thyroxine secretion rate	$\mu gT_4.100g^{-1}.24h^{-1}$	0.672	0.632	ns
Plasma thyroxine	$\mu g\ T_4\ dl^{-1}$	1.373	0.973	0.093
Shell weight	g	5.47	5.70	0.1
Shell weight per S A egg	$mg.cm^{-2}$	78.7	79.9	ns
Shell thickness	μm	344	357	ns
Egg conformation		1.36	1.36	ns
Porosity	$mg.cm^{-2}.24h^{-1}$	4.32	4.73	0.16
Body weight (18 weeks)	g	1555	1536	ns
Body weight (42 weeks)	g	1745	2155	ns
Body weight (66 weeks)	g	1730	2243	75

ns not significant

Variables feed intake, FCE, egg number and average egg weight determined over 18-66 weeks

Table 41. Summary of the Functional Differences Between Purebred Lines over the Production Period 22-42 weeks

Variable	Units	A_1	A_3	A_4	C_4	LSD (p = 0.01)
Feed intake (22-42 weeks)	$g.24^{-1}$	105.4	100.2	97.2	99.3	4.5
FCE (22-42 weeks)	%	24.6	27.7	22.5	23.3	4.1
Egg number (22-42 weeks)		77.7	74.8	60.0	65.2	ns
Average egg weight (22-42 weeks)	g	54.9	52.7	53.7	51.3	2.1
Metabolic rate	$KJ.W^{-0.75}.24h^{-1}$	341	341	343	355	ns
Water turnover	$ml.kg^{-1}.24h^{-1}$	124.3	124.4	121.9	127.8	ns
TBW% body weight	%	56.9	57.1	60.2	59.8	2.1
Thyroxine secretion rate	$\mu g\ T_4.100g^{-1}.24h^{-1}$	0.653	0.603	0.720	0.628	ns
Plasma thyroxine	$\mu g\ T_4\ dl^{-1}$	1.229	1.133	1.290	1.173	ns
Shell weight	g	5.73	5.60	5.73	5.39	0.25
Shell weight per S A egg	$mg.cm^{-2}$	80.5	79.4	79.9	77.0	ns
Shell thickness	μm	355	352	352	339	ns
Egg conformation		1.33	1.38	1.39	1.33	0.03
Porosity	$mg.cm^{-2}.24h^{-1}$	4.63	4.67	4.43	4.45	0.30
Body weight (18 weeks)	g	1595	1565	1520	1511	71
Body weight (42 weeks)	g	2052	1940	1897	1853	117
Body weight (66 weeks)	g	2100	2013	1901	1863	143
Bird Number		30	32	36	30	

Table 42. Summary of the Functional Differences Between Generations of the Purebred Birds over Production Period 22-42 weeks

Variable	Units	Generation				LSD (p = 0.01)
		1	2	3	4	
Feed intake (22-42 weeks)	$g.24h^{-1}$	86.0	105.3	98.0	100.2	ns
FCE (22-42 weeks)	%	39.4	26.9	22.6	22.4	4.1
Egg number (22-42 weeks)		89.0	75.0	61.7	62.4	11.0
Average egg weight (22-42 weeks)	g	53.6	54.3	52.1	52.3	2.1
Metabolic rate	$KJ.W^{-0.75}.24h^{-1}$	336	331	361	326	21
Water turnover	$ml.kg^{-1}.24h^{-1}$	152.4	116.1	125.0	134.0	15.2
TBW% body weight	%	66.9	58.3	57.0	61.9	2.1
Thyroxine secretion rate	$\mu g\ T_4.100g^{-1}.24h^{-1}$	0.475	0.531	0.794	0.512	0.114
Plasma thyroxine	$\mu g\ T_4\ dl^{-1}$	0.930	1.110	1.291	1.262	0.174
Shell weight	g	5.06	5.91	5.43	5.74	0.25
Shell weight per S A egg	$mg.cm^{-2}$	69.0	79.8	78.6	82.0	2.6
Shell thickness	μm	305	360	339	370	13
Egg conformation		1.42	1.34	1.37	1.36	0.03
Porosity	$mg.cm^{-2}.24h^{-1}$	4.3	4.5	4.5	4.6	ns
Body weight (18 weeks)	g	1461	1574	1537	1537	ns
Body weight (42 weeks)	g	1627	2154	1825	1884	116
Body weight (66 weeks)	g	1626	2221	1848	1886	141
Bird number		4	41	61	21	

Figure 1.

Histograms of the Production and Shell Quality
Differences between Purebred Hens on Restricted
and *Ad Libitum* Feeding over the Production
Period 18-66 Weeks

PRODUCTION

SHELL QUALITY

(mg. cm^{-2})
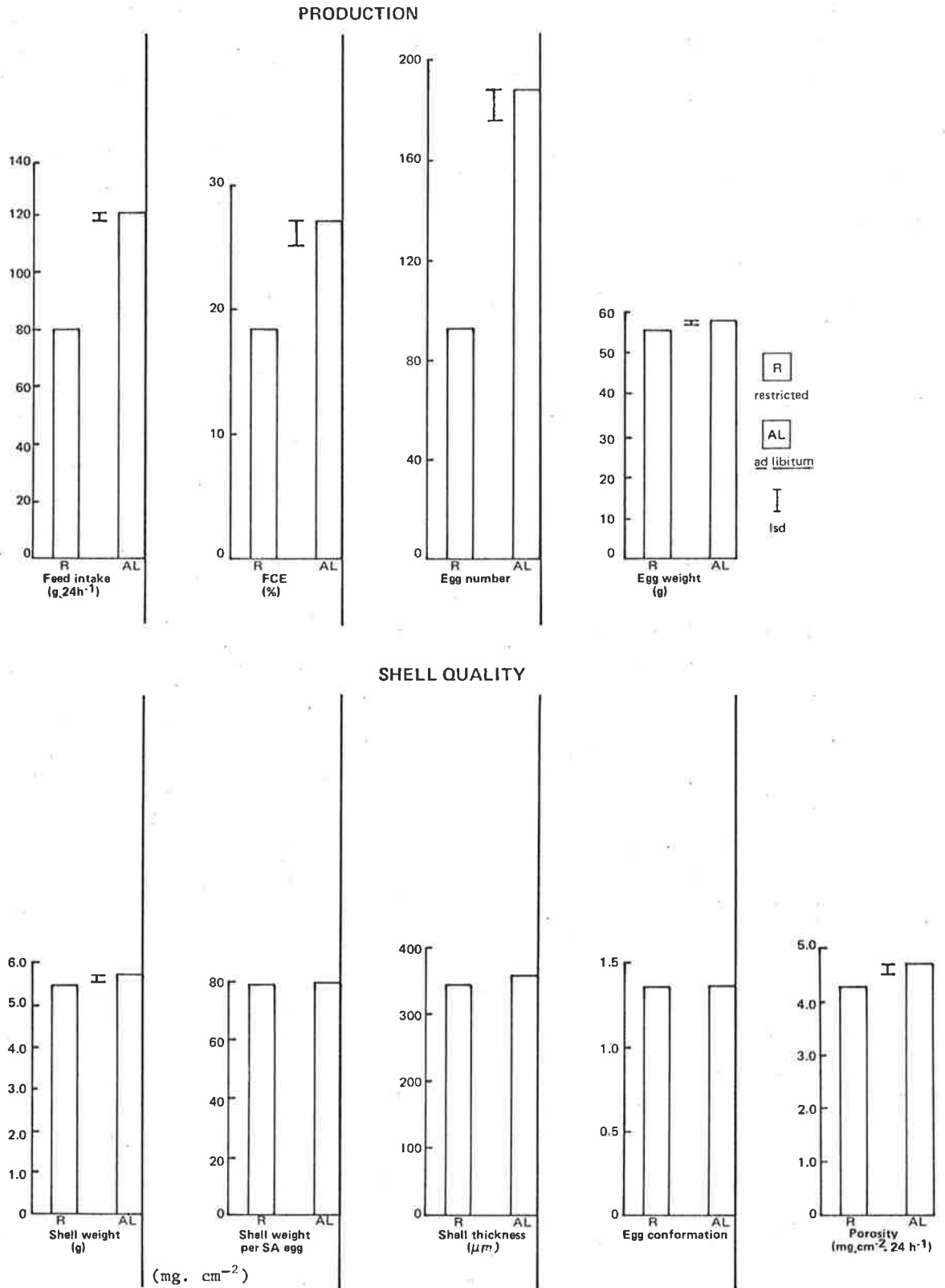
Least significant difference(lsd)is indicated where p < 0.05

Figure 2.

Histograms of the Physiological and Body
Weight Differences between Purebred Hens on
Restricted and *Ad Libitum* Feeding over the
Production Period 18-66 Weeks
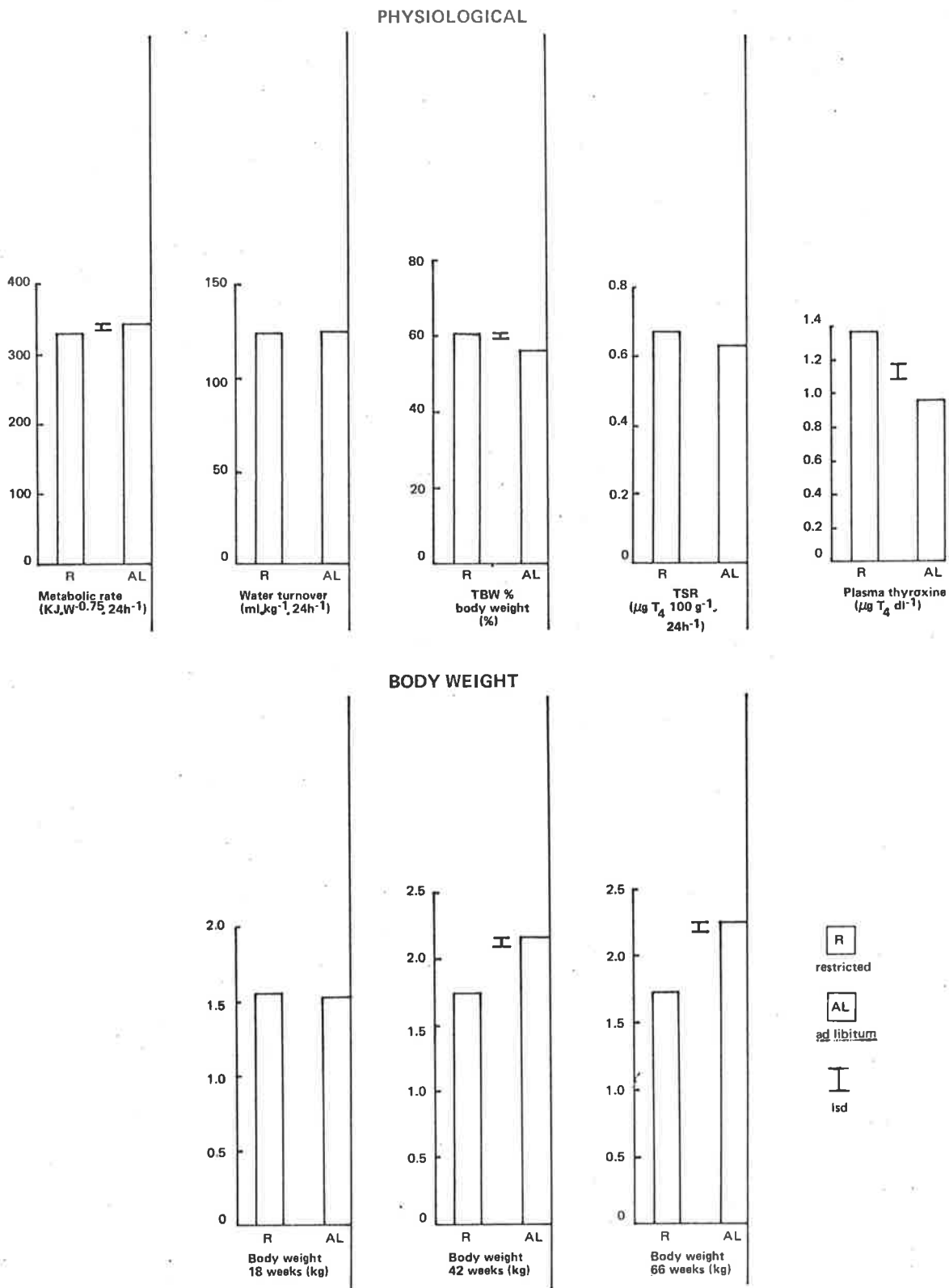
Least significant difference(lsd)is indicated where p < 0.05

Figure 3.

Histograms of the Production and Shell Quality
Differences between Purebred Lines over the
Production Period 22-42 Weeks

PRODUCTION

SHELL QUALITY
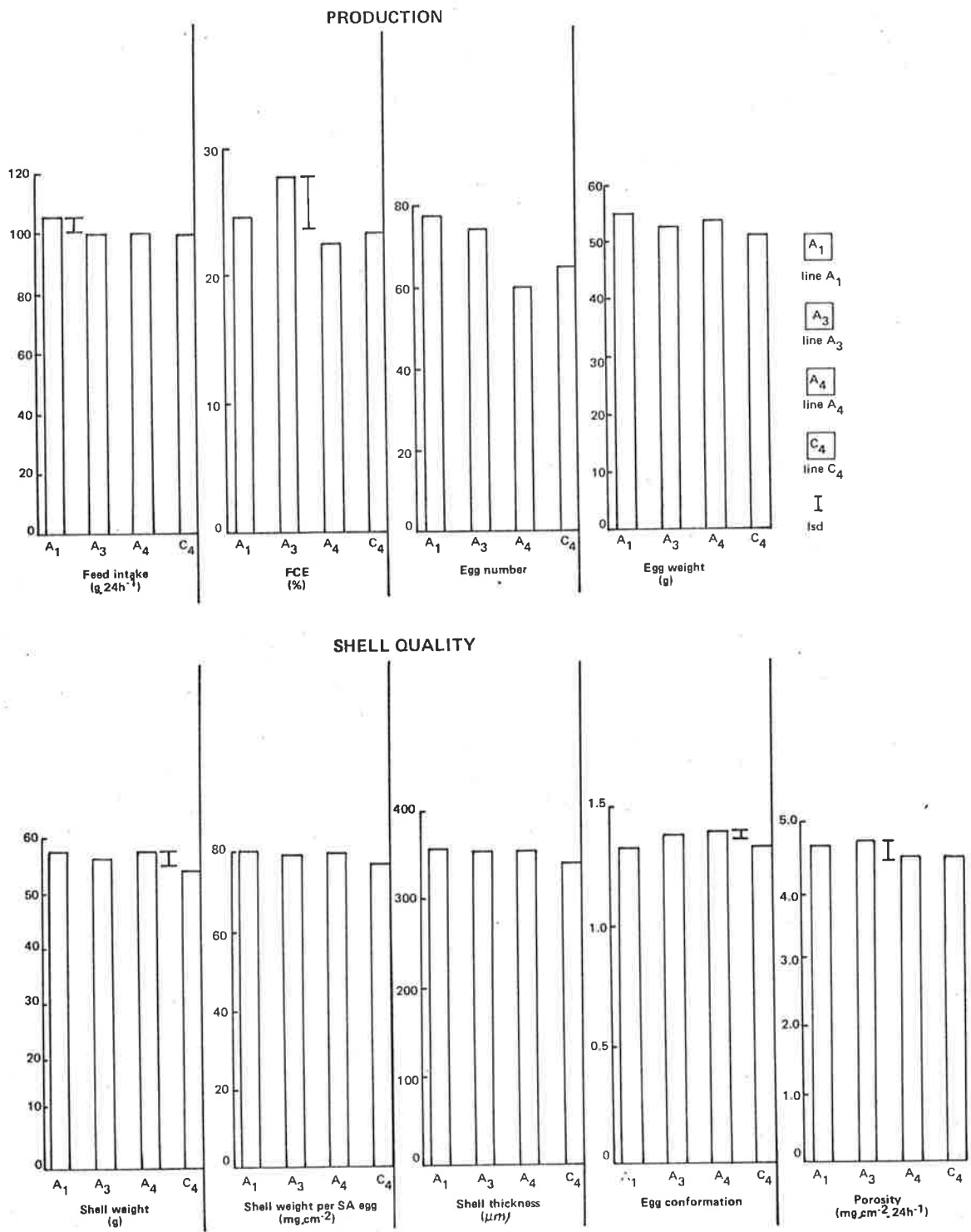
Least significant difference(lsd)is indicated where p < 0.01

The values given in these histograms are a mean of the
ad libitum and the restricted fed hens.

Figure 4.

Histograms of the Physiological and Body Weight
Differences between Purebred Lines over the Production Period 22-42 Weeks

PHYSIOLOGICAL

BODY WEIGHT
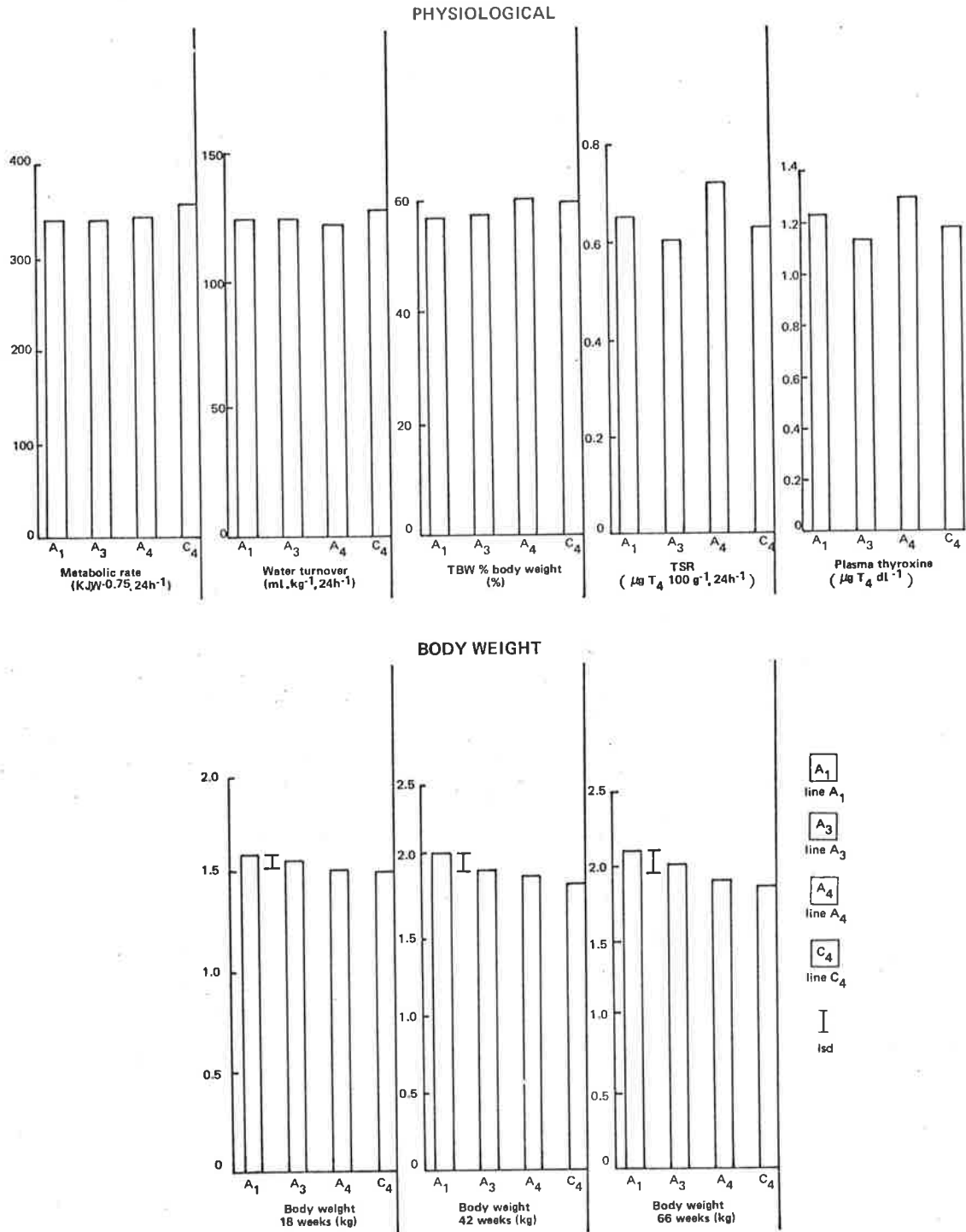
Least significant difference (lsd) is indicated where p < 0.01

The values given in these histograms are a mean of the
ad libitum and the restricted fed hens.

Figure 5.

Histograms of the Production and Shell Quality
Differences between Generations of the Purebred
Hens over the Production Period 22-42 Weeks
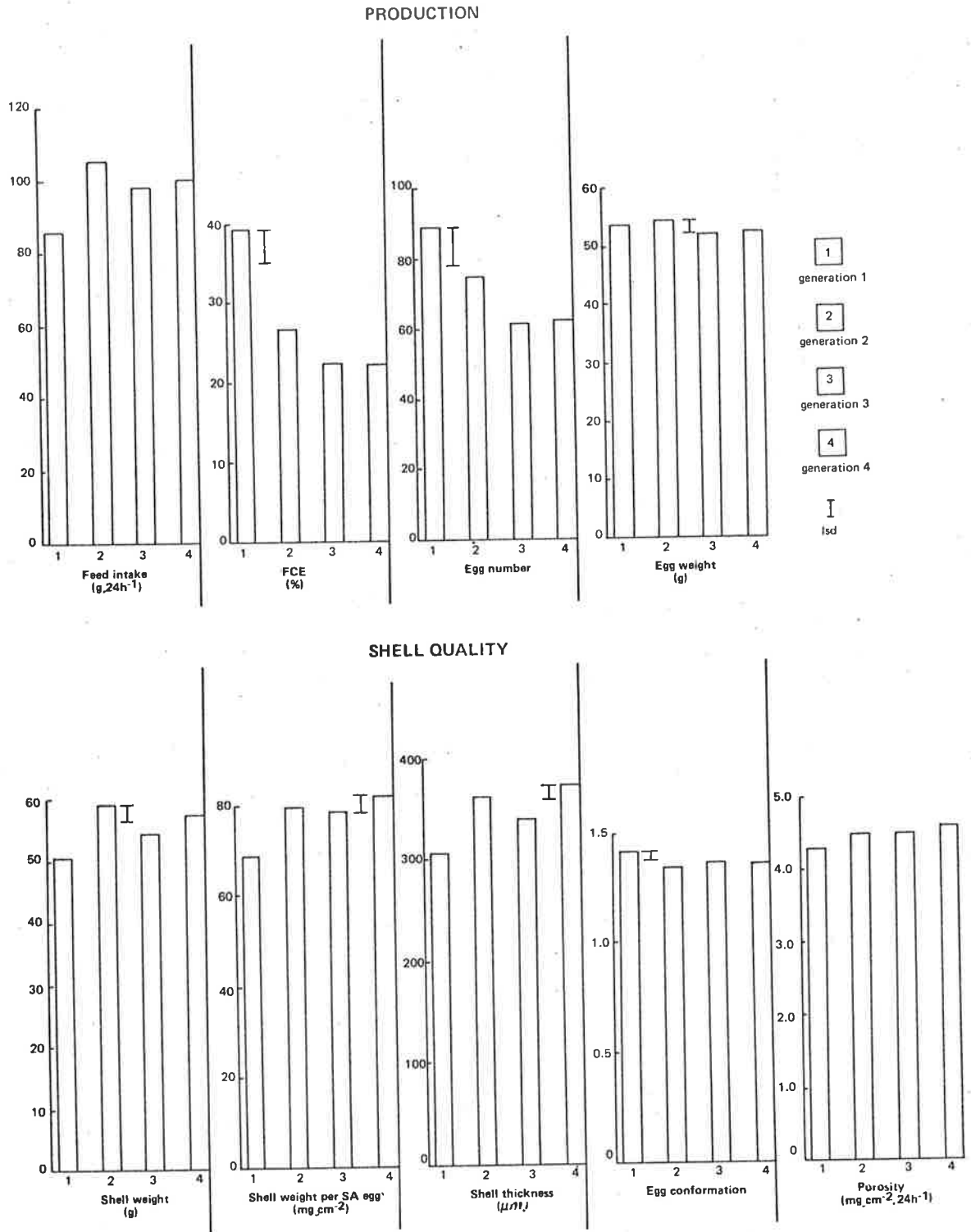
Least significant difference (lsd) is indicated where p < 0.01

The values given in these histograms are a mean of the *ad libitum*
and restricted fed hens.

Figure 6.

Histograms of the Physiological and Body Weight
Differences between Generations of the Purebred
Hens over the Production Period 22-42 Weeks

PHYSIOLOGICAL

Metabolic rate
(KJW$^{-0.75}$, 24h^{-1})

Water turnover
(ml. kg^{-1}, 24h^{-1})

TBW % body weight
(%)

TSR
(μg T$_4$ 100 g^{-1}, 24h^{-1})

Plasma thyroxine
(μg T$_4$ dl^{-1})

BODY WEIGHT

Body weight
18 weeks (kg)

Body weight
42 weeks (kg)

Body weight
66 weeks (kg)

1 generation 1

2 generation 2

3 generation 3

4 generation 4

lsd
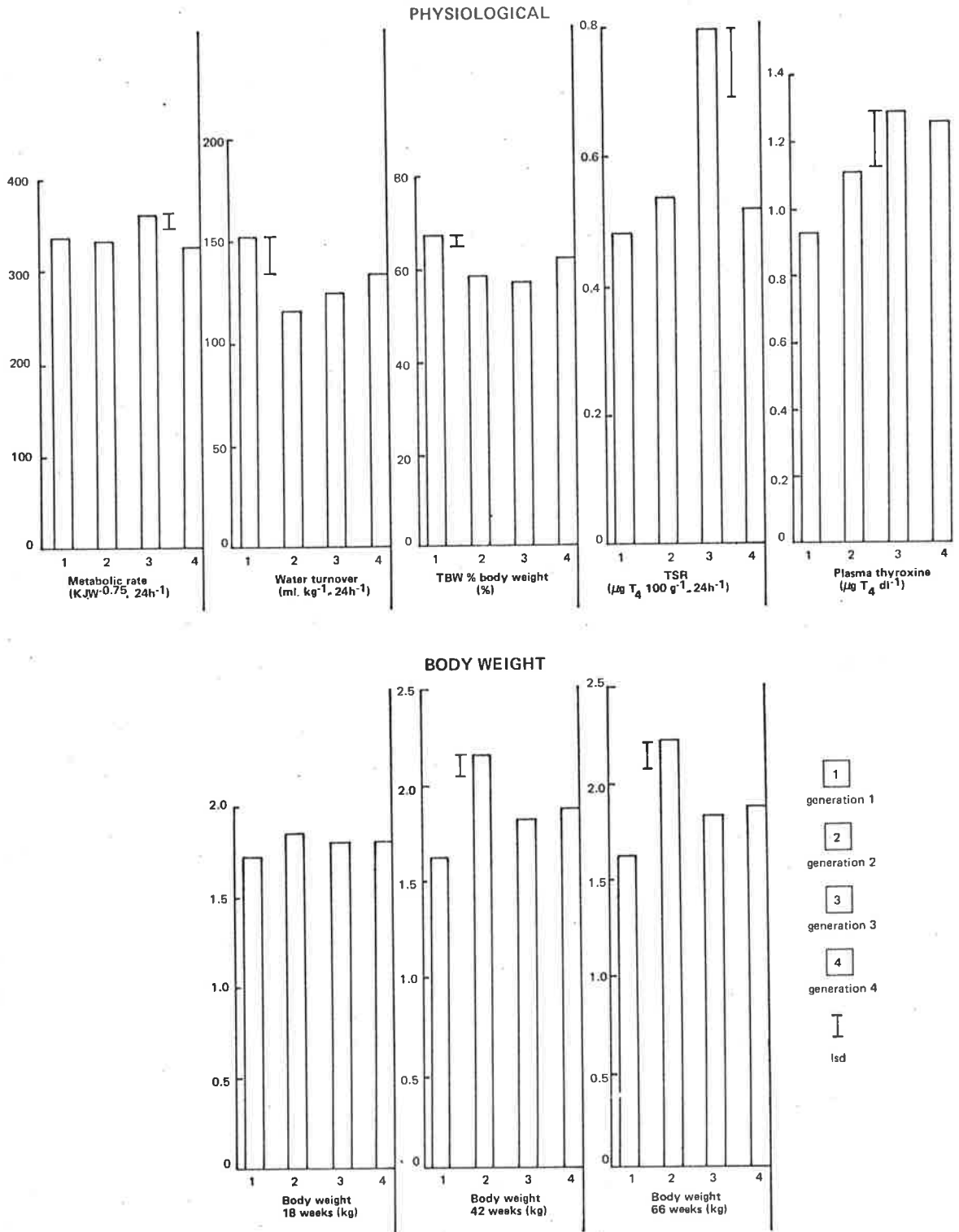
Least significant difference (lsd) is indicated where p < 0.01

The values given in these histograms are a mean of the *ad libitum*
and restricted fed hens.

6. Functional Differences Between Purebred Hens Classified According
    to Feed Conversion Efficiency

    (a) Approach to FCE Classification

         Additional to analyses of data by using multiple regression

    techniques and analysis of variance it was considered that

    segregation of birds with very   different FCE may give further

    useful information on the varying functions of hens. Thus

    the following section examines birds segregated according to

    their FCE. There were some difficulties in adopting a similar

    classification for birds on restricted feeding as for those on

    ad libitum feeding due to the different FCE frequency

    distributions of birds for the 2   feed levels. Subsequently

    birds were classified as efficient on restricted feed level

    if their FCE was greater than 30%. Birds were classified

    inefficient on the restricted feed level if they functioned on

    less than 10% FCE. For the *ad libitum* feed level, hens

    classified as efficient achieved a FCE greater than 35% and

    those hens classified as inefficient functioned at less than

    20% FCE.

    (b) Functional Differences Between Efficient and Inefficient Purebred
         Hens Subjected to Restricted Feeding (80g.24h^{-1}) over the
         Production Period 22-42 weeks (Table 44, Figures 7 and 8)

         From a population of 69 purebred laying hens subjected to

    restricted feeding (80g.24h^{-1}) over the production period 22-42

    weeks a total of 11 birds were classified according to their

    FCE. Individual birds that were classified into the 2

    efficiency groups are identified as Gold 76, Blue 32, Blue 60,

Gold 86, Pink 5, Pink 6, Yel 1, Yel 2, Blue 5, Blue 33 and Blue 28. These individual birds' production, physiological, egg shell quality and body weight data are listed in Appendices 1, 2, 3 and 4 respectively.

The efficient restricted birds had a superior egg production rate but their egg weight was about 4 g less than inefficient birds. Metabolic rate, TSR and plasma thyroxine were lower in the efficient hens but their water turnover was considerably higher than inefficient birds. Inefficient hens had a greater level of body fat which is reflected in their higher body weight at 42 weeks of age (Table 44, Figure 8). The efficient birds were converting more feed to eggs and depositing less fat than inefficient birds. The lower egg weight of efficient hens was paralleled by their lower shell weight. This appeared to effect the other shell strength values as shell thickness and shell weight per surface area of egg were also reduced compared to inefficient hens. The metabolic cost to hens of producing egg shell is high. Efficient birds may have directed some of their functional priorities from shell quality to FCE. It is considered that the small percentage of the population of hens which are highly efficient have genetic potential.

(c) Functional Differences Between Efficient and Inefficient Purebred Hens Allowed *Ad Libitum* Feeding over the Production Period 22-42 weeks (Table 43, Figures 9 and 10)

From a population of 59 purebred laying hens allowed *ad libitum* feeding over the production period 22-42 weeks a total

of 11 birds were classified according to their FCE. Individual birds that were classified into the 2 efficiency groups are identified as Gren 72, Blue 88, S 638, Pink 1, Gren 21, Gren 14, Green 58, Gold 9, Gold 14, S 640, and S 669. These individual birds' production, physiological, egg shell quality and body weight data are listed in Appendices 1, 2, 3 and 4 respectively.

From Table 43 and Figure 9 it is seen that the *ad libitum* feed intake of efficient and inefficient birds are similar, but egg production rate and egg weight were superior in the efficient hens. In the efficient restricted hens, egg weight was lower than inefficient birds, opposite to the *ad libitum* birds. This may indicate a reversal in metabolic priorities for efficient birds on *ad libitum* feed levels, although efficient birds of both feed levels had higher water turnover than inefficient birds. Shell weight of inefficient *ad libitum* fed hens was lower than efficient birds but there was no difference between two efficiency groups in other shell strength characters. Egg shell porosity, however, was elevated in the efficient type hens. The level of body fat in the efficient and inefficient hens fed *ad libitum* were similar, indicating perhaps, that with unlimited food supply the influence of fat deposition on FCE is not as important in birds fed *ad libitum* relative to those restricted.

Table 43. Summary of the Functional Differences Between Efficient and Inefficient Purebred Birds Allowed *Ad Libitum* Feeding over the Production Period 22-42 weeks

FCE Classification

Variable	Units	Efficient (>35.0)	Inefficient (<20.0)
Feed intake (22-42 weeks)	$g.24h^{-1}$	119.9 ± 4.8	122.1 ± 10.4
FCE (22-42 weeks)	%	36.8 ± 0.6	12.9 ± 4.6
Egg number (22-42 weeks)		109.6 ± 4.9	42.5 ± 15.1
Average egg weight (22-42 weeks)	g	56.6 ± 1.5	54.7 ± 0.96
Metabolic rate	$KJ\ W^{-0.75}.24h^{-1}$	395.0 ± 15.0	389.0 ± 23.0
Water turnover	$ml.kg^{-1}.24h^{-1}$	121.6 ± 8.4	110.8 ± 21.9
TBW% body weight	%	55.1 ± 1.8	56.0 ± 2.9
Thyroxine secretion rate	$\mu g\ T_4.100g^{-1}.24h^{-1}$	0.639 ± 0.050	0.670 ± 0.080
Plasma thyroxine	$\mu g\ T_4\ dl^{-1}$	1.190 ± 0.098	1.340 ± 0.196
Shell weight	g	6.06 ± 0.08	5.84 ± 0.24 (3)
Shell weight per S A egg	$mg.cm^{-2}$	80.7 ± 1.2	80.8 ± 1.8 (3)
Shell thickness	μm	361.0 ± 5.0	365.0 ± 11.0 (3)
Egg conformation		1.34 ± 0.02	1.37 ± 0.05 (3)
Porosity	$mg.cm^{-2}.24h^{-1}$	4.93 ± 0.11	4.33 ± 0.23 (3)
Body weight (18 weeks)	g	1511 ± 43	1613 ± 63
Body weight (42 weeks)	g	2191 ± 151	2230 ± 181
Body weight (66 weeks)	g	2351 ± 180	2389 ± 248
Bird number		7	4

Number in brackets are different from those bird numbers given in last row. One bird was a non layer during period shell quality measurement were made. ± standard error mean are indicated.

Table 44. Summary of the Functional Differences Between Efficient and Inefficient Purebred Birds Subjected to Restricted Feeding (80g.24h^{-1}) over the Production Period 22-42 weeks

Variable	Units	FCE Classification Efficient (>30.0)	FCE Classification Inefficient (<10.0)
Feed intake (22-42 weeks)	g.24h^{-1}	80.0	80.0
FCE (22-42 weeks)	%	37.2 ± 3.4	6.7 ± 0.7
Egg number (22-42 weeks)		81.0 ± 2.4	13.5 ± 1.4
Average egg weight (22-42 weeks)	g	51.3 ± 1.2	55.5 ± 1.3
Metabolic rate	KJ W$^{-0.75}$.24h^{-1}	319.0 ± 14.0	329.0 ± 8.0
Water turnover	ml.kg^{-1}.24h^{-1}	139.3 ± 7.4	100.7 ± 8.7
TBW% body weight	%	66.0 ± 2.4	61.1 ± 1.6
Thyroxine secretion rate	μg T$_4$.100g^{-1}.24h^{-1}	0.454 ± 0.055	0.849 ± 0.097
Plasma thyroxine	μg T$_4$ dl^{-1}	0.872 ± 0.158	1.535 ± 0.186
Shell weight	g	5.33 ± 0.22	5.60 ± 0.05
Shell weight per S A egg	mg.cm^{-2}	73.9 ± 3.0	79.5 ± 1.1
Shell thickness	μm	328 ± 15	344 ± 4
Egg conformation		1.37 ± 0.03	1.39 ± 0.03
Porosity	mg.cm^{-2}.24h^{-1}	4.4 ± 0.1	4.5 ± 0.2
Body weight (18 weeks)	g	1618 ± 81	1487 ± 79
Body weight (42 weeks)	g	1692 ± 96	1833 ± 123
Body weight (66 weeks)	g	1768 ± 109	1712 ± 118
Bird number		5	6

Figure 7.

Histograms of the Production and Shell Quality
Differences between Efficient and Inefficient
Purebred Hens on Restricted Feeding $(80g.24h^{-1})$
over the Production Period 22-42 Weeks

PRODUCTION

SHELL QUALITY
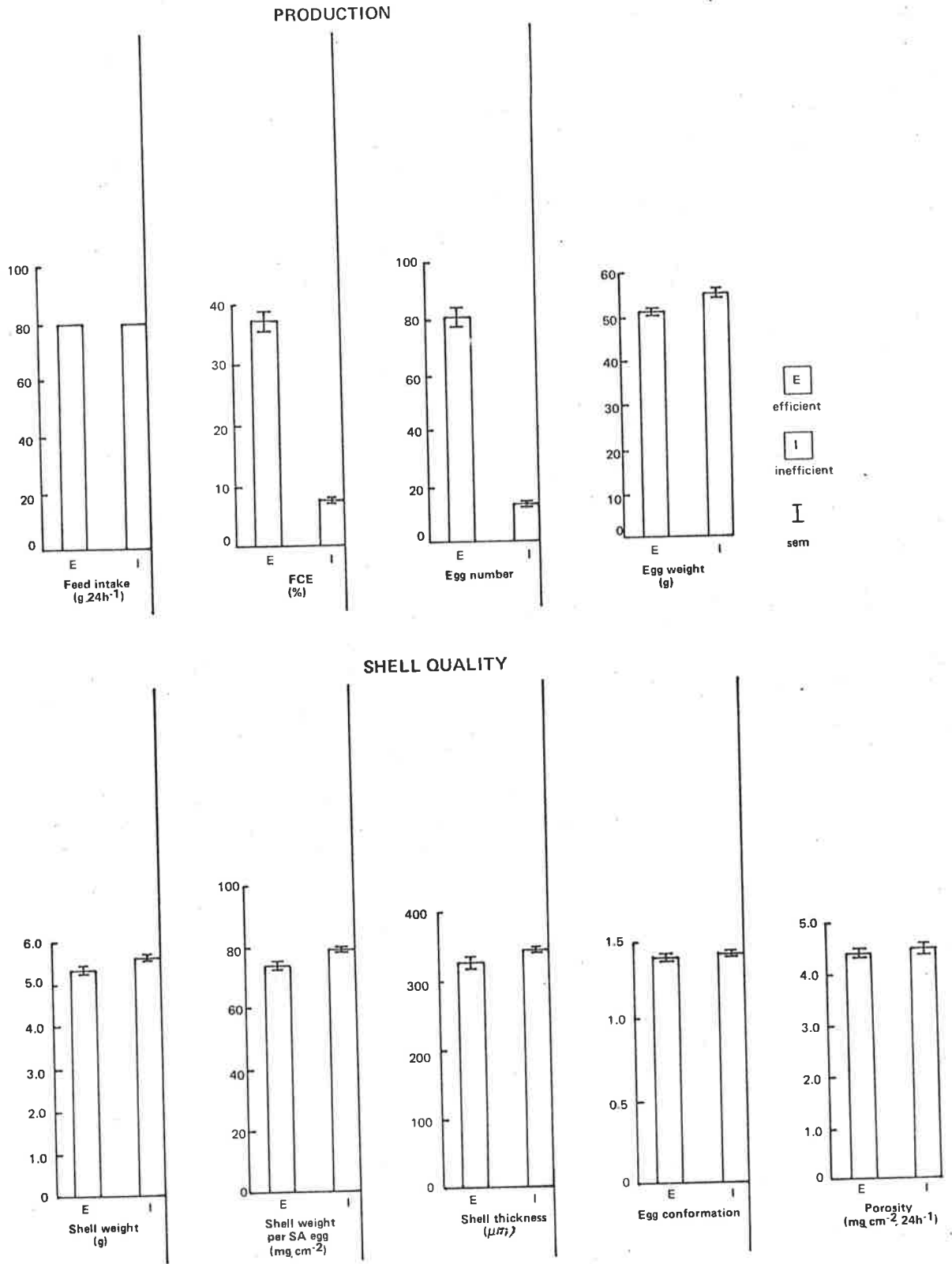
Standard error of the means (sem) are indicated

Figure 8.

Histograms of the Physiological and Body Weight Differences
between Efficient and Inefficient Hens on Restricted Feeding
$(80g.24h^{-1})$ over the Production Period   22-42 Weeks

PHYSIOLOGICAL

BODY WEIGHT
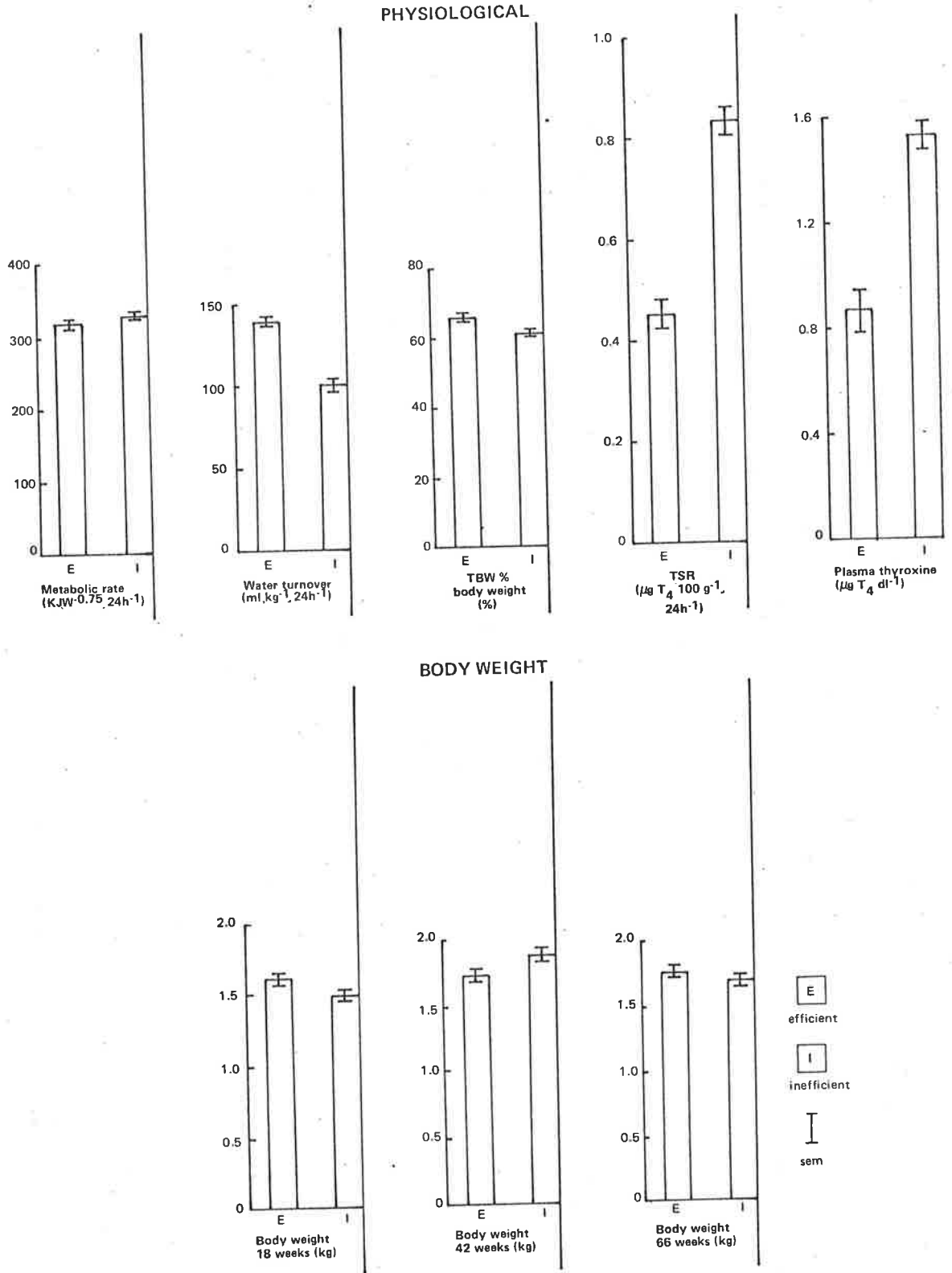
Standard error of the means (sem) are indicated

Figure 9.

Histograms of the Production and Shell Quality Differences
between Efficient and Inefficient Purebred Hens on *Ad Libitum*
Feeding over the Production Period 22-42 Weeks

PRODUCTION

SHELL QUALITY
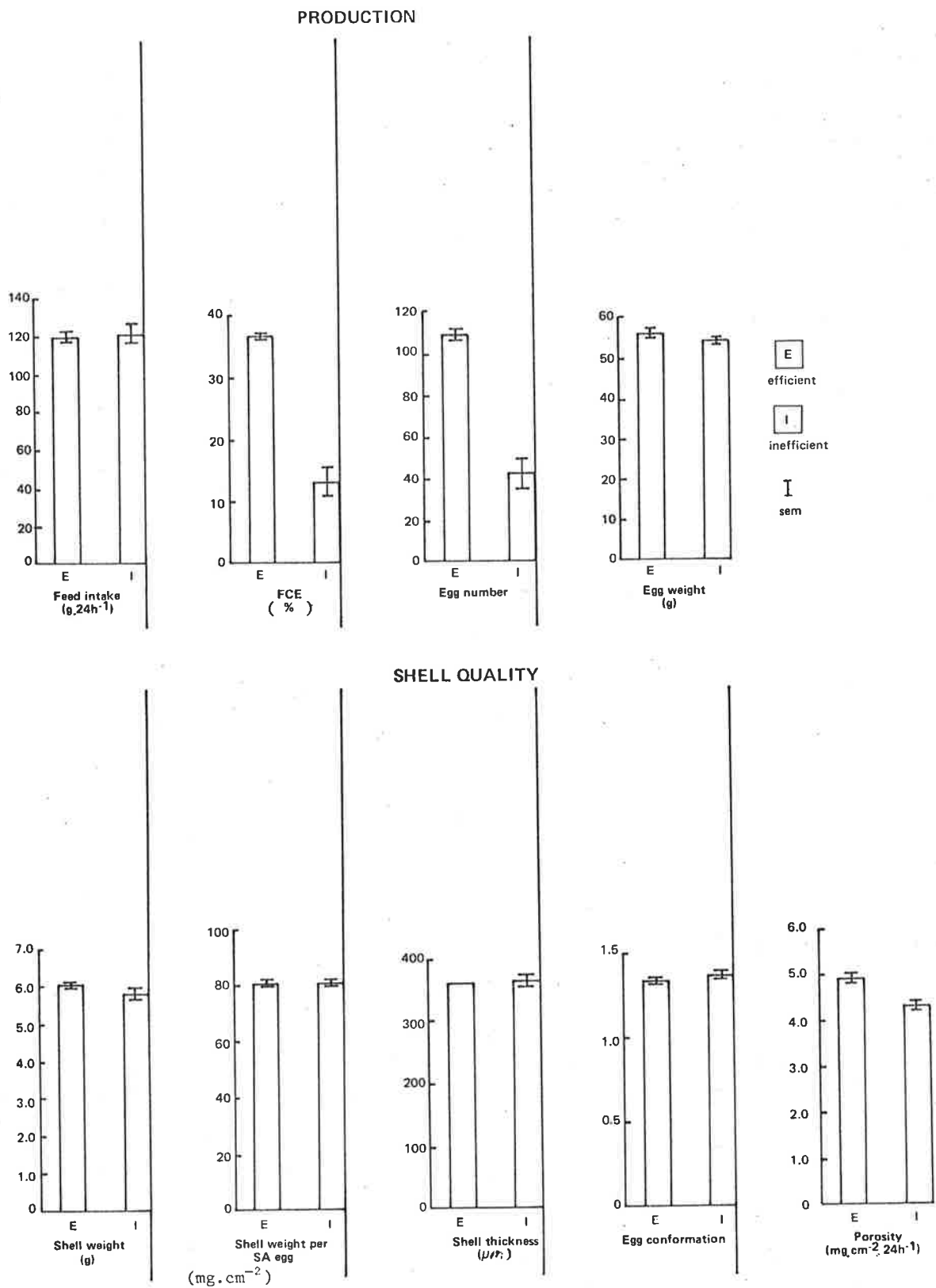
Standard error of the means (sem) are indicated

Figure 10.

Histograms of the Physiological and Body Weight
Differences between Efficient and Inefficient
Purebred Hens on *Ad Libitum* Feeding over the
Production Period 22-42 Weeks

PHYSIOLOGICAL

Metabolic rate
$(KJW^{-0.75} 24h^{-1})$

Water turnover
$(ml.kg^{-1}.24h^{-1})$

TBW %
body weight
(%)

TSR
$(\mu g\ T_4\ 100\ g^{-1},\ 24h^{-1})$

Plasma thyroxine
$(\mu g\ T_4\ dl^{-1})$

BODY WEIGHT

Body weight
18 weeks (kg)

Body weight
42 weeks (kg)

Body weight
66 weeks (kg)

E
efficient

I
inefficient

sem
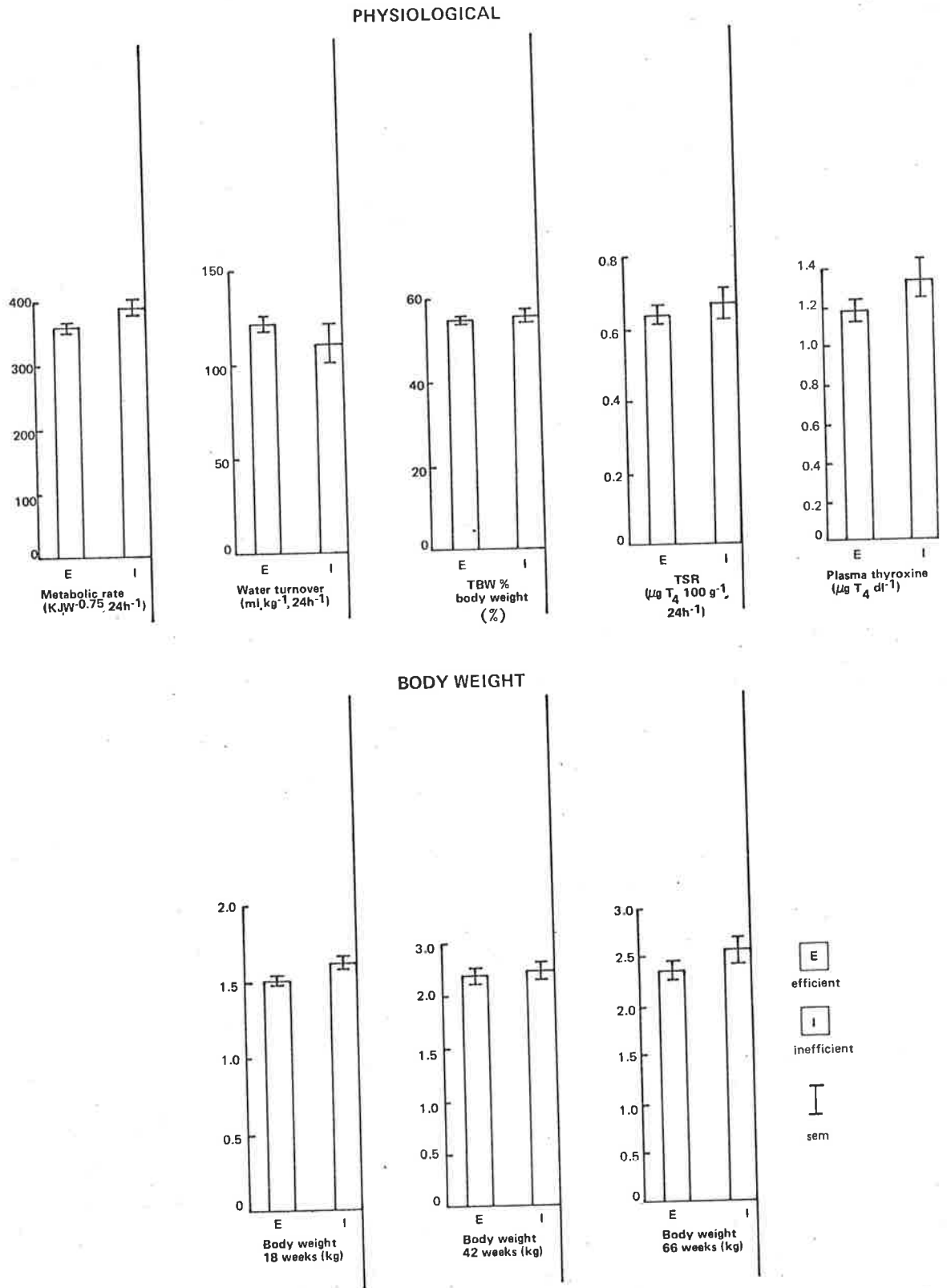
Standard error of the means (sem) are indicated

C. ANALYSIS OF VARIANCE FOR BREEDS

1. Introduction

In the previous section, interest was centred on observing the production, as well as the physiological, body weight and egg shell quality performance of lines of a White Leghorn breed of hens in relation to 2 different levels of feed intake. This section concerns the performance of different breeds of hen in relation to 4 feed intake levels (80 g.24h^{-1}, 90 g.24h^{-1}, 100 g.24h^{-1} and *ad libitum*) to see whether the trends noted for the purebred lines could be detected between breeds. The breeds consisted of the following:-

a) Purebred lines referred to in the previous section,

b) Line-crosses obtained from (a),

c) Out-cross birds consisting of crosses between an introduced sire with hens from purebred lines (a).

In this work the word breeds refers to the breed lines developed by crossing between the purebred lines and outcrossing with an introduced sire.

2. Analysis of Variance for Breeds Production Performance (Table 45)

(a) Breed (Table 46)

(i) Production Performance (Table 46)

There was a significant difference between breeds in FCE between 18 and 66 weeks. The FCE of purebred hens was the poorest. The different breeding technique used probably resulted in heterotic vigour for the line-cross and out-cross breeds. The introduction of a new gene type resulted in a breed (out-cross) which had the highest FCE. However, the differences between the breeds was not as obvious for FCE at 22-42 weeks as it was for FCE at 18-66 weeks. The out-cross breed produced significantly higher

egg numbers but egg weight remained largely similar to other breeds. There were some

interesting breed by feed level interactions for both feed intake and egg number.

These interactions are discussed later.

Table 45. Analysis of Variance for Production Performance of Birds

Source	df	FCE (18-66 weeks)	FCE (22-42 weeks)	Feed Intake (18-66 weeks)	Feed Intake (22-42 weeks)	Egg Number (18-66 weeks)	Egg Number (22-42 weeks)	Average Egg Weight (18-66 weeks)	Average Egg Wt. (22-42 weeks)
		F value	F value	F value	F value	F value	F value	F value	F value
Breed	2	15.42^{***}	23.05^{***}	2.45^{ns}	2.55^{ns}	17.36^{***}	28.79^{***}	3.28^{*}	5.34^{**}
Feed Level	3	20.81^{***}	12.24^{***}	504.06^{***}	429.78^{***}	77.25^{***}	61.27^{***}	2.65^{ns}	2.11^{ns}
Breed by Feed Level	6	2.17^{ns}	1.78^{ns}	3.05^{**}	2.72^{*}	3.05^{**}	2.37^{*}	0.77^{ns}	0.93^{ns}
Error df		92	92	92	92	92	92	92	92
Error Mean Square		29.389	39.531	20.896	26.520	975.840	244.961	9.916	7.964

* $p < 0.05$ *** $p < 0.001$

** $P < 0.01$ ns not significant

Table 46. The Mean Production Performance of Breeds

Breed	Bird Number	FCE (18-66 weeks)	FCE (22-42 weeks)	Feed Intake (18-66 weeks)	Feed Intake (22-42 weeks)	Egg Number (18-66 weeks)	Egg Number (22-42 weeks)	Average Egg Wt. (18-66 weeks)	Average Egg Wt. (22-42 weeks)
		(%)	$(g.24h^{-1})$	$(g.24h^{-1})$	$(g.24h^{-1})$			(g)	(g)
Purebred	42	21.9^a	21.3^a	97.5	97.5	130.8^a	57.1^a	55.7^a	52.4^a
Line-cross	39	25.1^b	28.1^b	97.9	99.2	145.8^a	72.8^b	57.3^a	54.3^b
Out-cross	23	28.4^c	30.6^b	97.9	98.7	165.9^b	82.9^c	56.0^a	53.0^{ab}
LSD (p = 0.02)		3.1	3.6	+ns	ns	17.7	8.9	1.8	1.6

[abc] Means that are differently superscripted in each column are significantly different (p<0.02).

[+]ns Not significant in analysis of variance (Table 45).

Table 47. The Mean Production Performance of Breeds for each Feed Level

Feed Level	Bird Number	FCE (18-66 weeks)	FCE (22-42 weeks)	Feed Intake (18-66 weeks)	Feed Intake (22-42 weeks)	Egg Number (18-66 weeks)	Egg Number (22-42 weeks)	Average Egg Wt. (18-66 weeks)	Average Egg Wt. (22-42 weeks)
80 g.24h^{-1}	30	19.2^a	21.6^a	80.0^a	80.0^a	93.8^a	46.4^a	55.6	52.6
90 g.24h^{-1}	27	23.4^b	14.5^{ac}	90.0^b	90.0^b	121.1^b	59.7^b	55.6	52.5
100 g.24h^{-1}	22	28.3^c	28.8^{bc}	100.0^c	100.0^c	167.8^c	75.2^c	57.0	53.8
ad libitum	25	28.6^c	30.1^b	126.2^d	128.2^d	209.0^d	99.4^d	57.6	54.2
LSD (p = 0.01)		4.0	4.6	3.3	3.8	22.8	11.4	$^+$ns	ns

abcd Means that are differently superscripted in columns are significantly different (p<0.01).

$^+$ns Not significant in analysis of variance (Table 45).

(b) Feed Level (Table 47)

    (i) Production Performance (Table 47)

When considering the combined performance of breeds, there
was no significant difference in FCE (18-66 weeks)
whether birds were allocated 100 g.$24h^{-1}$or *ad libitum*.
However, feed levels of 90 g.$24h^{-1}$ and 80 g.$24h^{-1}$ resulted
in a significant decline in FCE. The feed level of 100 g.
$24h^{-1}$ represents an average ME intake of 1105KJ.$24h^{-1}$ and
an average protein intake of 16.2 g.$24h^{-1}$. Supramaniam
(1970) as reported by Sykes (1972) showed that the
normal rate of egg production could be maintained with a
ME intake of 1129KJ.$24h^{-1}$. However, from Table 47 it can
be seen that egg production is significantly lower for
birds consuming 100 g.$24h^{-1}$ compared to *ad libitum*.
Subsequently in this present study the protein intake of
16.2 g.$24h^{-1}$ was not sufficient to support maximum egg
production. The work of Adams, *et al*. (1970) indicated
that birds required a protein intake of 17 g.$24h^{-1}$. To
achieve this daily protein intake would have required
only a further 5 g.$24h^{-1}$ of feed. It seems likely then
that the optimum feed intake of the combined breeds
required to support maximum FCE and egg production is
105 g.$24h^{-1}$ which represents a protein intake of
17 g.$24h^{-1}$ and ME intake of 1160KJ.$24h^{-1}$. Although there
is a trend towards higher egg weight with increasing feed
intake, the numerical differences are not significant.

There were significant interactions (Table 45) for breed
by feed level (Table 48) for feed intake (22-42 weeks and
18-66 weeks) and egg number (22-42 weeks and 18-66 weeks).
For the interaction of breed by feed level for feed intake
there were no differences in feed intake between breeds
for the feed levels of 80 g.24h^{-1}, 90 g.24h^{-1} and
100 g.24h^{-1}, and hence in Table 48 only *ad libitum* feed
level is examined.

Table 48. Breed by Feed Level for *Ad Libitum* Feed Intake (22-42 weeks
and 18-66 weeks)

Feed Level	Purebred	Line-cross	Out-cross	LSD (p = 0.02)
A(22-42 weeks)	(g) 122.5(10)[a]	(g) 131.0(9)[b]	(g) 133.7(6)[b]	6.1
A(18-66 weeks)	122.4(10)[a]	125.3(9)[a]	134.0(6)[a]	5.4

[ab] Means that are differently superscripted in each row are
significantly different (p<0.02).

Number of birds are indicated in brackets

A represents *ad libitum*

From Table 48 it is seen that out-cross breed maintained
significantly higher intake of food for both periods,
compared to the purebred. The line-cross was intermediate
in its response to *ad libitum* feeding conditions.

Table 49.   Breed by Feed Level for Egg Number (18-66 weeks)

Feed Level	Purebred	Line-cross	Out-cross	LSD (p=0.02)
	(Egg No.)	(Egg No.)	(Egg No.)	
80 g.24h^{-1}	89.4(11)^a	93.6(11)^a	100.0(8)^a	33.2
90 g.24h^{-1}	97.0(11)^a	135.3(9)^b	140.6(7)^b	34.9
100 g.24h^{-1}	148.8(10)^a	171.4(10)^a	244.5(2)^b	39.6
ad libitum	195.7(10)^a	191.7(9)^a	257.0(6)^b	37.1

^{ab} Means that are differently superscripted in each row are significantly

different (p<0.02).

Number of birds are indicated in brackets

Table 50.   Breed by Feed Level for Egg Number (22-42 weeks)

Feed Level	Purebred	Line-cross	Out-cross	LSD (p=0.02)
	(Egg No.)	(Egg No.)	(Egg No.)	
80 g.24h^{-1}	40.0(11)^a	47.3(11)^a	53.9(8)^a	16.6
90 g.24h^{-1}	40.8(11)^a	71.9(9)^b	73.7(7)^b	17.5
100 g.24h^{-1}	63.7(10)^a	79.2(10)^a	113.0(2)^b	19.9
ad libitum	87.1(10)^a	98.0(9)^a	122.2(6)^b	18.6

^{ab} Means that are differently superscripted in each row are significantly

different (p<0.02).

Number of birds are indicated in brackets.

The egg production performance (18-66 weeks and 22-42 weeks)
of the breeds (see Table 49) was similar with 80 g.24h^{-1}
intake but for the other 3 feed levels, differences
between breeds emerged. The out-cross breed maintained

superior egg production for each of the 3 higher feed

levels compared to the 2 other breeds except for those

eating 90 g.24h^{-1}. For this feed level the line-cross

had similar egg production to the outcross, but with

more food (100 g.24h^{-1} and *ad libitum*) line-cross birds

did not improve in egg production at the same rate as

the out-cross birds. Auckland and Wilson (1975a) also

found that there were strain differences in ability to

cope with restricted feeding. These results suggest

that arbitrary statements on levels of feed restriction

probably cannot be given before energy and protein

response curves for egg production are established for

each of the different breeds or strains of hen. Hence

a previous comment that the optimum feed intake to

support maximum egg production for the combined breeds

should be 105 g.24h^{-1}, is open to question in view of

the observed interactions.

Table 52. Analysis of Variance for Physiological Data of Breeds

Breed	df	Metabolic Rate	Water Turnover	TBW as % Body Weight	Thyroxine Secretion Rate	Plasma Thyroxine
		F value	F value	F value	F value	F value
Breed	2	11.98^{***}	5.80^{**}	4.42^{*}	8.51^{***}	8.76^{***}
Feed Level	3	1.21^{ns}	2.89^{*}	6.00^{**}	0.99^{ns}	19.62^{***}
Breed by Feed Level	6	1.05^{ns}	3.33^{**}	1.27^{ns}	2.03^{ns}	1.17^{ns}
Error df		92	92	92	92	92
Error Mean Square		28.115	723.182	13.328	0.017	0.045

* $p < 0.05$

** $p < 0.01$ TBW = Total body water

*** $p < 0.001$

ns   not significant

Note: Analysis of variance for metabolic rate was calculated using $Kcal.W^{-0.75}.24h^{-1}$
Conversion to appropriate KJ units occurs in LSD calculations.

Table 52. The Mean Physiological Performance of Breeds

Breed	Bird Number	Metabolic Rate	Water Turnover	TBW as % Body Weight	Thyroxine Secretion Rate	Plasma Thyroxine
		$(KJ.kg^{-0.75}.24h^{-1})$	$(ml.kg^{-1}.24h^{-1})$	%	$(\mu gT_4 100g^{-1}.24h^{-1})$	$(\mu gT_4 dl^{-1})$
Purebred	42	327^b	129.6^a	62.8^{ab}	0.451^b	1.198^b
Line-cross	39	306^a	138.1^a	61.1^a	0.336^a	1.009^a
Out-cross	23	302^a	160.3^b	63.4^b	0.326^a	1.133^b
LSD (p=0.02)		13	15.3	2.1	0.074	0.120

[ab] Means that are differently superscripted in each column

are significantly different (p<0.02).

3. Analysis of Variance for Breeds Physiological Data

(a) Breed

    (i) Physiological Performance (Table 52)

The purebred hens were observed to have the lowest FCE (Table 46) but the highest metabolic rate. This finding is similar to that of Morrison and Leeson (1978), who found that inefficient birds had significantly higher metabolic rates than efficient hens under conditions of *ad libitum* feeding or of starvation. In previous analysis of purebred data no significant correlation was found between FCE and metabolic rate. However, for purebreds, FCE was significantly correlated with TSR and this is also illustrated in results for breeds presented in Tables 46 and 52. Morrison and Leeson (1978) made the comment that "for high-producing birds, factors other than carcass size and body composition are responsible for the observed difference in feed conversion efficiency". Previous analyses (and results in Table 52) have shown that with restricted feeding, high body weight and high carcass fat are probably manifest in birds of poor efficiency. Also inefficient restricted hens have high levels of circulating thyroxine. In *ad libitum* fed birds, the thyroid gland assumes a lesser role in determining FCE. The question that arises is "At what feed level or energy intake does the thyroid gland assume a major role in determining FCE in hens?" It could be implied from Morrison and Leeson's work that thyroid gland involvement is also important in determining FCE of *ad libitum* fed birds as TSR in this present study was correlated with metabolic rate.

However, the previous analysis of purebred data showed that high water turnover was more important in determining high FCE in birds fed *ad libitum*. This is also indicated for the breeds (Table 52 and 46) where the out-cross line had a significantly higher water turnover than other breeds. These results may only indicate that water turnover is a more useful variable to measure than metabolic rate or thyroxine secretion rate when assessing efficiency in the *ad libitum* fed hen. Difficulties in assessing the role of metabolic rate and thyroxine secretion are probably confound by the wide variation in feed intake seen amongst birds fed *ad libitum*. It would appear, however, that in the *ad libitum* feeding environment efficient birds probably have a more responsive environmental neuro-endocrine setting for control of energy metabolism, with high water turnover reflecting their high egg production rate. However, complications arise when assessing water turnover between breeds as indicated by the significant interaction found between breed and feed level for water turnover (Table 53). The results in Table 53 indicate that water turnover measurements *per se* cannot be used to assess FCE between breeds.

Table 53.   Breed by Feed Level for Water Turnover

Feed Level	Purebred	Line-cross	Out-cross	LSD (p=0.02)
	$(ml.kg^{-1}.24h^{-1})$	$(ml.kg^{-1}.24h^{-1})$	$(ml.kg^{-1}.24h^{-1})$	
80 g.24h^{-1}	123.4(11)[a]	149.9(11)[a]	189.9(8)[b]	28.5
90 g.24h^{-1}	127.0(11)[a]	150.3(9)[a]	147.1(7)[a]	30.1
100 g.24h^{-1}	123.5(10)[a]	122.6(10)[a]	146.6(2)[a]	34.1
ad libitum	145.5(10)[a]	128.9(9)[a]	141.0(6)[a]	31.9
LSD (p=0.01)	30.2	31.7	40.9	

[ab] Means that are differently superscripted in each row (p<0.02) and column (p<0.01)

are significantly different.

Bird numbers are indicated in brackets.

This is probably due to the different physiological settings of energy and water metabolism between breeds, for *ad libitum* and restricted feeding conditions. In the previous analysis of purebreds there was no significant difference in water turnover between birds consuming 80 g.24h^{-1} or *ad libitum*. The results in Table 53 also indicate this, with the out-cross line showing significantly higher water turnover during restricted feeding. It was speculated earlier that with feed restriction boredom in hens may contribute to higher water intake and hence water turnover, leading to the difficulty in assessing water turnover measurements in relation to FCE between feed levels.

(b)   Feed Level

    (i)   Physiological Performance (Table 54)

In the previous analysis of purebred lines, metabolic rate was signficantly different between birds consuming 80 g.24h^{-1} and fed *ad libitum*.   But, in comparing the combined breeds over the 4 feed levels there was no significant difference. There is however, a numerically obvious trend to higher metabolic rate with the higher feed level. The difference between breeds in metabolic rate may account for this result. Water turnover followed the same trend described previously as did the carcass fat estimates, TSR and plasma thyroxine.

Table 54. The Mean Physiological Performance of Breeds for Each Feed Level.

Feed Level	Bird Number	Metabolic Rate	Water Turnover	TBW as a % Body Weight	Thyroxine Secretion Rate	Plasma Thyroxine
		$(KJ.kg^{-0.75}.24h^{-1})$	$(ml.kg^{-1}.24h^{-1})$	%	$(\mu gT_4.100\ g^{-1}.24h^{-1})$	$(\mu gT_4 dl^{-1})$
80 g.24h^{-1}	25	308	150.9^b	63.0^b	0.422	1.362^b
90 g.24h^{-1}	22	314	139.9^{ab}	64.2^b	0.362	1.003^a
100 g.24h^{-1}	30	314	125.2^a	62.1^{ab}	0.331	1.028^a
ad libitum	27	320	134.4^{ab}	59.7^a	0.395	1.006^a
LSD (p=0.01)		$^+$ns	19.7	2.7	ns	0.156

^{ab} Means that are differently superscripted in each column are significantly different (p<0.01).

$^+$ns Not significant in analysis of variance (Table 51).

4. <u>Analysis of Variance for Breeds Egg Shell Quality Data</u> <u>(Table 55)</u>.

   (a) <u>Breed</u>

      (i) <u>Egg Shell Quality Performance</u> (Table 56).

The out-cross line which had the highest FCE produced eggs of the lowest shell weight. The lower shell weight did not contribute to any significant decline in the other indirect shell quality measurements (shell weight per surface area of eggs or shell thickness), though there was a slight numerical decline in these measures of shell quality for the out-cross line. In previous analyses it was found that the hens with higher levels of carcass fat tended to produce eggs of higher porosity. The difference in porosity for breeds also tends to show this result, but even more it reflects the differences in the FCE and egg production (Table 46).

   (b) <u>Feed Level</u>

      (i) <u>Egg Shell Quality Performance</u> (Table 57)

As observed in the purebred analysis, feed restriction did not cause any significant decline in egg shell quality. These results confirm the observations of Gerry and Muir (1976), Al-Khazraji, *et al.* (1972), Kari (1977) and Muir and Gerry (1976). There was a significant difference in egg shell porosity between feed levels of 80 g.24h^{-1} and the 2 higher feed levels of 100 g.24h^{-1} and *ad libitum* (Table 57). Wells (1968) reports that the first egg of a clutch tends to have a lower porosity than other eggs in the same clutch.

In this present study, birds on the lower feed levels produced fewer eggs than the *ad libitum* fed hens, though the restricted hens probably had a larger number of clutches (usually 1 or 2 eggs per clutch) than *ad libitum* fed hens. This should lead to overall lower porosity in restricted feedings, knowing that the first egg of clutch tends to have a lower porosity than other eggs in the same clutch. The earlier speculation on higher water content of the eggs of *ad libitum* fed hens may explain why there is higher porosity in eggs of the *ad libitum* fed hen.

Table 55. Analysis of Variance for Breeds Egg Shell Quality Data

Source	df	Shell Weight	Shell Weight per Surface Area Egg	Shell Thickness	Egg Conformation	Porosity
		F value	F value	F value	F value	F value
Breed	2	4.51^{**}	2.76^{ns}	2.08^{ns}	0.03^{ns}	9.42^{***}
Feed Level	3	0.90^{ns}	0.28^{ns}	0.68^{ns}	1.66^{ns}	4.88^{**}
Breed by Feed Level	6	1.07^{ns}	1.56^{ns}	1.43^{ns}	0.54^{ns}	0.85^{ns}
Error df		91	91	91	91	91
Error Mean Square		0.132	14.865	352.334	0.003	0.183

* $p<0.05$ *** $p<0.001$

** $p<0.01$ ns   not significant

Table 56. The Mean Egg Shell Quality Data of Breeds

Breed	df	Shell Weight	Shell Weight per Surface Area Egg	Shell Thickness	Egg Conformation	Porosity
		(g)	$(mg.cm^{-2})$	(μm)		$(mg.cm^{-2}.24h^{-1})$
Purebred	41	5.69^{b}	81.5	368	1.35	4.6^{b}
Line-cross	39	5.64^{b}	80.4	360	1.35	4.2^{a}
Out-cross	23	5.42^{a}	79.0	358	1.34	4.0^{a}
LSD (p=0.02)		0.21	$^{+}$ns	ns	ns	0.3

[ab] Means differently superscripted in each column are significantly different ($p<0.02$).

Table 57. The Mean Egg Shell Quality from Breeds at Each Feed Level

Feed Level	Bird Number	Shell Weight	Shell Weight per Surface Area Egg	Shell Thickness	Egg Conformation	Porosity
		(g)	$(mg.cm^{-2})$	(μm)		$(mg.cm^{-2}.24h^{-1})$
80 g.24h^{-1}	30	5.58	80.0	361	1.36	4.1^a
90 g.24h^{-1}	26	5.53	80.5	362	1.33	4.2^{ab}
100 g.24h^{-1}	22	5.67	81.3	367	1.35	4.5^b
ad libitum	25	5.70	80.4	361	1.34	4.5^b
LSD (p=0.01)		$^+$ns	ns	ns	ns	0.3

^{ab} Means that are differently superscripted in each column are significantly different (p<0.01)

$^+$ns Not significant in analysis of variance (Table 55).

Table 58. Analysis of Variance for Breeds Body Weight Data

Source	df	Body Weight (Hatch)	Body Weight (6 weeks)	Body Weight (18 weeks)	Body Weight (42 weeks)	Body Weight (66 weeks)
		F value	F value	F value	F value	F value
Breed	2	4.02*	1.98^{ns}	0.78^{ns}	6.09**	5.96**
Feed Level	3	5.50**	0.96^{ns}	1.15^{ns}	34.20***	38.93
Breed by Feed Level	6	0.83^{ns}	1.25^{ns}	1.34^{ns}	1.48^{ns}	2.58*
Error df		92	92	92	92	92
Error Mean Square		15.350	2534.593	16114.978	29123.691	39212.031

*   p<0.05   *** p<0.001

Table 59.   The Mean Body Weight Data of Breeds

Breed	Bird Number	Body Weight (Hatch)	Body Weight (6 weeks)	Body Weight (18 weeks)	Body Weight (42 weeks)	Body Weight (66 weeks)
		(g)	(g)	(g)	(g)	(g)
Purebred	42	40.4^a	449	1541	1860^b	1884^{ab}
Line-cross	39	42.9^b	430	1518	1820^{ab}	1949^b
Out-cross	23	41.7^{ab}	457	1520	1710^a	1792^a
LSD (p=0.02)		2.2	$^+$ns	ns	97	112

^{ab} Means in the same column that are differently superscripted are significantly different (p<0.02).

$^+$ns Not significant in analysis of variance (Table 58).

5. <u>Analysis of Variance for Breeds Body Weight Data</u>

  (a)   <u>Breed</u>

     (i)   <u>Body Weight (Hatch, Table 59)</u>

The dams used to produce the different breeds comprised hens that were either on restricted or *ad libitum* feeding. The differences in hatching chicken weight between the purebred and out-cross breeds was probably due to the fact that out-cross matings occurred 2 weeks later than purebred matings and weight of fertile eggs incubated was probably slightly higher.

    (ii)   <u>Body Weight (6 weeks and 18 weeks, Table 59)</u>

There was no significant difference between breeds in 6-week and 18-week body weight. It is interesting to note that chickens of lower hatching weight were tending toward numerically higher 6-week and 18-week body weight, indicating superior growth rates of the lower hatching weight chickens.

   (iii)   <u>Body Weight (42 weeks and 66 weeks, Table 59)</u>

The out-cross breed had superior FCE compared to purebreds and this is reflected in lower body weight of the out-cross breed at 42 weeks. However, the differences at 42 weeks were not significant at 66 weeks but still numerically different.

Table 60.   The Mean Body Weight Data of Breeds for Each Feed Level

Feed Level	n	Body Weight (Hatch)	Body Weight (6 weeks)	Body Weight (18 weeks)	Body Weight (42 weeks)	Body Weight (66 weeks)
		(g)	(g)	(g)	(g)	(g)
80 g.24h^{-1}	30	40.0^a	442	1500	1645^a	1674^a
90 g.24h^{-1}	27	40.5^a	433	1507	1705^a	1805^{ab}
100 g.24h^{-1}	22	42.6^{ab}	451	1561	1852^b	1903^b
ad libitum	25	43.9^b	450	1555	2093^c	2222^c
LSD (p=0.01)		2.9	$^+$ns	ns	125	145.

^{abc} Means in the same column differently superscripted are significantly different (p<0.01).

$^+$ns Not significant in analysis of variance (Table 58).

Please note that specified feed levels in above table only applied to birds from 18 weeks to 66 weeks. *Ad libitum* feeding from 0-18 weeks.

(b) Feed Level

(i) Body Weight (Hatch, Table 60).

As stated previously the dams used to produce the different

breeds comprised hens that were either on restricted

feeding or *ad libitum* feeding. Chickens from these dams

were allocated to lower adult feeding levels if their

mother's FCE were high. This has probably resulted in the

observed differences of chicken hatching weight. The more

efficient individuals selected as dams were mainly hens

on restricted feed and were probably producing eggs of

lower weight.

(ii) Body Weight (6 weeks and 18 weeks, Table 60).

There were no significant differences between 6 and 18-

week body weight of chickens allocated different feeding

levels from 18 weeks of age. But the combined breed

hatching body weight and 18-week body weight masked the

observations made previously, on the relation between

breeds and growth rate. In fact there is a trend for

higher 6-week and 18-week body weight if hatching weight

is higher. This is opposite to trends seen in Table 59 and

indicates breed differences.

(iii) Body Weight (42 weeks and 66 weeks, Table 60).

The significantly lower body weights at 42 weeks and 66

weeks of age observed with feed restriction confirms the

observations of many restricted feeding experiments (Sykes,

1972). There was a breed by feed level interaction for

66-week body weight.

Table 61.   Breed by Feed Level for Body Weight (66 weeks)

Feed Level	Purebred	Line-cross	Out-cross	LSD (p=0.02)
	(g)	(g)	(g)	
80 g.24h^{-1}	1704(11)^a	(1694(11)^a	(1604(8)^a	210
90 g.24h^{-1}	1862(11)^a	1839(9)^a	1672(7)^a	222
100 g.24h^{-1}	1904(10)^b	1982(10)^b	1503(2)^a	251
ad libitum	2087(10)^a	2334(9)^b	2279(6)^{ab}	235

^{ab} Means that are differently superscripted in each row are significantly different (p<0.02).

Numbers of birds are indicated in brackets.

From Table 61 it can be seen that differences between breeds only become significant at the higher feeding levels. However, the differences between breeds at lower feed levels is numerically obvious. The most efficient breed (out-cross) showed the tendency for lower 66-week body weight at all feed levels except *ad libitum*.

6. Summary of the Functional Differences Between Breeds

(a)   Summary of the Functional Differences Between Breeds over the Production Period 18-66 weeks (Table 62, Figures 13 and 14)

There was a significant difference between breeds in FCE and egg production rate. The purebreds were inferior in FCE and egg production to the line-cross and out-cross hens. The improvement in performance of the line-cross and out-cross was considered to be due to heterotic vigour. The out-cross breed

which was the most efficient, had the highest water turnover, which paralleled its reduced body fat content and lower body weight. Shell weight of the out-cross line, however, was inferior to the other breeds, but this characteristic was not reflected in the other shell strength levels, which were different from the other breeds.

(b) Summary of the Functional Differences Between Hens Fed 80 g.24h^{-1}, 90 g.24h^{-1}, 100 g.24h^{-1} and *Ad Libitum* over the Production Period 18-66 weeks (Table 63, Figures 11 and 12).

Birds on feed levels of 80 g.24h^{-1} and 90 g.24h^{-1} showed lower FCE and egg production rates than birds on the higher feeding level. Egg weight, however, was not affected by the amount of feed. There was a trend toward increased metabolic rate with increasing feeding rate. TSR was, however, opposite to this trend. Water turnover was highest in birds on the lowest feed intake. Body fat content tended to increase with the feed consumed as did body weight. There was no difference in the strength of egg shells from hens on the different feeding levels, but there was a trend toward increasing shell porosity with increasing feed intake of hens.

Table 62. Summary of the Averaged Functional Differences Between Breeds over the Production Period 18-66 weeks

Variable	Units	Purebred	Line-cross	Out-cross	LSD (p=0.02)
Feed intake (18-66 weeks)	$g.24h^{-1}$	97.9	97.9	97.9	ns
FCE (18-66 weeks)	%	21.9	25.1	28.4	3.1
Egg number (18-66 weeks)		130.8	145.8	165.9	17.7
Average egg weight (18-66 weeks)	g	55.7	57.3	56.0	1.8
Metabolic rate	$KJ.W^{-0.75}.24h^{-1}$	327.0	306.0	302.0	13.0
Water turnover	$ml.kg^{-1}.24h^{-1}$	129.6	138.1	160.3	15.3
TBW% body weight	%	62.8	61.1	63.4	2.1
Thyroxine secretion rate	$\mu g\ T_4.100\ g^{-1}.24h^{-1}$	0.451	0.336	0.326	0.074
Plasma thyroxine	$\mu g\ T_4\ dl^{-1}$	1.198	1.009	1.133	0.120
Shell weight	g	5.69	5.64	5.42	0.21
Shell weight per S A egg	$mg.cm^{-2}$	81.5	80.4	79.0	ns
Shell thickness	μm	368.0	360.0	358.0	ns
Egg conformation		1.35	1.35	1.34	ns
Porosity	$mg.cm^{-2}.24h^{-1}$	4.6	4.2	4.0	0.3
Body weight (18 weeks)	g	1541	1518	1520	ns
Body weight (42 weeks)	g	1860	1820	1710	97
Body weight (66 weeks)	g	1884	1949	1792	112
Bird number		42	39	23	

ns   Not significant

Values given average the performance of each breed over all feed levels (80 $g.24h^{-1}$, 90 $g.24h^{-1}$, 100 $g.24h^{-1}$ and *ad libitum*).

Table 63. Summary of the Averaged Functional Differences Between Birds Fed 80 g.24h^{-1}, 90 g.24h^{-1}, 100 g.24h^{-1} and *Ad libitum* over the Production Period 18-66 weeks

Variable	Units	Feed Level				LSD (p=0.01)
		80 g.24h^{-1}	90 g.24h^{-1}	100 g.24h^{-1}	*Ad libitum*	
Feed Intake (18-66 weeks)	g.24h^{-1}	80.0	90.0	100.0	128.0	3.8
FCE (18-66 weeks)	%	19.2	23.4	28.3	28.6	4.0
Egg number (18-66 weeks)		93.8	121.1	167.8	209.0	22.8
Average egg weight (18-66 weeks)	g	55.6	55.6	57.0	57.6	ns
Metabolic rate	KJ.W$^{-0.75}$.24h^{-1}	308.0	314.0	314.0	320.0	ns
Water Turnover	ml.kg^{-1}.24h^{-1}	150.9	139.9	125.2	138.4	19.7
TBW% body weight	%	63.0	64.2	62.1	59.7	2.7
Thyroxine secretion rate	μg T$_4$.100 g^{-1}.24h^{-1}	0.422	0.362	0.331	0.395	ns
Plasma thyroxine	μg T$_4$ dl^{-1}	1.362	1.003	1.028	1.006	0.156
Shell weight	g	5.58	5.53	5.67	5.70	ns
Shell weight per S A egg	mg.cm^{-2}	80.0	80.5	81.3	80.4	ns
Shell thickness	μm	361.0	362.0	367.0	361.0	ns
Egg conformation		1.36	1.33	1.35	1.34	ns
Porosity	mg.cm^{-2}.24h^{-1}	4.1	4.2	4.5	4.5	0.3
Body weight (18 weeks)	g	1500	1507	1561	1555	ns
Body weight (42 weeks)	g	1645	1705	1852	2093	125
Body weight (66 weeks)	g	1674	1805	1903	2222	145
Bird number		25	22	30	27	

ns   Not significant

Values given average the performance of the purebred, line-cross and out-cross hens for the respective feed levels.

Figure 11.

Histograms of the Production and Shell Quality
Differences between Hens Fed $80.24h^{-1}$, $90g.24h^{-1}$,
$100g.24h^{-1}$ and *Ad Libitum* over the Production
Period 18-66 Weeks.

PRODUCTION

SHELL QUALITY
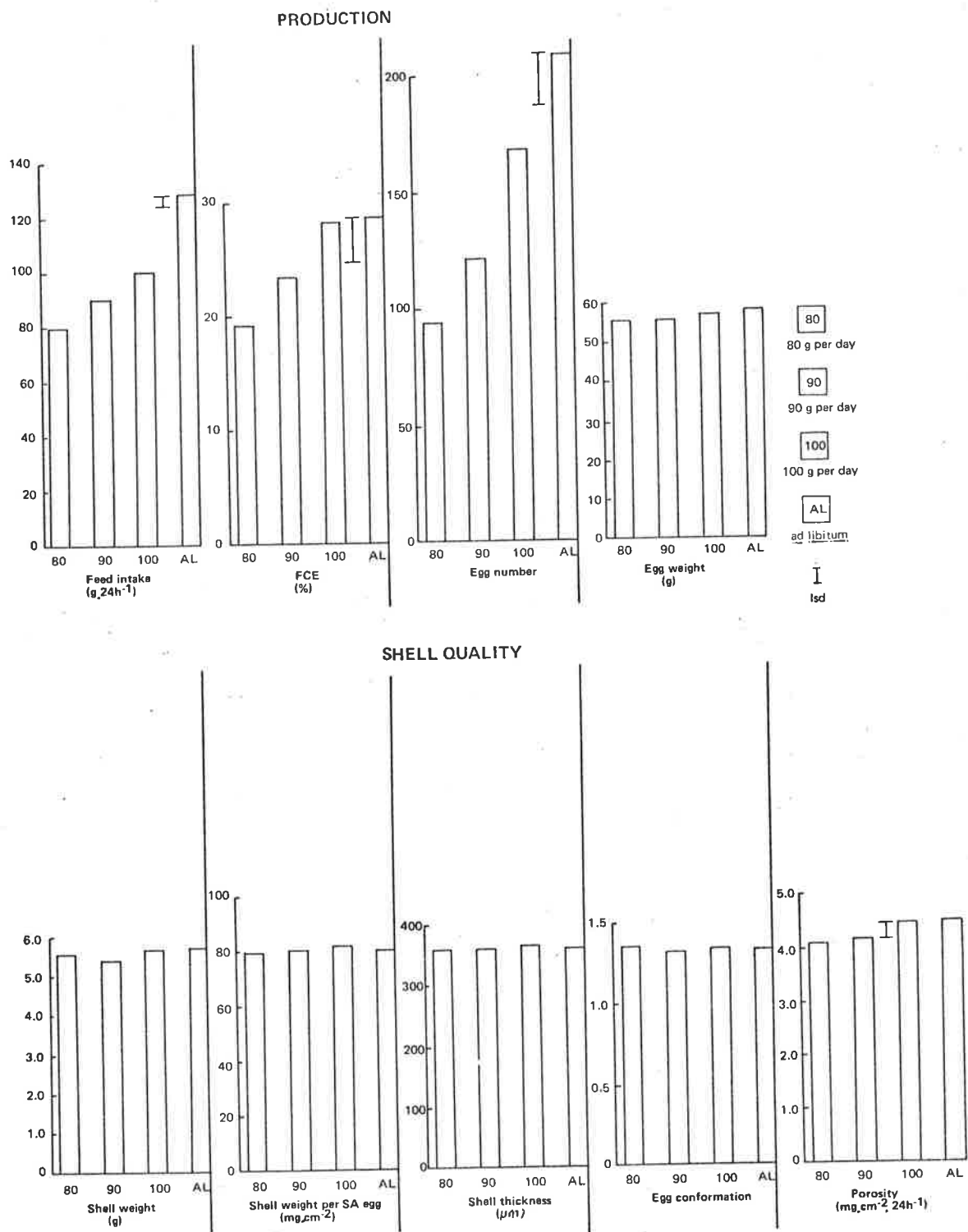
Least significant difference (lsd) is indicated where $p < 0.01$

Figure 12.

Histograms of the Physiological and Body Weight
Differences between Hens Fed $80.g24h^{-1}$, $90g.24h^{-1}$,
$100g.24h^{-1}$ and *Ad Libitum* over the Production
Period 18-66 Weeks

PHYSIOLOGICAL

Metabolic rate
$(KJ.W^{-0.75}.24h^{-1})$

Water turnover
$(ml.kg^{-1}.24h^{-1})$

TBW % body weight
(%)

TSR
$(\mu g\ T_4\ 100\ g^{-1}.24h^{-1})$

Plasma thyroxine
$(\mu g\ T_4\ dl^{-1})$

BODY WEIGHT

Body weight
18 weeks (kg)

Body weight
42 weeks (kg)

Body weight
66 weeks (kg)

80 — 80 g per day
90 — 90 g per day
100 — 100 g per day
AL — ad libitum
I — lsd
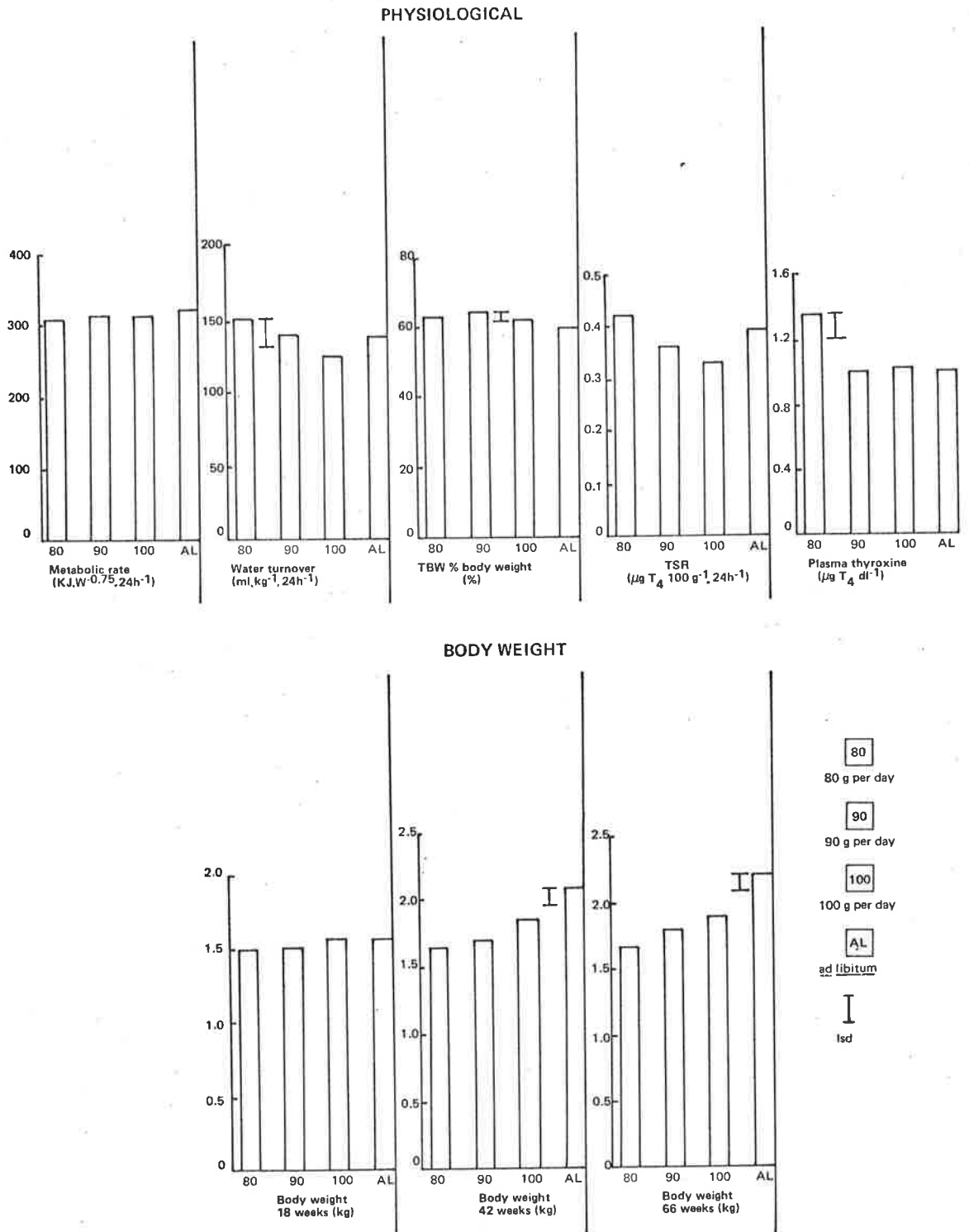
Least significant difference (lsd) is indicated where $p < 0.01$

Figure 13.
Histograms of the Production and Shell Quality
Differences between Breeds over the Production
Period 18-66 Weeks
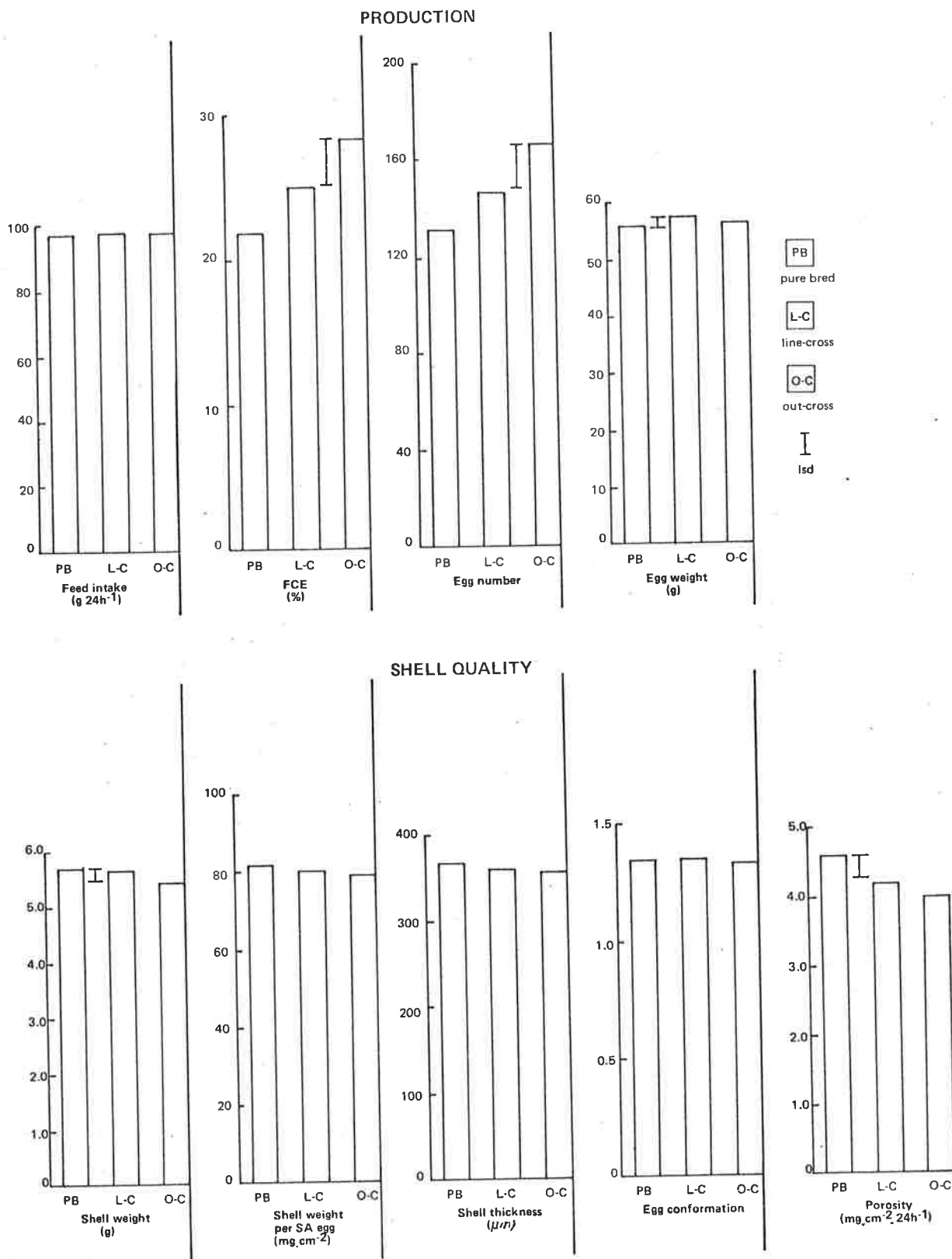
Least significant difference (lsd) is indicated where p < 0.02

The values given in these histograms average the performance of
each breed over all feed levels (80g.24h^{-1}, 90g.24h^{-1}, 100g.24h^{-1}
and *ad libitum*).

Figure 14.

Histograms of the Physiological and Body Weight
Differences between Breeds over the Production
Period 18-66 Weeks.

PHYSIOLOGICAL

Metabolic rate
(KJ.W$^{-0.75}$ 24h^{-1})

Water turnover
(ml.kg^{-1} 24h^{-1})

TBW %
body weight
(%)

TSR
(μg T$_4$ 100 g^{-1} 24h^{-1})

Plasma thyroxine
(μg T$_4$ dl^{-1})

BODY WEIGHT

Body weight
18 weeks (kg)

Body weight
42 weeks (kg)

Body weight
66 weeks (kg)

PB — pure bred

L-C — line-cross

O-C — out-cross

lsd
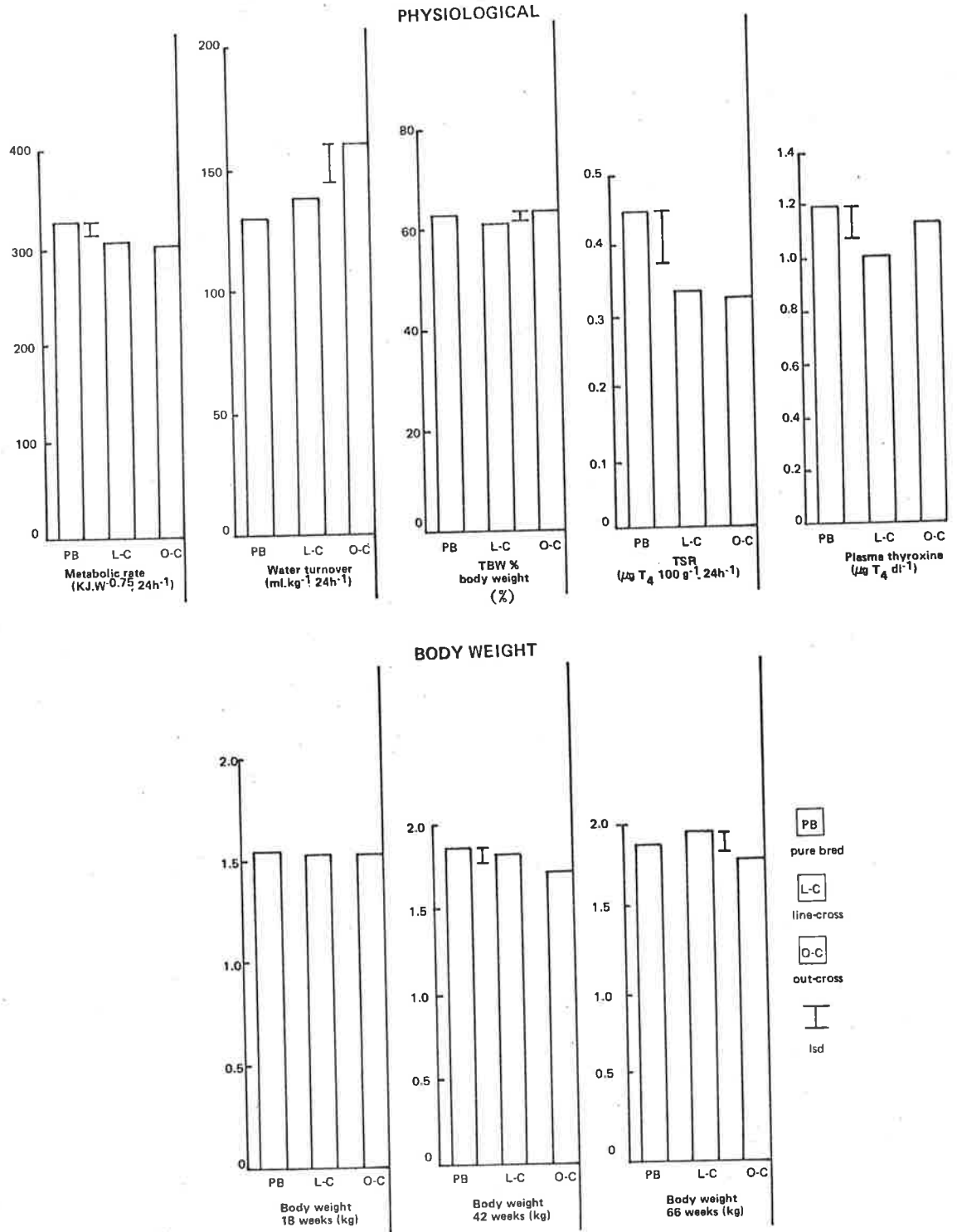
Least significant difference (lsd) is indicated where p < 0.02

The values given in these histograms average the performance of
each breed over all feed levels (80g.24h^{-1}, 90g.24h^{-1}, 100g.24h^{-1}
and *ad libitum*).

D. GENERAL CONCLUSIONS

Because of the rising costs of poultry food the search for birds that could produce satisfactory numbers and qualities of eggs on less food, was undertaken. Some of these birds were found and an analysis of physiological contributions to their efficiency was made, while studying several generations of hens selected for efficiency on low feed intake. A 33% reduction of intake below the *ad libitum* level was made so that a strong selective pressure was applied.

This project then, has examined two aspects of functional efficiencies in laying hens. The first was an investigation of the relationship between FCE and physiological variables in hens fed *ad libitum* or on restricted amounts of food. This was examined in 2 experiments, one on the relationship between FCE and physiological variables in 4 generations and 4 family lines of a White Leghorn breed, and the other on the relationship between FCE and physiological variables during restricted feeding in 3 White Leghorn breed lines (i.e. family line, family line-cross and out-cross).

Since there have been few studies (Booker and Sturkie, 1950; Ota and McNally, 1961; Chapman and Black, 1967; Chapman and Mihai, 1972; Grandhi and Brown, 1975; Morrison and Leeson, 1978; and Brake, Thaxton and Benton, 1979) of hens on *ad libitum* and restricted feeding relating FCE to water turnover, MR and thyroid function, the effect of food restriction on carcass fat, water turnover, plasma T_4, TSR and body weight was examined. Multiple linear regression analysis brought out the fact that efficient restricted hens had lower levels of plasma T_4 and lower body weight than inefficient hens on restricted intake.

The water turnover rates of efficient hens fed *ad libitum* were higher than among the inefficient birds. In hens fed *ad libitum*

plasma thyroxine did not reach a statistically significant relationship with FCE as observed in the restricted hens, where the level of circulating plasma T_4 is probably important in metabolising the limited food. The lower plasma T_4 values of the efficient restricted hens compared to inefficient birds could represent one of the following possible mechanisms:

1. A decreased output by efficient birds of T_4 from the thyroid gland. Brake and Thaxton (1979) have observed that an increase in plasma T_4 was coincident with a loss of weight and presumably reduced function of the ovaries. This could be due to slower inactivation of T_4.

2. There may be lower plasma T_4 values among efficient restricted birds, because greater amounts of T_4 are converted to T_3 by peripheral monodeiodination. Hence efficient restricted hens may have an increased extrathyroidal pool of T_3 compared to inefficient birds. Oppenheimer *et al.* (1972) and Ingbar and Braverman (1975) have suggested that T_4 is a pro-hormone, and only T_3 has intrinsic hormonal activity (though this concept is not well supported). If efficient restricted hens have higher levels of T_3, this could then account for the increased egg production rates of the efficient birds. Grandhi and Brown (1975) have speculated that T_3 has the direct role of mobilizing nutrients for egg production. They observed that growing chickens have a higher $T_4:T_3$ ratio than laying hens. The plasma level of T_4 relative to T_3 may control the priorities of metabolic activities associated with growth, maintenance and egg production. Assuming that there is a nearly constant iodohormone synthesis in all hens, adult birds with higher plasma T_4 (and hence greater $T_4:T_3$ ratio) may be more primed for growth processes. Such birds may continue to grow and lay

down fat at the expense of egg production. This is reflected in their higher body weight and lower FCE. In the hens fed *ad libitum* thyroxine probably assumes a minor role in determining efficiency.

The efficient hens in these experiments were those turning over more water, which carries nutrients and energy for egg production. But Chapman and Black (1967) indicated that water turnover in the hen was not correlated with egg production. Further work is required to find how water turnover is associated with some hens being more efficient in egg production than others. It could be that like the pig, they drink more when food is in short supply.

Regression analysis failed to find a significant correlation between FCE and MR, as in the work of Ota and McNally (1961). But in a different analysis where birds were classified according to their FCE ratings (using an approach similar to that used by Morrison and Leeson (1978)) it was found that restricted birds with high FCE had lower MR than birds with low FCE on restricted feeding. This result is similar to the findings of Morrison and Leeson (1978).

Furthermore my studies indicated (using FCE rating analysis) that food-restricted birds with high FCE, also had lower TSR, plasma T_4 and body fat, but higher water turnover than birds with low FCE on restricted feeding. *Ad libitum* fed birds of high efficiency had lower plasma T_4, but higher water turnover than birds with low FCE. This small proportion of the hens studied offers potential for genetic improvement of FCE. The regression analysis also indicates that hens on restricted feeding exhibit a greater range of functional efficiencies since the differences observed between the lines on restricted feed are not apparent among lines of birds fed *ad libitum*. These findings indicate that there is potential for genetic studies in a wide range of metabolic characteristics of birds exposed to

stress situations such as restricted feeding. The regression
equations also show that both plasma T_4 (for restricted birds) and
water turnover (for *ad libitum* fed birds) could be used as
selection variables early in the laying life of the hens.

For the birds fed *ad libitum* or restricted there was a
significant decline in average FCE from generation 1 to 4. This was
despite selection of birds of high FCE for breeding from each
generation. The decline in FCE observed was probably due to the
effects of inbreeding. Selection of highly efficient hens from a
large population of birds (e.g. 1000 hens) could have resulted in a
smaller decline in efficiency of hens from generation 1 to 4. The
level of food restriction imposed, however was too severe and would
not have commercial advantage at this stage, but this restriction
showed that inefficient hens tended to lay down fat and produce fewer
eggs. The second experiment extended earlier observations made during
this project on family lines, that there were relationships between
FCE and selected physiological parameters. FCE, MR, water turnover,
carcass fat, plasma T_4, TSR and body weight were measured in 3
breed lines of White Leghorn hens (family line, family line-cross and
out-cross) offered feed at 4 levels (80g. $24h^{-1}$, 90g.$24h^{-1}$,
100g.$24h^{-1}$ and *ad libitum*.

The FCE differed significantly between lines. The family line
was inferior in FCE to the family line-cross and the out-cross.
Auckland and Fulton (1973) and Auckland and Wilson (1975) have also
observed strain differences in FCE performance with restricted
feeding. But no workers have attempted to interrelate the
performance of various breed lines of hens with physiological
measurements such as MR, water turnover and thyroid function which
should be involved in food use. In this study the hens bred by

family line had the lowest FCE and were found to show higher MR, TSR and plasma T4 than the other lines. The outcross birds which were the most efficient, had the highest water turnover, associated with a lower body fat content and lower body weight. In the previous experiment it was found that with restricted feeding, high body weight and high T_4 are manifest in birds of poor efficiency. In this later experiment the family line had the highest body weight, TSR and plasma T_4. They were also the least efficient hens, confirming the results of the first experiment. The initial experiment showed that high water turnover was important in determining high FCE in birds fed *ad libitum*. In the second experiment the out-cross line (which was the most efficient breed line on *ad libitum* feeding), also had a significantly higher water turnover than the 2 other breed lines. Because of interaction, however, of level of food intake with water turnover the turnover measurements *per se* cannot be used to assess FCE between lines. This could be due to different physiological settings of energy and water metabolism among lines, for *ad libitum* and restricted feeding conditions. Differences between breed lines of hens in FCE and egg production rate can in part, be accounted for physiologically, an example being the least efficient breed line which had an elevated TSR and plasma T_4, but lower water turnover than the most efficient line. There clearly are, thus, lean hens with low MR and plasma T_4, which turn over large amounts of water, and whose eggs are produced with greater energetic efficiency than the average. The greatest efficiency of food conversion was obtained by out-crossing. Crossing between lines, strains or breeds of hen selected on the basis of physiological measurements early in laying life could increase FCE. It remains to be determined whether these

physiological characteristics measured during the growing period would allow more rapid improvement of the efficiency of hens.

The second aspect of this project was an investigation of the consequences to egg shell quality of restricted feeding in the laying hen and the relationship of FCE to the egg shell quality.

The studies of egg shell quality were made because little was known of the relationship between the food conversion of the hen and egg shell quality at variable levels of calcium intake (Foster and Neil, 1972; and Agriculture Research Council, 1975) and at fixed levels (Al-Khazraji, Al-Fayadh and Shirley, 1972; Gerry and Muir, 1976; Muir and Gerry, 1976; and Kari, Quisenberry and Bradley, 1977). There has been deterioration of egg shell quality in the egg industry and with the rising cost of egg production it has become more vital to maintain adequate shell quality. Shell quality was assessed in terms of shell weight, shell weight per unit surface area of egg, shell thickness, egg shape and egg shell porosity, among the 4 family lines and 4 generations of the White Leghorn breed of laying hen in both an *ad libitum* regime and in birds restricted to $80g.24h^{-1}$, used in the first experiment.

Significant differences in shell weight and egg shape were observed among the various lines, but there was no difference between lines in other measurements of shell strength. Shell thickness was significantly correlated with body weight ($r=0.257**$) and egg weight ($r=0.225*$). This contrasts with the findings of Foster and Neil (1972) who reported that variations in body weight and egg weight had inconsistent effects upon shell thickness. This difference might be due to birds in my study being a more homogeneous population (due to inbreeding) than those birds used by Foster and Neil (1972). Cipera and Grunder (1976) showed that birds which

produced thicker shells had lower body weights, in contrast to the findings of my study. Egg shell porosity correlated positively with all production variables (FCE, r=0.257**, food intake, r=0.314***, egg number r=0.30***). The rate of water movement through the egg shell could be linked with the rate of water turnover in the hen, which was found to be related to efficiency in the previous study. Permeability of the integument to water is a function of rate of water turnover (Haines *et al.* 1974).

Birds restricted in feed intake consumed an average of 3 g calcium per day, and the ARC (1975) concluded that the calcium requirement for maximum egg output was 3.0 g.24h^{-1}. However, the shell weight of eggs of birds on 80g of feed daily was significantly lower than for eggs from birds fed *ad libitum* Kari, Quisenberry and Bradley (1977) observed no significant changes in shell weight of eggs with 12% feed restriction, but in my study feed restriction was approximately 33%. It is possible that the calcium intake of these birds was not adequate to meet the requirements for satisfactory shell formation. There were, however, no significant differences in shell weight per surface area of egg or shell thickness, between the 2 feed levels. Similarly, Al-Khazraji, Al-Fayadh and Shirley (1972) and Gerry and Muir (1976) did not observe any significant decline in shell quality with 15% feed restriction.

The first generation of hens produced thinner shells and eggs with less shell weight per unit surface area, but higher egg shape index, than all other generations. This generation of hens was also the most efficient.

The efficient food restricted birds had a superior egg production rate, but the average egg weight was about 4 g less than from inefficient birds. The lower egg weight of efficient hens was

paralleled by their lower shell weight. This appeared to affect other shell strength parameters such as shell thickness and shell weight per unit surface area of egg, which were also reduced compared to inefficient hens. The metabolic cost to hens of producing egg shell is high. Efficient birds appear to use limited food resources to maintain egg numbers, rather than shell or egg weight.

The *ad libitum* feed intake of efficient and inefficient birds was similar but, unlike the response to restricted feeding, egg production rate and egg weight were greater in the efficient hens, so they sustained a high rate of conversion of food to eggs.

Shell weights of inefficient hens fed *ad libitum* was lower than those from efficient birds, but there was no difference between the 2 efficiency groups in other shell strength characters. Egg shell porosity, however, was still elevated in the efficient hens, with high water turnover. These studies indicate that changes in shell quality reflect differences in levels of bird efficiency. Selection of birds which achieve high levels of efficiency as well as good shell quality on restricted feed, offers an opportunity to improve profitability by reducing shell breakage.

These studies have indicated that individual birds differ in the effective use of energy, egg production and shell quality. Those birds which are highly efficient and have adequate shell quality on low feeding regimes have considerable potential for selection and breeding. Further hormone turnover studies in relation to use of energy and fat deposition could lead to a better understanding of efficiency in laying hens.

APPENDICES

A. ANALYTICAL METHODS

1. Determination of Crude Protein

    (a) Equipment

        Digestion flasks (100 ml)

        Digestion rack with electric heaters

        Markham still

        Ehrlenmeyer flasks (100 ml)

    (b) Reagents

        - Catalyst mixture - Selenium Kjeldahl catalyst tablet (each tablet containing 1 g of $Na_2 SO_4$ and 0.05 g of Se).

        - Concentrated sulphuric acid

        - 40% Sodium hydroxide solution

        - 1 % Boric acid (indicator solution)

        Prepared by dissolving 10 g H_3BO_3 (Boric acid) in approximately 500 ml distilled water and 0.016 g methyl red and 0.008 g bromocresol green dissolved in 200 ml ethanol. These two solutions were mixed and made up to nearly 1 l with distilled water. The pH of the solution was adjusted with 0.1 N NaOH solution until the solution was brownish red and then made up to volume.

        - 0.01 N Potassium bi-iodate solution.

    (c) Method

        (i) 0.5 g of feed sample was weighed accurately and transferred to a 100 ml digestion flask.

        (ii) To this was added a catalyst tablet and 5 ml of concentrated

H_2SO_4. The solution was heated until clear and then heated for a further 20 min.

(iii)   The digestion flask and contents was allowed to cool to room temperature and then made to volume (100 ml) with distilled water, and shaken vigorously.

(iv)   5 ml of the digest was pipetted into the Markham still and 5 ml of 40% NaOH added. When the solution in the still was boiling, distillation was allowed to proceed for 2.5 min with the tip of the condenser immersed in 5 ml of boric acid solution (indicator). Distillation proceeded for a further 0.5 min with the collection flasks lowered to wash the tip of the condenser.

(v)   This distillate was titrated with 0.01 N KH $(IO_3)_2$ colour change being from green to pink.

2.   Determination of Amino-Acids

(a)   Equipment

Beckman amino-acid analyzer

Digestion flasks (1 1, 250 ml)

Reflux condenser

Rotary evaporator

Cylinder of nitrogen gas

Heating mantle

Whatman filter paper (no. 54)

Round bottom flask (250 ml)

(b)   Reagents

-6N Hydrochloric acid

-10% Sodium citrate in propanol (pH 2.5)

- 30% H_2O_2

- 90% Formic acid

(c) <u>Method</u>

(i) 0.5 g of powdered feed sample was weighed and transferred to a 500 ml conical flask. This was placed in an ice bath and cooled to 0°C.

(ii) 10 ml of performic acid (5 ml of 30% H_2O_2 was added to 45 ml of 90% formic acid and the mixture allowed to stand at room temperature for 1 h to allow the formation of performic acid) cooled to 0°C, was added to the feed in the flask and oxidation allowed to proceed for 16 h at 0°C.

(iii) Removal of the performic acid was achieved by first adding 20 ml of ice cold water and freeze drying.

(iv) The freeze dried residue from the oxidation reaction was washed into a 1 l round bottom flask and 600 ml of 6N HCL added.

(v) This solution was refluxed for 20 h on a heating mantle at 110°C. After cooling, the solution was filtered through a No. 54 Whatman filter paper under vacuum and diluted to 1 l with distilled water.

(vi) 45 ml (25 mg protein) of this solution was transferred to a 250 ml round bottom flask and evaporated to dryness using a rotary evaporator. The residue was washed twice with 10 ml of distilled water, each time being evaporated to dryness using the rotary evaporator.

(vii) The amino-acid residue was taken up as a solution in 10% sodium citrate buffer containing 10 µg protein ml^{-1} and pH adjusted to 2.5.

(viii) 10 µl of the amino-acid buffer mixture was injected down
the column of the Beckman amino-acid analyzer and
concentration of eluted amino-acids graphed in order of
elution. Sample amino-acids were referred to standard
amino-acids.

3. Determination of Gross Energy and Metabolizable Energy of Feed

(a) Method

   (i) Representative samples of both the feed and excreta were
ground to a powder.

   (ii) The bomb calorimeter was calibrated using a standard
sample of benzoic acid (99.7% purity) with a known calorific
value. Benzoic Acid (0.5 g) was weighed into a crucible
and compacted.

   (iii) The crucible was placed on the support pillar in the base
of the bomb. A standard length of sewing cotton was inserted
between the coils of the firing wire. The other end of the
cotton was rested onto the test sample. The bomb was lowered
onto the locking ring which was turned until it clamped the
bomb body to the base. The thermocouple was then plugged
into the top of the bomb body.

   (iv) The valve of the oxygen cylinder was opened and the valve
on the panel of the control box turned allowing the oxygen
pressure within the bomb assembly to rise to about 30
atmospheres.

   (v) By means of the 'Galvo Zero' knob on the control panel, the
light spot index of the galvanometer was brought to zero and
allowed to stabilize.

(vi) The firing button was then pressed. Immediately after the deflection had been recorded, the gas was released through the pressure release valve at the base of the bomb.

(vii) Both feed and excreta samples were treated in the same manner as benzoic acid, each sample repeated until a constant deflection on the galvanometer was recorded. A blank run was made with cotton and crucible only.

(viii) The GE of the feed and faeces was then calculated.

(viiii) The ME of the diet was then determined (without correction for Nitrogen retention). ME $(KJ.kg^{-1})$ = GE feed consumed − GE excreta collected.

4. <u>Determination of Plasma Thyroxine</u>

(a) <u>Equipment</u>

Reaction tubes (3 ml plastic vials)

Plastic centrifuge tubes, 10 ml

Vortex mixer (Townson & Mercer)

Water bath, thermoregulated to $45^{\circ}C \pm 1^{\circ}C$

Multiple air flow device (This apparatus permitted controlled flow of air into the reaction tubes contained in a test tube rack in the water bath. This increased rate of evaporation of alcohol from reaction tubes (Murphy and Jachan, 1965).

"Autospenser "

Resin dispenser (allocating 0.5 ml quantities of resin simultaneously into the reaction tubes).

Automatic Quickfit dispensers (1 ml amd 3 ml)

Counting tubes (the solution to be counted was placed in a

small 3 ml plastic vial, capped and these placed inside
plastic counting tubes 1.2 x 7.0 cm).

Gamma counter (Packard)

(b) Reagents

- Radioactive ^{125}I-L-thyroxine

- Stable thyroxine: sodium pentahydrate-l-thyroxine (Sigma)

- Ethyl Alcohol 95%

- Anion exchange resin, Dowex 2

- Barbital buffer, 0.075 M, pH 8.6 (stored in refrigerator at 4°C)

- Propylene glycol

- Phenol

- Human plasma

- Stock Standard, 1 mg.ml^{-1} 25 mg L-thyroxine and 2.5 ml
propylene glycol was added to a 25 ml volumetric flask. It
was dissolved by adding 0.1 N NaOH in 2 ml aliquots with
swirling until a clear solution was observed. This was then
made up to volume with distilled water. Stored in a freezer,
this solution lasts 6 months.

- Dilute Standard A, 10 μg ml^{-1} 0.5 ml 0.5 N NaOH. One ml
propylene glycol and 1 ml stock standard solution was added
to a 100 ml volumetric flask. This was diluted to volume with
distilled water, mixed and stored at 4°C in a refrigerator.
This solution was prepared fresh with each total T$_4$ determination.

- Dilute Working Standard B, 0.1 μg ml^{-1}. Into a 100 ml
volumetric flask was added 0.2 ml 0.5 N NaOH and 1 ml dilute
Standard A, diluted to volume with 95% ethanol. This solution

was prepared fresh with each total T_4 determination.

- TBG-^{125}I-T_4 Reagent. Pooled human serum 15.0 ml which contained TBG, 1% (w/v) phenol (5 ml) and 5 ml propylene glycol was added to a 500 ml volumetric flask. This was diluted with 0.075 M barbital buffer and 25 µCi of ^{125}I-T_4 (0.25 ml) was added. After mixing buffer was made to volume.

(c) Method

(i) 0.6 ml of 95% ethanol was added to 0.3 ml of each plasma sample in a centrifuge tube, capped and mixed immediately on the vortex for 10 seconds. The sample was then centrifuged at 2,000 rpm for 10 min.

(ii) Duplicate samples (0.3 ml) of the supernatant were transferred to reaction tubes and evaporated to dryness in a water bath at 45°C with a gentle stream of air. Standard samples of 0.0, 0.01, 0.03 and 0.05 ml of dilute working standard B were pipetted in duplicate into reaction tubes and evaporated to dryness.

(iii) One ml of TBG-^{125}I-T_4 reagent was added to each dried tube (automatic Quickfit dispenser). The rack of tubes was shaken mechanically for 2 min. The samples were then heated at 45°C in a water bath for 8 min, removed and shaken mechanically for 2 min.

(iv) The rack in an ice bath was then placed in the refrigerator for 45 min. The rack was then removed from the refrigerator, and the resin added to all reaction tubes. All reaction tubes in the rack were shaken mechanically for exactly 1 min , replaced in the ice-water bath, and 3 ml

(automatic Quickfit dispenser) cold buffer (4°C) added. The reaction tubes were capped and shaken manually by inverting rack of tubes 6 times. The resin settled rapidly and 1.5 ml aliquots of the clear supernatant were pipetted directly ("Autospenser") into the glass counting vials. These were capped and placed in the counting tubes.

(d) Determination of Recovery

The main source of error in the total thyroxine method is the incomplete extraction of thyroxine in ethanol. Thus the recovery of thyroxine from ethanol extraction was determined.

One ml of a solution of radioactive thyroxine in 95% ethanol (approximately 20,000 cpm.ml^{-1}) was added to each of 20 counting tubes and evaporated to dryness. One ml of pooled hen plasma was added to each tube and mixed gently. This solution was incubated for 8 min at 45°C, shaken again and counted to 20,000 counts.

Two ml of 95% ethanol was added to each tube and mixed on the Vortex.

The tubes were then centrifuged at 2,000 rpm for 10 min. One ml of the supernatant was transferred to a second counting tube and counted to 20,000 counts.

$$\% \text{ Recovery} = \frac{\text{cpm supernatant X 3}}{\text{cpm added}} \text{ X } 100$$

The % recovery of the ^{125}I-T$_4$ from an ethanolic extraction was 77.26% with a S E of 0.37%.

(e) Control Data

A pooled plasma sample stored frozen was assayed with each total thyroxine estimation.

A mean value of $1.34\mu g.dl^{-1}$ (S E = $0.14\mu g.dl^{-1}$) was obtained for 20 separate determinations.

(f) Calculations of Unknown Samples

The standard solutions of 0.0, 0.01, 0.03 and 0.05 ml corresponded to thyroxine values of 0, 1, 3, and 5 $\mu g.dl^{-1}$ respectively, under the conditions of the method. The mean time for 20,000 counts was plotted against thyroxine $(\mu g.dl^{-1})$. The regression equation for the data was determined and the mean time for each sample using the regression equation gave the thyroxine concentration in $\mu g.dl^{-1}$. The concentration obtained was corrected for the recovery of thyroxine from plasma.

5. Determination of Thyroxine Secretion Rate

(a) Labelled Thyroxine Solution for Injection

The $^{125}I-T_4$ solution for injection was made up as follows:- 0.5 ml of 200 $\mu Ci.ml^{-1}$ of $^{125}I-T_4$ was added to a bottle containing 14.5 ml sterile saline. Five ml of hen plasma was added to this mixture together with 2 mg of penicillin. This gave a resulting $^{125}I-T_4$ solution with a concentration of approximately 5 $\mu Ci.ml^{-1}$.

(b) TSR Determination

After weighing birds, 1 ml of 5 $\mu Ci.ml^{-1}$ of $^{125}I-T_4$ was injected intramuscularly into each bird. In order to determine the time for equilibration of $^{125}I-T_4$ with the thyroxine distribution

space and before significant recirculation of ^{125}I-T$_4$

occurred, blood samples were drawn from the brachial vein at

1 h, 2 h, 3 h, 4 h, 5 h, 6 h, 9 h, 12 h, 14 h, 20 h, 24 h and 27 h.

Log PB^{125}I concentration (counts per 600 sec per 0.2 ml) was

plotted against time (h). It was observed that an exponential

decline of PB^{125}I counts occurred from 4 h to 12 h, after

which a change in slope occurred.

For routine TSR determinations samples were drawn at
4 h, 7 h and 10 h after injection of ^{125}I-T$_4$. The radioactivity
was measured in an aliquot (0.2 ml) of plasma. The aliquot of
hen plasma was made up to 1.0 ml with addition of 0.8 ml of
sheep plasma containing TBG. This ensured that 99.9% of the
^{125}I-T$_4$ in the hen plasma was protein bound.

(i) Determination of Labelled Thyroxine Recovery in Bird Plasma
     added to Sheep Plasma Following Precipitation

A source of error in the method of determination of
TSR in birds is due to labelled thyroxine in plasma not
being completely bound to the protein component. This
was overcome by adding sheep plasma contining TBG to the
hen plasma, ensuring all the ^{125}I-T$_4$ in the plasma was
protein bound.

To test the compatability of the hen plasma with the
sheep plasma with respect to binding of thyroxine,
duplicate samples of 0.1, 0.2, 0.3 and 0.4 ml of ^{125}I-T$_4$
labelled hen plasma (20,000 cpm .ml^{-1}) was made up to
1 ml volume with sheep plasma in counting tubes. 1.0 ml

hen plasma was used as a comparison.

This mixture was then incubated for 30 min at $37^{o}C$ and counted. The protein component of the plasma mixture was precipitated using Smogyis reagent. The protein precipitate was washed 3 times using distilled water, and then counted (Packard Gamma Counter).

$$\% \text{ Recovery} = \frac{\text{counts plasma}}{\text{counts precipitate}} \text{ X } 100$$

The percentage recovery of bird and sheep plasma following precipitation was 99.6% with S E of 0.2%. Percentage recovery of hen plasma alone was 99.1%.

(ii) Precipitation of Labelled Protein Bound Iodine

To 0.2 ml of hen plasma in a 16 mm x 125 mm pyrex counting tube was added 0.8 ml of sheep plasma. This was incubated at $37^{o}C$ for 20 min. To the counting tube was added 7 ml of distilled water followed by 1 ml of 10% (w/v) $ZnSO_4.7H_2O$ and 1 ml of 0.5 N NaOH, the contents of the tube being thoroughly stirred after each addition. The protein precipitate was allowed to stand for 1 h, and then separated by centrifuging at 2,000 rpm for 10 min. The supernatant was decanted and the precipitate washed 3 times by resuspending it in successive 10 ml portions of water, stirring with a glass rod, centrifuging and discarding the washings.

The protein precipitate was then counted in a Gamma counter for 600 sec. Each sample was referred to

a standard sample count of 5 m μCi.ml^{-1} of the injected ^{125}I-T$_4$ solution.

The log of the count rate (counts per 600 sec) of the samples was regressed against time and the equation extrapolated to zero time (T$_0$) to obtain an estimate of the count rate at the time of injection. The biological half-life (t$_{\frac{1}{2}}$) of the ^{125}I-T$_4$ in the circulation was estimated from the regression equation and the rate constant for loss (K, % day) was calculated as

$$\text{as } K = \frac{0.693}{t_{\frac{1}{2}}}$$

The distribution volume (DV) of the hormone was then calculated.

$$DV \text{ (ml)} = \frac{\text{Standard count x counts injected x volume of plasma used}}{\text{Counts at } T_0}$$

Plasma thyroxine concentration was determined on samples by the competitive protein-binding assay of Murphy and Jachan (1965).

The daily secretion of thyroxine was then calculated.

T$_4$ pool (μg T$_4$) = DV x plasma thyroxine concentration

From the half-time, the thyroxine pool turnover in one day was calculated (i.e. μg T$_4$/day).

TSR in μgT$_4$.100g^{-1}.24h^{-1} was then calculated using body weight of the bird.

(iii)   Correction Factor for TSR

Due to the rapid turnover of thyroxine in the bird, determination of TSR does not take into account the iodide component of thyroid hormone turnover. Before precipitation of plasma $PB^{125}I$, plasma $^{125}I-T_4$ counts were obtained first and then plasma $PB^{125}I-T_4$ counts were made on the 3 samples taken from each bird and correction factor calculated.

6. Determination of Metabolic Rate

(a)   Method

(i)   Bird under study was starved for a period of 12 h.

(ii)   Bird was weighed and then placed in an air tight chamber connected to an oxygen supply at one end and to a metabolimeter (300 Volume Meter, Med-Science Electronics, St. Louis Inc.) at the other end. The base of the chamber contained a carbon dioxide absorbing material (Sodasorb) and a water vapour absorbent (Silica Gel).

The bird was prevented from contact with the absorbing materials by a section of wire mesh placed over these materials.

(iii)   At the time the bird was placed in the metabolimeter, records were made of the air temperature and the atmospheric pressure (mbar).

(iv)   The chamber was filled with oxygen from a pressurized source and the bird was allowed 15 min to equilibrate in the chamber.

(v) Measurement was then made of the oxygen consumed by the bird, while the carbon dioxide and water vapour produced were absorbed. Oxygen consumption reduced the volume of the system which was compensated for by the piston of volume meter moving to the right, into the cylinder, recorded by a pen moving across a strip chart fastened to the front of the volume meter.

(vi) The oxygen uptake by the bird was recorded in 5 runs of 10 min.

(vii) The respiratory quotient was assumed to be one for all birds. (They were on the same diet).

(viii) Metabolic rate was then calculated correcting volume of oxygen consumed to standard temperature and pressure and was expressed as $KJ.kg^{-0.75}.24h^{-1}$.

7. Determination of Water Turnover, Total Body Water and Carcass Fat

(a) Equilibration Period

A dose of 50 µCi of TOH (0.5 ml of 100 $µCi.ml^{-1}$ TOH) was injected intramuscularly. Birds were starved for 12 h and taken off water prior to injection so that no new water was added to their system. Blood samples of 2 ml were taken at 1, 2, 3 and 4 h after which hens were given access to their food and water. Further blood samples were taken at 6 h, 12 h, 14 h, 20 h, 48 h, 72 h and 96 h after injection. TOH was obtained by sublimation of whole blood with liquid nitrogen *in vacuo* (0.01 Torr) using a cold trap (Cooper, Radin and Borden, 1958). TOH concentration relative to HOH was then determined on aliquots (0.5 ml) dissolved in

dioxan scintillation fluid (7 ml) which contained PPO (5 g), napthalene (80 g), ethanol (250 ml), toluene (375 ml) and dioxan (375 ml). This mixture converted β electrons to photons which were detected by photomultipliers. The samples were counted in a Packard liquid scintillation counter. After 4 h there was an exponential decline in tritium counts.

(b) Total Body Water and Water Turnover

For routine determination of total body water and water turnover, blood samples were taken 4 h, 1 day, 4 days and 7 days after injection of 0.5 ml of 100 $\mu Ci.ml^{-1}$ TOH.

Total Body Water (TBW). A standard was counted to obtain the value for the dose of TOH injected.

$$TBW \ (ml) = \frac{counts \ injected}{counts \ at \ equilibrium}$$

Water turnover was derived from the half-life of TOH in the bird.

The rate constant for reduction of TOH concentration is

$$K = \frac{0.693}{t_{\frac{1}{2}} \ days} \ X \ 100$$

K is the exponentially derived fraction of the water pool turned over per unit time. The volume of water passing through — water turnover — is the fraction of total body water turned over daily.

$$K \ X \ TBW = ml. \ 24h^{-1}$$

The water turnover was then related to the body weight as $ml.kg^{-1}.24h^{-1}$.

(c) Carcass Fat Estimates

Total body water (ml) was divided by body weight (g) to give a carcass fat estimate expressed as a percentage.

8. Determination of Shell Quality Variables

(a) Egg Conformation, Shell Weight, Shell Weight per Surface Area Egg and Shell Thickness.

(i) Method

A total of 10 eggs from each bird were collected over the age period 45-55 weeks. Each of these eggs was used for measurement of egg conformation, shell weight, shell weight per surface area of egg and shell thickness.

The weight of each fresh egg was measured to the nearest 0.01 g after which egg width and length were determined with a precision of ± 0.005 cm using a vernier caliper. Shape index or egg conformation was calculated as the quotient of egg length divided by egg width. A line was drawn around each egg at its equator after which the contents were discarded and the shell membranes and cuticle removed by the method of Tyler and Geake (1953). The shells were rinsed thoroughly and dried in an oven at $80^{\circ}C$ for 24 h. Dried shells were weighed to the nearest 0.01 g, and shell thickness (to the nearest micron) was taken as the average of five measurements at the equator using an anvil-jawed micrometer. The quotient of dried shell weight and fresh egg surface area was calculated to give shell weight per

surface area of egg (mg.cm^{-2}). Egg surface area was calculated using the formula of Mueller and Scott (1940).

$$S = 4.67 \ W^{0.66} \quad \text{where}$$

S = surface area of the egg in cm^2, and

W = fresh egg weight in g

The results for all eggs from each bird were averaged.

(b) Shell Porosity

(i) Method

A total of 10 eggs from each individual bird were collected over the age period 45-55 weeks for measurement of egg shell porosity.

The weight of each egg was measured to the nearest 0.01 g before and after a 7-day incubation at a temperature of approximately 38°C and a relative humidity in the region of 80%. The quotient of egg weight loss (over 7 days of incubation) and fresh egg surface area was calculated to give weight of water loss per day (mg.cm^{-2}.24h^{-1}). Egg surface area was calculated using the formulae of Mueller and Scott (1940). The results for all eggs from each bird were averaged.

B. LISTING OF DATA

1. Abbreviations

The following abbreviations are used in the listing of data. Units of variables are indicated where applicable.

		Units
I D	Identification	
G E N	Generation	
F D L V L	Feed Level	
F 1 8 - 6 6	Feed Intake (18-66 weeks)	$g.24h^{-1}$
F 2 2 - 4 2	Feed Intake (22-42 weeks)	$g.24h^{-1}$
E G G 1 8 - 6 6	Egg Number (18-66 weeks)	
E G G 2 2 - 4 2	Egg Number (22-42 weeks)	

		UNITS
FCE18-66	FCE (18-66 weeks)	%
FCE22-42	FCE (22-42 weeks)	%
AEW18-66	Average Egg Weight (18-66 weeks)	g
AEW22-42	Average Egg Weight (22-42 weeks)	g
ADL	*ad libitum*	
CROS	Line-cross	
PURE	Purebred	
OUTC	Out-cross	
ST	Introduced Sire	
MR	Metabolic Rate	$KJ.W^{-0.75}.24h^{-1}$
WTURN	Water Turnover	$ml.kg^{-1}.24h^{-1}$
TOTWAT	Total Body Water as a % of Body Weight	%

TSR	Thyroxine Secretion Rate	$\mu g T_4 . 100 g^{-1} . 24 h^{-1}$
PLT4	Plasma Thyroxine	$\mu g\ T_4\ dl^{-1}$
SHELL	Shell Weight	g
SWSA	Shell Weight per SA Egg	$mg.cm^{-2}$
STHICK	Shell Thickness	μm
POR	Egg Porosity	
ECON	Egg Conformation	
BW 1	Body Weight (Hatch)	g
BW 2	Body Weight (1 Week)	"
BW 3	Body Weight (2 Weeks)	"
BW 4	Body Weight (3 Weeks)	"
BW 5	Body Weight (4 Weeks)	"
BW 6	Body Weight (5 Weeks)	"
BW 7	Body Weight (6 Weeks)	"
BW 8	Body Weight (8 Weeks)	"
BW 9	Body Weight (10 Weeks)	"
BW 10	Body Weight (12 Weeks)	"
BW 11	Body Weight (14 Weeks)	"
BW 12	Body Weight (16 Weeks)	"
BW 13	Body Weight (18 Weeks)	"
BW 14	Body Weight (22 Weeks)	"
BW 15	Body Weight (26 Weeks)	"
BW 16	Body Weight (30 Weeks)	"
BW 17	Body Weight (34 Weeks)	"
BW 18	Body Weight (38 Weeks)	"
BW 19	Body Weight (42 Weeks)	"
BW 20	Body Weight (46 Weeks)	"
BW 21	Body Weight (50 Weeks)	"

		Units
BW 22	Body Weight (54 Weeks)	g
BW 23	Body Weight (58 Weeks)	g
BW 24	Body Weight (62 Weeks)	g
BW 25	Body Weight (66 Weeks)	g

2. Listing of Purebred Data
Production Variables

LINE	GEN	FDLVL	ID	F18/66	F22/42	EGG18/66	EGG22/42	FCE18/66	FCE22/42	AEW18/66	AEW22/42
A1	1	80	YEL1	80	80	199	96	39.0	43.7	52.6	51.0
A1	2	ADL	GREN26	128	138	191	104	24.4	27.7	54.4	51.6
A1	2	ADL	GREN35	127	133	231	108	29.2	29.7	54.1	51.0
A1	2	ADL	GREN92	128	134	216	90	31.5	29.0	62.6	60.2
A1	2	ADL	GREN72	140	143	120	46	15.4	13.0	60.3	56.2
A1	2	ADL	GREN58	130	133	214	118	32.7	40.3	66.8	63.7
A1	2	ADL	GOLD4	141	141	177	84	23.5	25.0	63.0	58.9
A1	2	80	BLUE2	80	80	74	34	17.0	17.8	61.7	58.7
A1	2	80	BLUE25	80	80	85	43	18.1	20.9	57.4	54.3
A1	3	ADL	S623	123	134	161	83	24.2	25.7	62.3	57.9
A1	3	ADL	S626	128	130	209	104	27.5	30.6	56.6	53.7
A1	3	ADL	S628	131	132	195	92	26.3	27.7	59.3	55.8
A1	3	ADL	S640	94	97	190	88	35.3	36.4	58.8	56.3
A1	3	ADL	S647	99	107	154	93	26.6	34.4	57.5	55.3
A1	3	ADL	S641	131	134	213	104	28.6	30.4	59.0	54.9
A1	3	80	GOLD49	80	80	73	37	14.5	17.2	53.5	52.2
A1	3	80	GOLD19	80	80	53	36	10.9	17.4	55.2	54.0
A1	3	80	GREN65	80	80	51	19	11.0	10.2	57.8	59.9
A1	3	80	GOLD61	80	80	124	57	24.1	25.2	52.2	49.6
A1	3	80	GOLD62	80	80	70	37	14.6	17.7	56.1	53.5
A1	3	80	S566	80	80	55	29	11.6	14.1	56.5	54.6
A1	3	80	S568	80	80	91	48	18.4	22.2	54.4	51.7
A1	3	80	GOLD6	80	80	110	62	21.8	28.4	53.2	51.2
A1	3	80	GRN100	80	80	67	39	14.1	18.9	56.6	54.4
A1	4	ADL	PINK80	141	142	230	103	28.4	27.7	58.5	53.6
A1	4	ADL	PINK52	133	136	168	78	20.1	20.6	53.5	50.3
A1	4	ADL	PINK53	132	128	191	84	23.7	23.4	54.9	50.0
A1	4	80	GREEN4	80	80	110	55	21.5	24.7	52.4	50.2
A1	4	80	PINK99	80	80	71	36	14.2	16.2	53.9	50.5
A1	4	80	GREEN1	80	80	102	49	20.5	22.0	54.0	50.3
A3	1	80	YEL2	80	80	195	98	39.9	46.9	55.0	53.6
A3	2	ADL	GREN25	112	119	196	99	31.8	33.1	61.0	55.7
A3	2	ADL	GREN14	115	125	235	120	34.4	36.5	56.7	53.3
A3	2	ADL	GREN15	117	117	132	89	17.8	27.6	53.1	50.6
A3	2	ADL	GREN96	108	112	183	99	27.7	33.5	55.0	53.1
A3	2	ADL	GOLD9	97	108	170	95	32.0	36.9	61.5	58.6
A3	2	ADL	GOLD12	108	114	178	87	28.9	30.3	58.8	55.3
A3	2	ADL	GOLD16	101	110	170	96	27.8	32.6	55.3	52.4
A3	2	80	BLUE5	80	80	130	72	25.2	31.4	52.2	48.8
A3	2	80	BLUE21	80	80	141	69	26.7	29.1	50.9	47.2
A3	2	80	BLUE30	80	80	89	54	18.3	24.7	55.1	51.3
A3	3	ADL	S629	125	127	179	97	28.3	34.3	66.6	62.8
A3	3	ADL	S638	138	137	93	71	9.8	19.7	48.7	52.9
A3	3	ADL	S639	133	130	172	78	23.5	23.9	60.8	55.7
A3	3	ADL	S649	118	120	193	88	27.6	28.4	56.8	54.3
A3	3	ADL	S659	130	126	230	106	27.6	29.8	52.3	49.4

Listing of Purebred Data
Production Variables   (Continued)

LINE	GEN	FDLVL	ID	F18 $\overline{66}$	F22 $\overline{42}$	EGG18 $\overline{66}$	EGG22 $\overline{42}$	FCE18 $\overline{66}$	FCE22 $\overline{42}$	AEW18 $\overline{66}$	AEW22 $\overline{42}$
A3	3	ADL	S660	.124	.127	261	121	34.6	35.6	55.3	52.2
A3	3	ADL	S662	122	1.18	205	96	27.6	31.0	55.3	53.0
A3	3	80	GOLD69	80	80	83	38	16.2	16.6	54.6	48.9
A3	3	80	GOLD72	80	80	105	55	19.8	24.2	50.7	49.2
A3	3	80	GOLD92	80	80	70	46	13.0	19.6	49.9	47.8
A3	3	80	GOLD93	80	80	97	51	19.4	23.2	53.6	51.0
A3	3	80	S574	80	80	94	51	18.1	22.7	51.8	49.9
A3	3	80	GREN91	80	80	61	32	11.0	13.1	48.5	45.9
A3	3	80	GREN95	80	80	81	45	15.8	20.2	52.5	50.3
A3	3	80	S571	80	80	76	46	16.8	23.6	50.3	57.3
A3	3	80	GOLD75	80	80	88	52	18.2	24.6	55.6	53.0
A3	4	ADL	GREN22	110	123	110	87	15.6	27.4	52.2	54.1
A3	4	ADL	GREN24	108	112	212	102	32.7	34.4	56.1	53.0
A3	4	80	GREN16	80	80	104	53	20.7	23.9	53.5	50.5
A3	4	80	GREN17	80	80	83	45	18.2	23.0	59.0	57.2
A3	4	80	GREN31	80	80	87	55	17.0	24.9	52.6	50.8
A4	1	80	YEL3	80	80	101	46	20.5	21.9	54.4	53.4
A4	2	ADL	GREEN3	121	126	202	94	28.4	28.7	57.3	53.8
A4	2	ADL	GREN21	121	124	241	116	34.9	36.6	58.8	54.5
A4	2	ADL	GREN31	120	130	127	75	21.4	26.8	68.3	65.0
A4	2	ADL	GREN68	123	129	212	108	31.1	33.9	60.5	56.5
A4	2	80	BLUE9	80	80	117	65	23.5	29.2	54.1	50.4
A4	2	80	BLUE22	80	80	61	31	13.1	15.3	57.9	55.1
A4	2	80	BLUE24	80	80	106	54	21.2	24.0	53.6	49.8
A4	2	80	BLUE31	80	80	94	47	18.0	19.9	51.4	47.4
A4	2	80	BLUE32	80	80	56	11	13.0	5.9	62.2	59.8
A4	2	80	BLUE38	80	80	78	24	16.6	11.4	57.3	53.2
A4	2	80	BLUE33	80	80	107	66	22.6	32.1	56.8	54.5
A4	3	ADL	GOLD79	106	114	191	105	27.9	33.1	52.1	50.2
A4	3	ADL	S634	106	122	151	99	23.8	31.3	56.0	54.0
A4	3	ADL	BLUE81	138	139	178	85	22.8	23.3	59.1	53.4
A4	3	ADL	S642	124	129	192	97	30.5	33.6	66.1	62.4
A4	3	ADL	S644	127	132	170	95	22.3	27.8	56.0	54.1
A4	3	ADL	S645	122	118	218	97	33.1	34.6	62.3	59.1
A4	3	ADL	S655	131	133	204	110	25.0	29.8	53.8	50.3
A4	3	80	BLUE51	80	80	64	30	13.2	14.4	55.4	53.7
A4	3	80	BLUE99	80	80	108	48	19.3	20.1	51.7	46.9
A4	3	80	BLU100	80	80	132	62	26.2	28.4	53.3	51.3
A4	3	80	BLUE60	80	80	62	17	12.2	7.8	52.9	51.2
A4	3	80	BLUE74	80	80	117	56	25.2	27.6	57.8	55.2
A4	3	80	BLUE90	80	80	66	32	13.6	15.0	55.5	52.7
A4	3	80	GOLD89	80	80	126	66	24.6	29.0	52.5	49.2
A4	3	80	BLUE86	80	80	82	43	16.3	18.0	53.5	47.0
A4	3	80	GOLD84	80	80	61	27	12.3	12.5	54.1	52.0
A4	3	80	GOLD86	80	80	46	15	9.8	7.4	57.1	55.4
A4	3	80	GOLD88	80	80	57	31	11.3	14.0	53.2	50.6

Listing of Purebred Data
Production Variables   (Continued)

LINE	GEN	FDLVL	ID	F 18 $\overline{6}$ 6	F 22 $\overline{4}$ 2	EGG 18 $\overline{6}$ 6	EGG 22 $\overline{4}$ 2	FCE 18 $\overline{6}$ 6	FCE 22 $\overline{4}$ 2	AEW 18 $\overline{6}$ 6	AEW 22 $\overline{4}$ 2
A4	4	ADL	PINK1	118	110	163	53	24.9	18.9	59.7	54.9
A4	4	ADL	PINK3	119	124	230	96	32.1	30.0	56.3	54.2
A4	4	ADL	PINK81	122	108	210	89	33.4	31.9	57.3	54.4
A4	4	80	PINK5	80	80	83	12	17.5	5.8	56.7	53.7
A4	4	80	PINK6	80	80	70	17	16.3	8.9	62.7	58.7
A4	4	80	PINK7	80	80	89	43	17.7	19.1	53.3	49.6
C4	1	ADL	YEL4	98	104	251	116	43.6	44.9	57.4	56.4
C4	2	ADL	GREN41	116	127	161	88	23.4	26.5	56.9	53.6
C4	2	ADL	GREN47	110	118	190	100	31.4	34.3	60.9	56.6
C4	2	ADL	GREN55	117	120	203	91	31.3	31.1	60.7	57.2
C4	2	ADL	GOLD11	126	123	205	105	27.5	31.8	56.9	52.3
C4	2	ADL	GOLD14	117	126	214	109	32.9	35.6	60.7	57.5
C4	2	ADL	GOLD15	126	127	219	95	32.1	31.7	62.1	59.4
C4	2	80	BLUE11	80	80	107	45	20.7	20.0	52.1	49.7
C4	2	80	BLUE20	80	80	97	44	20.4	21.1	56.5	53.6
C4	2	80	BLUE26	80	80	100	41	20.0	19.0	53.8	52.0
C4	2	80	BLUE28	80	80	149	73	29.3	31.8	52.8	48.8
C4	2	80	BLUE41	80	80	105	55	20.9	25.1	53.6	51.0
C4	2	80	BLUE44	80	80	83	30	17.0	13.9	55.0	51.8
C4	3	ADL	BLUE67	100	106	136	85	19.4	26.3	47.6	46.0
C4	3	ADL	BLUE87	139	141	212	91	24.4	22.6	53.6	49.1
C4	3	ADL	BLUE88	88	99	0	0	0.0	0.0	.	.
C4	3	ADL	S551	124	126	250	112	31.0	31.0	51.6	48.8
C4	3	ADL	S575	138	139	207	99	23.3	25.4	52.0	49.8
C4	3	80	GOLD76	80	80	45	9	9.1	4.4	54.0	54.4
C4	3	80	BLUE54	80	80	95	31	16.7	12.1	47.1	43.6
C4	3	80	BLUE96	80	80	135	61	26.3	27.4	52.4	50.4
C4	3	80	GOLD99	80	80	59	32	11.1	13.7	50.5	48.1
C4	3	80	S582	80	80	80	39	15.5	17.2	52.0	49.3
C4	3	80	S680	80	80	97	55	18.0	23.5	50.0	47.9
C4	3	80	S682	80	80	88	38	15.9	15.7	48.4	46.2
C4	3	80	S578	80	80	113	58	22.0	25.6	52.3	49.4
C4	4	ADL	PINK33	125	128	229	92	30.6	27.0	56.2	52.8
C4	4	ADL	PINK34	116	114	214	87	31.1	29.0	56.5	53.2
C4	4	80	PINK44	80	80	105	42	20.7	18.5	53.0	49.3
C4	4	80	PINK45	80	80	79	33	15.2	14.0	51.7	47.5

3. Listing of Purebred Data
   Physiological Variables

LINE	GEN	FDLVL	ID	MR	WTURN	TOTWAT	TSR	PLT4
A1	1	80	YEL1	355.6	167.0	70.1	0.450	0.740
A1	2	ADL	GREN26	325.9	131.9	54.3	0.896	1.399
A1	2	ADL	GREN35	332.2	106.8	54.3	0.404	1.019
A1	2	ADL	GREN92	347.7	111.0	51.3	0.485	1.019
A1	2	ADL	GREN72	377.4	83.0	55.8	0.853	1.899
A1	2	ADL	GREN58	367.4	94.4	49.1	0.509	1.016
A1	2	ADL	GOLD4	363.6	105.2	53.1	0.687	1.460
A1	2	80	BLUE2	305.4	106.6	65.0	0.297	0.344
A1	2	80	BLUE25	300.4	140.9	61.0	0.255	0.866
A1	3	ADL	S623	326.4	100.4	48.8	0.760	0.890
A1	3	ADL	S626	418.0	156.5	51.3	0.735	1.250
A1	3	ADL	S628	358.6	112.9	50.9	1.074	1.448
A1	3	ADL	S640	368.6	115.9	59.1	0.671	0.839
A1	3	ADL	S647	407.1	125.5	51.9	0.642	1.058
A1	3	ADL	S641	340.2	134.3	51.8	0.562	0.804
A1	3	80	GOLD49	295.4	111.4	53.5	0.532	1.548
A1	3	80	GOLD19	298.7	104.7	65.3	0.928	1.277
A1	3	80	GREN65	325.1	119.0	61.2	1.361	2.150
A1	3	80	GOLD61	360.7	93.7	53.9	0.612	1.200
A1	3	80	GOLD62	343.1	175.3	55.8	0.751	1.449
A1	3	80	S566	359.4	93.4	54.4	0.843	1.316
A1	3	80	S568	327.6	146.5	54.2	0.741	1.277
A1	3	80	GOLD6	334.7	92.9	58.2	0.670	1.458
A1	3	80	GRN100	330.1	120.7	55.0	0.724	1.367
A1	4	ADL	PINK80	336.0	153.6	60.2	0.487	1.290
A1	4	ADL	PINK52	326.4	137.3	60.4	0.567	1.116
A1	4	ADL	PINK53	325.5	173.8	59.1	0.519	0.948
A1	4	80	GREEN4	343.9	183.2	63.9	0.302	1.355
A1	4	80	PINK99	312.5	84.3	62.8	0.668	1.755
A1	4	80	GREEN1	322.6	148.1	62.1	0.590	1.322
A3	1	80	YEL2	305.4	142.2	65.0	0.310	0.610
A3	2	ADL	GREN25	377.0	106.5	54.5	0.640	1.138
A3	2	ADL	GREN14	297.9	99.8	53.7	0.678	1.104
A3	2	ADL	GREN15	319.2	118.4	57.3	0.473	0.701
A3	2	ADL	GREN96	380.3	109.4	61.7	0.667	1.206
A3	2	ADL	GOLD9	322.6	115.7	51.7	0.581	1.413
A3	2	ADL	GOLD12	358.6	133.3	57.6	0.706	0.913
A3	2	ADL	GOLD16	372.4	102.2	58.3	0.587	0.958
A3	2	80	BLUE5	273.2	131.8	65.2	0.358	0.893
A3	2	80	BLUE21	274.9	122.7	62.0	0.395	1.272
A3	2	80	BLUE30	273.6	109.8	61.8	0.702	1.139
A3	3	ADL	S629	355.6	158.4	56.3	1.082	1.487
A3	3	ADL	S638	452.3	122.1	52.9	0.727	1.238
A3	3	ADL	S639	383.7	138.6	55.4	0.864	1.193
A3	3	ADL	S649	353.5	138.7	53.9	1.097	1.131
A3	3	ADL	S659	431.0	103.8	57.1	0.673	1.049
A3	3	ADL	S660	409.6	148.2	52.3	0.768	1.500
A3	3	ADL	S662	380.7	95.1	50.9	0.740	1.449
A3	3	80	GOLD69	413.8	100.4	53.3	0.676	1.406
A3	3	80	GOLD72	351.5	129.8	56.9	0.567	1.283
A3	3	80	GOLD92	302.5	149.1	55.7	0.556	1.451
A3	3	80	GOLD93	366.9	101.4	54.5	0.597	1.490
A3	3	80	S574	329.7	124.5	57.5	0.817	1.380

Listing of Purebred Data
Physiological Variables   (Continued)

LINE	GEN	FDLVL	ID	MR	WTURN	TOTWAT	TSR	PLT4
A3	3	80	GREN91	332.6	129.4	52.4	0.568	1.006
A3	3	80	GREN95	290.4	143.5	56.9	0.216	1.006
A3	3	80	S571	339.7	129.0	61.8	0.568	1.097
A3	3	80	GOLD75	348.9	138.8	57.8	0.759	1.187
A3	4	ADL	GREN22	303.3	109.8	56.5	0.337	0.922
A3	4	ADL	GREN24	319.7	116.2	57.1	0.675	1.168
A3	4	80	GREN16	284.9	136.9	59.5	0.235	1.219
A3	4	80	GREN17	309.6	121.6	61.1	0.300	1.213
A3	4	80	GREN31	283.7	154.0	60.2	0.392	1.116
A4	1	80	YEL3	337.2	125.8	65.0	0.760	1.600
A4	2	ADL	GREEN3	355.6	108.9	53.4	0.457	1.033
A4	2	ADL	GREN21	401.7	153.2	62.3	0.442	1.024
A4	2	ADL	GREN31	338.9	97.0	55.6	0.508	1.078
A4	2	ADL	GREN68	316.3	125.4	52.7	0.420	0.810
A4	2	80	BLUE9	265.7	98.3	57.7	0.446	0.940
A4	2	80	BLUE22	272.8	98.0	61.8	0.586	1.472
A4	2	80	BLUE24	312.1	119.8	66.1	0.528	1.319
A4	2	80	BLUE31	317.1	133.8	69.4	0.779	1.452
A4	2	80	BLUE32	333.9	106.4	59.4	0.544	1.539
A4	2	80	BLUE38	328.4	129.1	57.5	0.533	1.239
A4	2	80	BLUE33	316.7	126.3	58.0	0.574	1.472
A4	3	ADL	GOLD79	364.0	114.0	54.8	0.810	0.925
A4	3	ADL	S634	374.9	119.9	57.9	0.630	1.006
A4	3	ADL	BLUE81	422.6	110.7	57.9	0.681	1.130
A4	3	ADL	S642	376.6	172.7	53.6	0.621	1.246
A4	3	ADL	S644	386.6	131.9	53.7	0.847	1.367
A4	3	ADL	S645	400.8	138.9	51.4	0.607	1.229
A4	3	ADL	S655	386.2	146.2	57.2	0.789	1.148
A4	3	80	BLUE51	315.1	86.8	56.0	1.638	1.664
A4	3	80	BLUE99	310.9	96.5	68.2	0.719	0.980
A4	3	80	BLU100	361.1	99.7	59.7	0.705	1.110
A4	3	80	BLUE60	318.4	78.9	59.8	1.178	1.238
A4	3	80	BLUE74	298.7	168.1	61.5	0.737	1.458
A4	3	80	BLUE90	379.5	128.0	62.0	0.791	1.587
A4	3	80	GOLD89	282.0	106.1	64.3	0.890	1.315
A4	3	80	BLUE86	410.5	111.8	61.6	1.214	1.922
A4	3	80	GOLD84	331.0	120.9	65.2	0.489	1.380
A4	3	80	GOLD86	310.9	75.8	65.7	0.792	1.199
A4	3	80	GOLD88	421.7	162.4	59.6	1.434	1.445
A4	4	ADL	PINK1	340.6	167.5	64.1	0.589	1.220
A4	4	ADL	PINK3	359.0	167.1	58.1	0.354	1.574
A4	4	ADL	PINK81	349.4	147.1	63.5	0.534	0.839
A4	4	80	PINK5	313.8	94.7	63.4	0.894	1.555
A4	4	80	PINK6	327.2	123.5	63.4	0.648	1.265
A4	4	80	PINK7	322.2	97.0	64.3	0.767	1.678
C4	1	ADL	YEL4	347.3	174.5	67.5	0.380	0.780
C4	2	ADL	GREN41	343.1	103.1	56.8	0.476	1.154
C4	2	ADL	GREN47	335.6	102.2	55.9	0.456	1.026
C4	2	ADL	GREN55	311.7	113.6	55.3	0.529	0.946
C4	2	ADL	GOLD11	374.5	105.5	54.9	0.522	1.060
C4	2	ADL	GOLD14	344.3	124.2	57.2	0.822	1.443
C4	2	ADL	GOLD15	348.5	117.9	53.1	0.673	1.347
C4	2	80	BLUE11	276.6	132.9	56.9	0.364	0.862

Listing of Purebred Data
Physiological Variables   (Continued)

LINE	GEN	FDLVL	ID	MR	WTURN	TOTWAT	TSR	PLT4
C4	2	80	BLUE20	277.8	114.0	59.4	0.302	0.983
C4	2	80	BLUE26	402.5	138.3	64.2	0.390	1.006
C4	2	80	BLUE28	342.7	129.3	71.8	0.579	0.646
C4	2	80	BLUE41	355.2	152.9	63.2	0.247	0.720
C4	2	80	BLUE44	327.2	101.7	61.8	0.439	1.232
C4	3	ADL	BLUE67	433.0	122.4	60.4	0.696	1.109
C4	3	ADL	BLUE87	400.0	120.4	55.7	0.675	1.058
C4	3	ADL	BLUE88	387.0	70.5	51.2	0.500	0.985
C4	3	ADL	S551	398.7	155.8	57.1	0.788	1.230
C4	3	ADL	S575	335.6	124.7	57.3	0.564	1.174
C4	3	80	GOLD76	325.9	125.0	54.5	1.035	2.412
C4	3	80	BLUE54	372.8	135.8	57.8	0.652	1.193
C4	3	80	BLUE96	359.0	129.1	58.8	0.987	1.155
C4	3	80	GOLD99	363.6	145.6	61.5	1.057	1.561
C4	3	80	S582	339.3	124.9	59.8	0.899	1.200
C4	3	80	S680	477.8	154.0	65.1	0.808	1.135
C4	3	80	S682	380.7	216.8	57.8	1.210	1.380
C4	3	80	S578	321.3	101.6	58.5	0.889	1.445
C4	4	ADL	PINK33	362.3	148.2	64.2	0.433	0.948
C4	4	ADL	PINK34	344.8	134.7	63.4	0.366	0.845
C4	4	80	PINK44	328.9	111.8	66.8	0.567	1.548
C4	4	80	PINK45	336.4	103.3	65.0	0.535	1.613

4. Listing of Purebred Data
Egg Shell Variables

LINE	GEN	FDLVL	ID	SHELL	SWSA	STHICK	POR	ECON
A1	1	80	YEL1	4.75	67.6	288	4.8	1.39
A1	2	ADL	GREN26	5.92	83.8	375	4.2	1.34
A1	2	ADL	GREN35	5.34	77.1	365	6.1	1.36
A1	2	ADL	GREN92	6.52	85.2	396	4.9	1.29
A1	2	ADL	GREN72	6.14	81.2	369	4.4	1.28
A1	2	ADL	GREN58	6.16	75.9	346	4.5	1.28
A1	2	ADL	GOLD4	5.97	76.3	346	5.3	1.27
A1	2	80	BLUE2	5.92	76.9	337	3.6	1.33
A1	2	80	BLUE25	6.45	87.1	398	5.0	1.32
A1	3	ADL	S623	5.63	77.0	329	4.7	1.41
A1	3	ADL	S626	5.84	82.8	367	4.9	1.46
A1	3	ADL	S628	5.73	78.0	336	5.6	1.44
A1	3	ADL	S640	6.09	85.2	375	4.7	1.28
A1	3	ADL	S647	5.85	81.8	343	5.1	1.43
A1	3	ADL	S641	6.63	91.6	400	4.8	1.31
A1	3	80	GOLD49	4.64	73.0	308	3.8	1.25
A1	3	80	GOLD19	4.70	69.4	293	4.0	1.32
A1	3	80	GREN65	5.44	74.0	311	5.1	1.30
A1	3	80	GOLD61	5.43	80.7	359	4.7	1.37
A1	3	80	GOLD62	6.05	85.0	360	4.1	1.32
A1	3	80	S566	5.89	85.4	377	3.7	1.42
A1	3	80	S568	5.56	81.8	355	4.0	1.34
A1	3	80	GOLD6	5.67	81.5	347	4.7	1.26
A1	3	80	GRN100	5.40	81.6	340	4.4	1.29
A1	4	ADL	PINK80	5.57	79.3	354	5.4	1.20
A1	4	ADL	PINK52	5.73	83.1	365	4.6	1.34
A1	4	ADL	PINK53	5.70	83.3	373	5.1	1.33
A1	4	80	GREEN4	5.63	85.1	396	4.2	1.25
A1	4	80	PINK99	5.80	83.5	377	4.5	1.32
A1	4	80	GREEN1	5.97	81.5	380	4.2	1.33
A3	1	80	YEL2	5.00	66.9	301	4.2	1.46
A3	2	ADL	GREN25	6.65	85.6	385	4.4	1.39
A3	2	ADL	GREN14	6.20	83.7	382	5.2	1.33
A3	2	ADL	GREN15	6.26	85.5	390	4.3	1.40
A3	2	ADL	GREN96	5.55	77.0	348	4.5	1.30
A3	2	ADL	GOLD9	6.29	80.7	357	4.8	1.42
A3	2	ADL	GOLD12	6.02	79.5	367	4.8	1.34
A3	2	ADL	GOLD16	6.23	88.3	397	5.0	1.36
A3	2	80	BLUE5	5.69	80.4	363	4.2	1.36
A3	2	80	BLUE21	5.35	79.4	346	5.6	1.30
A3	2	80	BLUE30	5.74	77.1	345	•	1.34
A3	3	ADL	S629	6.23	78.2	350	5.3	1.42
A3	3	ADL	S638	5.36	77.5	343	3.9	1.43
A3	3	ADL	S639	6.22	82.5	351	3.6	1.40
A3	3	ADL	S649	5.29	75.3	334	5.1	1.40
A3	3	ADL	S659	5.23	80.9	348	4.6	1.35
A3	3	ADL	S660	5.65	81.0	367	4.9	1.31
A3	3	ADL	S662	5.31	77.4	344	5.3	1.48
A3	3	80	GOLD69	4.92	72.0	304	5.3	1.35
A3	3	80	GOLD72	5.29	77.1	324	3.6	1.53
A3	3	80	GOLD92	5.31	80.7	354	4.3	1.33
A3	3	80	GOLD93	5.41	78.3	341	4.6	1.33
A3	3	80	S574	5.18	78.3	337	5.2	1.39

Listing of Purebred Data
Egg Shell Variables   (Continued)

LINE	GEN	FDLVL	ID	SHELL	SWSA	STHICK	POR	ECON
A3	3	80	GREN91	5.00	79.0	332	3.9	1.32
A3	3	80	GREN95	5.12	80.1	350	4.8	1.35
A3	3	80	S571	5.75	79.0	344	4.1	1.43
A3	3	80	GOLD75	5.49	80.0	364	4.1	1.39
A3	4	ADL	GREN22	5.74	81.0	361	5.0	1.44
A3	4	ADL	GREN24	5.35	76.8	348	5.9	1.32
A3	4	80	GREN16	5.31	79.2	353	5.1	1.31
A3	4	80	GREN17	5.77	81.2	360	4.6	1.41
A3	4	80	GREN31	5.49	79.9	364	4.5	1.41
A4	1	80	YEL3	5.25	72.1	318	4.2	1.43
A4	2	ADL	GREEN3	5.92	79.7	366	4.3	1.36
A4	2	ADL	GREN21	6.07	79.5	353	5.1	1.39
A4	2	ADL	GREN31	7.24	85.7	386	4.5	1.37
A4	2	ADL	GREN68	6.68	88.6	403	4.1	1.36
A4	2	80	BLUE9	6.47	86.7	389	4.1	1.36
A4	2	80	BLUE22	5.11	72.5	319	3.9	1.35
A4	2	80	BLUE24	5.99	81.7	367	4.1	1.31
A4	2	80	BLUE31	5.48	75.6	342	4.5	1.36
A4	2	80	BLUE32	5.52	75.2	337	5.2	1.33
A4	2	80	BLUE38	5.81	80.4	349	5.0	1.41
A4	2	80	BLUE33	5.93	80.7	353	4.6	1.31
A4	3	ADL	GOLD79	5.16	78.5	344	4.6	1.40
A4	3	ADL	S634	5.28	73.4	318	4.6	1.38
A4	3	ADL	BLUE81	5.69	82.4	364	3.5	1.44
A4	3	ADL	S642	6.83	87.9	394	4.9	1.45
A4	3	ADL	S644	5.41	76.3	346	4.8	1.38
A4	3	ADL	S645	5.77	79.0	356	4.9	1.37
A4	3	ADL	S655	5.06	73.5	312	4.5	1.41
A4	3	80	BLUE51	5.35	77.2	328	4.3	1.38
A4	3	80	BLUE99	5.33	76.3	319	3.9	1.38
A4	3	80	BLU100	5.12	75.7	332	4.2	1.36
A4	3	80	BLUE60	5.63	83.0	344	4.2	1.45
A4	3	80	BLUE74	5.85	81.1	354	3.9	1.39
A4	3	80	BLUE90	5.62	78.9	342	4.4	1.48
A4	3	80	GOLD89	5.49	81.3	354	4.4	1.31
A4	3	80	BLUE86	5.56	79.4	344	4.2	1.52
A4	3	80	GOLD84	5.56	82.0	360	4.3	1.40
A4	3	80	GOLD86	5.46	79.6	335	4.4	1.34
A4	3	80	GOLD88	5.48	77.1	326	5.0	1.42
A4	4	ADL	PINK1	6.01	83.6	382	4.7	1.40
A4	4	ADL	PINK3	6.32	89.6	400	4.3	1.35
A4	4	ADL	PINK81	5.59	78.6	346	4.5	1.40
A4	4	80	PINK5	5.73	80.3	356	4.7	1.51
A4	4	80	PINK6	5.74	78.3	356	4.5	1.39
A4	4	80	PINK7	5.71	83.6	377	4.5	1.38
C4	1	ADL	YEL4	5.23	69.4	312	4.0	1.41
C4	2	ADL	GREN41	6.21	85.4	387	4.9	1.34
C4	2	ADL	GREN47	5.93	74.4	334	4.9	1.39
C4	2	ADL	GREN55	5.94	78.2	366	4.1	1.32
C4	2	ADL	GOLD11	5.74	78.2	363	5.0	1.37
C4	2	ADL	GOLD14	5.97	78.7	351	5.3	1.38
C4	2	ADL	GOLD15	5.47	71.9	339	4.7	1.34
C4	2	80	BLUE11	5.20	75.7	338	4.2	1.29

Listing of Purebred Data
Egg Shell Variables   (Continued)

LINE	GEN	FDLVL	ID	SHELL	SWSA	STHICK	POR	ECON
C4	2	80	BLUE20	5.71	80.2	356	4.4	1.33
C4	2	80	BLUE26	5.37	77.6	328	5.1	1.28
C4	2	80	BLUE28	5.26	73.8	336	4.4	1.31
C4	2	80	BLUE41	5.32	75.2	346	4.5	1.32
C4	2	80	BLUE44	5.59	77.4	345	4.8	1.32
C4	3	ADL	BLUE67	4.77	70.8	301	5.3	1.33
C4	3	ADL	BLUE87	5.23	74.5	287	4.2	1.30
C4	3	ADL	BLUE88	.	.	.	.	.
C4	3	ADL	S551	4.46	69.6	298	4.6	1.28
C4	3	ADL	S575	4.69	70.6	306	4.5	1.29
C4	3	80	GOLD76	5.50	80.4	336	3.9	1.31
C4	3	80	BLUE54	4.46	70.5	302	4.4	1.31
C4	3	80	BLUE96	5.00	72.5	310	4.2	1.34
C4	3	80	GOLD99	5.71	83.7	354	3.7	1.31
C4	3	80	S582	4.94	73.9	307	4.8	1.31
C4	3	80	S680	4.83	77.5	338	4.2	1.31
C4	3	80	S682	4.93	75.4	309	4.4	1.29
C4	3	80	S578	5.56	84.1	361	3.6	1.36
C4	4	ADL	PINK33	5.68	81.1	374	4.8	1.30
C4	4	ADL	PINK34	5.86	82.0	379	4.1	1.35
C4	4	80	PINK44	5.98	84.6	378	4.3	1.40
C4	4	80	PINK45	5.87	86.3	398	3.7	1.38

5. Listing of Purebred Data
Body Weights

LINE	GEN	FDLVL	ID	BW1	BW2	BW3	BW4	BW5	BW6	BW7	BW8
A1	1	80	YEL1	.	.	.	.	.	.	.	.
A1	2	ADL	GREN26	40	46	79	135	208	283	370	529
A1	2	ADL	GREN35	40	55	104	174	248	337	420	537
A1	2	ADL	GREN92	45	59	104	177	265	371	444	675
A1	2	ADL	GREN72	40	52	93	155	227	300	365	585
A1	2	ADL	GREN58	52	62	109	176	253	342	429	675
A1	2	ADL	GOLD4	50	59	99	159	230	303	377	585
A1	2	80	BLUE2	48	73	114	181	264	363	469	620
A1	2	80	BLUE25	48	64	102	174	246	338	393	523
A1	3	ADL	S623	48	60	111	183	243	348	455	705
A1	3	ADL	S626	43	66	116	187	246	338	428	640
A1	3	ADL	S628	43	56	87	147	207	299	377	610
A1	3	ADL	S640	41	78	143	210	295	375	460	695
A1	3	ADL	S647	39	75	136	203	290	354	430	670
A1	3	ADL	S641	40	73	136	210	295	365	485	710
A1	3	80	GOLD49	47	67	122	190	260	365	450	665
A1	3	80	GOLD19	45	73	135	203	272	390	485	740
A1	3	80	GREN65	43	73	129	175	290	375	515	760
A1	3	80	GOLD61	39	75	137	217	312	388	500	720
A1	3	80	GOLD62	38	73	131	215	310	375	500	730
A1	3	80	S566	41	62	107	187	255	340	440	795
A1	3	80	S568	42	71	130	211	280	370	485	830
A1	3	80	GOLD6	44	63	114	175	230	310	400	620
A1	3	80	GRN100	41	75	127	175	291	375	500	705
A1	4	ADL	PINK80	48	64	114	191	285	375	514	765
A1	4	ADL	PINK52	46	72	127	209	296	341	455	680
A1	4	ADL	PINK53	46	73	130	205	289	351	406	600
A1	4	80	GREEN4	37	65	119	196	275	390	508	780
A1	4	80	PINK99	39	66	124	190	264	354	455	635
A1	4	80	GREEN1	37	69	129	205	275	390	500	710
A3	1	80	YEL2	.	.	.	.	.	.	.	.
A3	2	ADL	GREN25	50	49	75	125	192	272	362	560
A3	2	ADL	GREN14	49	61	102	156	238	330	421	604
A3	2	ADL	GREN15	47	53	89	146	219	299	378	546
A3	2	ADL	GREN96	45	64	105	168	233	303	369	510
A3	2	ADL	GOLD9	43	59	110	179	263	353	393	600
A3	2	ADL	GOLD12	42	56	93	154	220	305	352	530
A3	2	ADL	GOLD16	42	54	96	156	218	294	355	485
A3	2	80	BLUE5	44	69	112	169	243	300	402	605
A3	2	80	BLUE21	47	61	108	175	238	313	410	488
A3	2	80	BLUE30	51	67	114	187	274	360	445	655
A3	3	ADL	S629	42	47	82	132	184	240	360	540
A3	3	ADL	S638	43	85	149	231	326	422	555	830
A3	3	ADL	S639	42	71	125	192	275	346	555	659
A3	3	ADL	S649	44	78	138	218	302	380	510	740
A3	3	ADL	S659	40	76	133	201	264	350	440	665
A3	3	ADL	S660	40	89	149	209	265	376	475	715
A3	3	ADL	S662	40	62	111	174	220	335	420	650
A3	3	80	GOLD69	39	75	133	212	295	380	500	705
A3	3	80	GOLD72	38	72	130	210	304	390	540	785
A3	3	80	GOLD92	39	71	130	205	289	367	465	674
A3	3	80	GOLD93	34	65	123	194	280	365	490	740
A3	3	80	S574	37	62	110	175	251	356	450	535

Listing of Purebred Data
Body Weights   (Continued)

LINE	GEN	FDLVL	ID	BW1	BW2	BW3	BW4	BW5	BW6	BW7	BW8
A3	3	80	GREN9.1	40	70	135	180	310	400	520	745
A3	3	80	GREN95	37	72	132	190	305	400	510	765
A3	3	80	S571	42	70	120	195	273	384	505	885
A3	3	80	GOLD75	43	73	126	180	240	335	440	675
A3	4	ADL	GREN22	36	60	115	193	285	385	510	720
A3	4	ADL	GREN24	39	62	117	185	245	325	425	640
A3	4	80	GREN16	43	61	120	197	278	387	515	775
A3	4	80	GREN17	40	64	117	195	280	408	545	755
A3	4	80	GREN3.1	38	61	110	165	235	302	410	634
A4	1	80	YEL3	•	•	•	•	•	•	•	•
A4	2	ADL	GREEN3	56	84	126	208	311	423	530	735
A4	2	ADL	GREN21	43	53	87	148	226	311	391	533
A4	2	ADL	GREN31	42	70	129	211	275	353	393	524
A4	2	ADL	GREN68	39	54	98	165	240	320	389	560
A4	2	80	BLUE9	44	75	113	180	261	355	453	614
A4	2	80	BLUE22	49	70	121	192	282	380	470	562
A4	2	80	BLUE24	48	72	123	203	297	407	460	598
A4	2	80	BLUE3.1	47	67	117	196	285	386	467	650
A4	2	80	BLUE32	46	63	114	196	291	411	531	780
A4	2	80	BLUE38	46	57	103	153	253	345	445	535
A4	2	80	BLUE33	47	56	95	169	256	375	438	670
A4	3	ADL	GOLD79	45	72	130	194	280	319	440	650
A4	3	ADL	S634	42	54	100	148	228	300	410	610
A4	3	ADL	BLUE81	42	50	89	137	201	270	396	610
A4	3	ADL	S642	40	77	126	193	267	620	425	645
A4	3	ADL	S644	40	66	111	179	260	334	450	680
A4	3	ADL	S645	40	68	121	190	271	315	450	680
A4	3	ADL	S655	39	61	107	162	220	284	355	540
A4	3	80	BLUE51	41	57	94	142	188	286	360	545
A4	3	80	BLUE99	40	47	76	113	185	231	365	565
A4	3	80	BLU.100	43	50	81	123	197	261	364	540
A4	3	80	BLUE60	45	49	68	102	155	234	320	576
A4	3	80	BLUE74	40	48	82	134	216	294	406	611
A4	3	80	BLUE90	41	47	80	129	187	235	340	515
A4	3	80	GOLD89	42	69	123	187	255	330	461	685
A4	3	80	BLUE86	39	43	63	102	158	182	295	440
A4	3	80	GOLD84	44	73	116	180	255	340	455	690
A4	3	80	GOLD86	46	63	101	155	214	250	334	540
A4	3	80	GOLD88	41	72	134	201	290	387	522	790
A4	4	ADL	PINK1	47	71	133	205	276	365	465	650
A4	4	ADL	PINK3	45	67	115	190	255	315	386	606
A4	4	ADL	PINK8.1	36	46	76	131	181	237	305	505
A4	4	80	PINK5	43	61	105	182	252	320	393	595
A4	4	80	PINK6	43	57	101	156	244	322	426	665
A4	4	80	PINK7	39	52	92	150	215	286	385	605
C4	1	ADL	YEL4	•	•	•	•	•	•	•	•
C4	2	ADL	GREN41	45	65	108	166	236	313	376	491
C4	2	ADL	GREN47	47	71	118	193	264	351	393	507
C4	2	ADL	GREN55	37	57	95	142	195	263	340	382
C4	2	ADL	GOLD11	45	60	100	161	236	316	354	505
C4	2	ADL	GOLD14	52	65	95	147	209	281	340	489
C4	2	ADL	GOLD15	50	68	122	196	283	373	435	625
C4	2	80	BLUE11	49	81	136	216	304	407	502	704

Listing of Purebred Data
Body Weights   (Continued)

LINE	GEN	FDLVL	ID	BW1	BW2	BW3	BW4	BW5	BW6	BW7	BW8
C4	2	80	BLUE20	51	66	121	191	268	361	565	789
C4	2	80	BLUE26	51	71	115	248	333	401	590	850
C4	2	80	BLUE28	54	64	108	176	253	331	399	570
C4	2	80	BLUE41	49	61	104	163	242	316	389	500
C4	2	80	BLUE44	49	64	112	161	247	328	390	540
C4	3	ADL	BLUE67	43	65	125	190	258	334	420	644
C4	3	ADL	BLUE87	37	49	95	153	232	310	429	640
C4	3	ADL	BLUE88	36	44	75	109	175	215	299	505
C4	3	ADL	S551	33	53	98	152	215	295	310	510
C4	3	ADL	S575	39	67	105	160	216	285	384	445
C4	3	80	GOLD76	41	71	122	167	230	307	360	560
C4	3	80	BLUE54	38	59	113	183	255	349	424	639
C4	3	80	BLUE96	36	47	84	138	186	251	360	529
C4	3	80	GOLD99	39	69	114	175	230	326	410	610
C4	3	80	S582	40	69	113	166	205	294	360	585
C4	3	80	S680	39	68	121	176	206	305	380	590
C4	3	80	S682	37	70	127	181	230	319	435	661
C4	3	80	S578	36	63	101	147	210	370	370	443
C4	4	ADL	PINK33	44	66	104	115	230	315	400	605
C4	4	ADL	PINK34	46	70	125	210	277	365	454	655
C4	4	80	PINK44	36	63	116	190	270	344	446	680
C4	4	80	PINK45	36	60	107	172	250	325	426	665

Listing of Purebred Data
Body Weights   (Continued)

LINE	GEN	FDLVL	ID	BW9	BW10	BW11	BW12	BW13	BW14	BW15	BW16
A1	1	80	YEL1	.	.	.	.	1340	1535	1390	1250
A1	2	ADL	GREN26	761	995	1215	1425	1545	1850	2005	2170
A1	2	ADL	GREN35	747	970	1245	1445	1650	1960	2145	2265
A1	2	ADL	GREN92	860	1125	1410	1635	1655	2160	2320	2505
A1	2	ADL	GREN72	800	1105	1360	1590	1705	2090	2105	2535
A1	2	ADL	GREN58	880	1100	1345	1445	1600	2125	2020	2275
A1	2	ADL	GOLD4	830	1110	1455	1635	1795	2285	2355	2330
A1	2	80	BLUE2	867	1115	1350	1570	1695	1790	1855	2130
A1	2	80	BLUE25	685	942	1210	1345	1460	1690	1810	1985
A1	3	ADL	S623	965	1185	1345	1515	1715	2110	2145	2250
A1	3	ADL	S626	890	1110	1275	1425	1565	1985	2015	2010
A1	3	ADL	S628	875	1145	1355	1520	1755	2105	2095	2110
A1	3	ADL	S640	865	1180	1280	1245	1280	1535	1740	1530
A1	3	ADL	S647	870	1080	1185	1285	1440	1680	1800	1620
A1	3	ADL	S641	950	1060	1255	1420	1590	1975	1955	1825
A1	3	80	GOLD49	860	1055	1190	1300	1465	1545	1695	1960
A1	3	80	GOLD19	960	1140	1300	1440	1630	1735	1920	2005
A1	3	80	GREN65	1025	1280	1445	1615	1720	1730	1895	1965
A1	3	80	GOLD61	925	1200	1335	1445	1650	1755	1700	1700
A1	3	80	GOLD62	995	1225	1415	1585	1695	1830	2135	1810
A1	3	80	S566	1015	1145	1400	1505	1610	1790	1870	2085
A1	3	80	S568	1025	1125	1340	1430	1510	1705	1620	1700
A1	3	80	GOLD6	845	1100	1230	1360	1590	1765	1780	1800
A1	3	80	GRN100	930	1135	1265	1440	1590	1690	2025	1900
A1	4	ADL	PINK80	1000	1265	1470	1397	1610	2075	2175	2245
A1	4	ADL	PINK52	900	1135	1320	1530	1720	1915	2180	2200
A1	4	ADL	PINK53	820	1050	1245	1410	1600	2010	1940	1990
A1	4	80	GREEN4	1035	1225	1350	1580	1735	1810	2055	1855
A1	4	80	PINK99	845	1030	1180	1345	1390	1580	1710	1645
A1	4	80	GREEN1	920	1125	1260	1460	1535	1730	1765	1750
A3	1	80	YEL2	.	.	.	.	1660	1905	1710	1585
A3	2	ADL	GREN25	754	980	1210	1365	1490	1790	1845	1985
A3	2	ADL	GREN14	812	1050	1290	1410	1465	1890	1955	2095
A3	2	ADL	GREN15	752	945	1150	1305	1475	1775	2185	1960
A3	2	ADL	GREN96	665	891	1105	1210	1285	1605	1672	1755
A3	2	ADL	GOLD9	810	1020	1230	1380	1550	1850	2025	2065
A3	2	ADL	GOLD12	730	905	1150	1330	1480	1720	1620	1810
A3	2	ADL	GOLD16	685	880	1040	1210	1350	1590	1600	1540
A3	2	80	BLUE5	816	1060	1260	1450	1615	1900	1760	1860
A3	2	80	BLUE21	692	945	1200	1440	1565	1710	1780	2015
A3	2	80	BLUE30	915	1200	1405	1650	1785	2020	1680	1880
A3	3	ADL	S629	770	920	1135	1210	1485	1840	1680	1880
A3	3	ADL	S638	1100	1230	1475	1585	1695	1965	2090	1895
A3	3	ADL	S639	925	1050	1310	1475	1625	2020	2095	1780
A3	3	ADL	S649	965	1005	1195	1320	1430	1937	1935	1870
A3	3	ADL	S659	870	1090	1275	1425	1545	1845	1910	1975
A3	3	ADL	S660	945	914	1325	1525	1610	1865	2140	2150
A3	3	ADL	S662	880	1085	1275	1460	1565	1750	1740	1650
A3	3	80	GOLD69	930	1150	1270	1410	1545	1860	1760	1650
A3	3	80	GOLD72	1000	1200	1390	1545	1715	1615	1705	1575
A3	3	80	GOLD92	865	905	1065	1215	1450	1785	1910	1680
A3	3	80	GOLD93	1010	1015	1200	1335	1630	1665	1750	1720
A3	3	80	S574	750	950	1135	1290	1485	1665	1750	1720

Listing of Purebred Data
Body Weights (Continued)

LINE	GEN	FDLVL	ID	BW9	BW10	BW11	BW12	BW13	BW14	BW15	BW16
A3	3	80	GREN91	885	1170	1240	1470	1605	1735	1965	1820
A3	3	80	GREN95	995	1210	1360	1560	1630	1830	2015	1790
A3	3	80	S57.1	1115	1205	1455	1560	1675	1800	1710	1710
A3	3	80	GOLD75	860	1090	1195	1370	1635	1745	1710	1710
A3	4	ADL	GREN22	990	1220	1375	1490	1635	1830	1915	1925
A3	4	ADL	GREN24	845	1060	1190	1315	1415	1710	1845	1775
A3	4	80	GREN16	1010	1250	1375	1465	1610	1740	1960	1735
A3	4	80	GREN17	1020	1240	1360	1455	1625	1690	1870	1955
A3	4	80	GREN31	780	1065	1310	1470	1710	1775	1950	1820
A4	1	80	YEL3	·	·	·	·	1490	1605	1815	1620
A4	2	ADL	GREEN3	922	1165	1380	1540	1550	1865	1750	1955
A4	2	ADL	GREN21	737	940	1180	1375	1520	2040	2280	2430
A4	2	ADL	GREN31	747	885	1120	1340	1460	1930	1835	1850
A4	2	ADL	GREN68	775	1045	1180	1360	1490	1795	1565	1685
A4	2	80	BLUE9	802	1015	1320	1500	1650	1875	2040	2010
A4	2	80	BLUE22	765	1025	1275	1540	1700	1920	1650	1795
A4	2	80	BLUE24	808	1035	1315	1500	1570	1855	1645	1900
A4	2	80	BLUE31	900	1180	1345	1540	1680	1735	1870	1780
A4	2	80	BLUE32	1045	1345	1540	1680	1735	1870	1780	2100
A4	2	80	BLUE38	775	1020	1285	1425	1585	1735	1760	2070
A4	2	80	BLUE33	985	1180	1490	1645	1760	1995	1930	1780
A4	3	ADL	GOLD79	900	1000	1205	1340	1450	1850	1837	1730
A4	3	ADL	S634	840	1045	1240	1425	1595	1940	1870	1980
A4	3	ADL	BLUE81	880	1075	1320	1375	1615	1890	2260	2085
A4	3	ADL	S642	905	1035	1290	1485	1645	1955	2075	1935
A4	3	ADL	S644	925	1110	1310	1400	1540	1895	2245	1935
A4	3	ADL	S645	925	1030	1275	1445	1600	1903	2200	1725
A4	3	ADL	S655	730	910	1075	1225	1365	1710	1760	1780
A4	3	80	BLUE51	770	950	1140	1300	1405	1490	1660	1785
A4	3	80	BLUE99	841	1050	1215	1340	1490	1660	1655	1555
A4	3	80	BLU100	785	955	1180	1275	1490	1655	1875	1645
A4	3	80	BLUE60	855	1080	1290	1450	1610	1805	1955	1935
A4	3	80	BLUE74	850	1005	1250	1435	1590	1755	1380	1610
A4	3	80	BLUE90	770	945	1175	1275	1565	1605	1715	1710
A4	3	80	GOLD89	835	945	1235	1260	1365	1635	1575	1355
A4	3	80	BLUE86	638	835	1030	1130	1285	1510	1530	1635
A4	3	80	GOLD84	925	965	1265	1355	1475	1625	1660	1660
A4	3	80	GOLD86	765	810	1110	1215	1345	1470	1570	1565
A4	3	80	GOLD88	1045	1075	1365	1475	1635	1830	1705	1640
A4	4	ADL	PINK1	892	1105	1315	1510	1615	1825	1950	1725
A4	4	ADL	PINK3	790	935	1120	1345	1465	1745	1760	1560
A4	4	ADL	PINK81	720	945	1145	1300	1385	1505	1630	1585
A4	4	80	PINK5	780	960	1120	1235	1270	1405	1440	1510
A4	4	80	PINK6	840	990	1150	1295	1335	1580	1632	1680
A4	4	80	PINK7	810	1110	1170	1355	1420	1565	1800	1640
C4	1	ADL	YEL4	·	·	·	·	1352	1630	1582	1660
C4	2	ADL	GREN41	707	920	1200	1420	1545	1930	2205	2185
C4	2	ADL	GREN47	702	905	1152	1350	1515	1870	1955	2100
C4	2	ADL	GREN55	553	735	1020	1225	1410	1740	2015	2025
C4	2	ADL	GOLD11	655	890	1105	1295	1510	1970	1890	2105
C4	2	ADL	GOLD14	715	975	1215	1370	1520	1825	1820	1980
C4	2	ADL	GOLD15	895	1190	1365	1570	1665	1940	1970	2065
C4	2	80	BLUE11	912	1150	1360	1550	1650	1955	1735	1920

Listing of Purebred Data
Body Weights   (Continued)

LINE	GEN	FDLVL	ID	BW9	BW10	BW11	BW12	BW13	BW14	BW15	BW16
C4	2	80	BLUE20	1020	1205	1440	1580	1645	1670	1775	2020
C4	2	80	BLUE26	1085	1320	1470	1475	1700	1690	1905	1850
C4	2	80	BLUE28	740	975	1230	1370	1480	1700	1440	1575
C4	2	80	BLUE41	710	960	1180	1330	1425	1625	1705	1790
C4	2	80	BLUE44	785	1045	1305	1540	1625	1875	1720	1925
C4	3	ADL	BLUE67	885	1065	1205	1365	1520	1770	1792	1740
C4	3	ADL	BLUE87	885	1110	1300	1450	1585	1870	1825	1880
C4	3	ADL	BLUE88	695	885	1110	1230	1435	1715	1810	2010
C4	3	ADL	S551	710	890	1130	1290	1415	1775	1820	1835
C4	3	ADL	S575	700	935	1155	1335	1380	1690	1950	1985
C4	3	80	GOLD76	780	1035	1180	1355	1510	1585	1690	1565
C4	3	80	BLUE54	905	1110	1325	1510	1680	1750	1815	1690
C4	3	80	BLUE96	770	970	1180	1275	1490	1635	1518	1480
C4	3	80	GOLD99	835	1060	1215	1390	1470	1675	1540	1660
C4	3	80	S582	805	1010	1180	1335	1400	1565	1665	1660
C4	3	80	S680	755	785	955	1140	1240	1395	1500	1510
C4	3	80	S682	890	1110	1275	1405	1480	1680	1775	1670
C4	3	80	S578	670	870	1100	1275	1465	1675	1490	1605
C4	4	ADL	PINK33	814	1005	1195	1355	1490	1715	1765	1655
C4	4	ADL	PINK34	855	1045	1210	1325	1465	1775	1715	1670
C4	4	80	PINK44	930	1125	1305	1502	1610	1785	1615	1695
C4	4	80	PINK45	889	1130	1360	1545	1640	1830	1765	1770

Listing of Purebred Data
Body Weights (Continued)

LINE	GEN	FDLVL	ID	BW17	BW18	BW19	BW20	BW21	BW22	BW23	BW24	BW25
A1	1	80	YEL1	1320	1270	1350	1370	1430	1270	1450	1330	1340
A1	2	ADL	GREN26	2275	2220	2335	2235	2490	2485	2505	2575	2640
A1	2	ADL	GREN35	2235	2100	2380	2330	2245	2340	2305	2325	2405
A1	2	ADL	GREN92	2700	2750	2760	2740	2700	2765	2745	2735	2700
A1	2	ADL	GREN72	2640	2660	2740	2945	2655	2695	2680	2915	2915
A1	2	ADL	GREN58	2535	2650	2820	2820	2895	2945	3040	3085	3220
A1	2	ADL	GOLD4	2510	2500	2680	2560	2385	2470	2510	2625	2695
A1	2	80	BLUE2	1900	1820	1915	1815	1830	1890	1965	1760	1925
A1	2	80	BLUE25	2050	2060	2175	2100	1980	1945	1900	1980	2015
A1	3	ADL	S623	2240	2242	2455	2465	2485	2505	2250	2570	2335
A1	3	ADL	S626	2010	2065	2175	2040	2250	2245	2225	2370	2300
A1	3	ADL	S628	2145	2295	2285	2180	2295	2345	2265	2750	2320
A1	3	ADL	S640	1640	1675	1530	1615	1620	1610	1690	1620	1710
A1	3	ADL	S647	1800	1865	1775	1895	1980	2025	1770	1820	1890
A1	3	ADL	S641	2085	2140	2055	2138	2210	2300	2360	2300	2340
A1	3	80	GOLD49	1760	1775	1560	1675	1540	1580	1610	1700	1785
A1	3	80	GOLD19	1920	1860	1815	1932	1840	1870	1790	1930	2045
A1	3	80	GREN65	2110	2345	2050	1970	1930	1955	1965	1940	1850
A1	3	80	GOLD61	1810	1700	1610	1760	1635	1640	1700	1595	1650
A1	3	80	GOLD62	1940	1860	1805	1910	1770	1695	1705	1810	1840
A1	3	80	S566	2025	1840	1980	1835	2025	1880	1770	1800	1910
A1	3	80	S568	1825	1600	1720	1595	1580	1520	1480	1565	1590
A1	3	80	GOLD6	1825	1730	1745	1720	1880	1640	1675	1720	1870
A1	3	80	GRN100	1845	1860	1770	1868	1835	1765	1745	1825	1900
A1	4	ADL	PINK80	2035	2275	2470	2405	2400	2355	2280	2480	2145
A1	4	ADL	PINK52	2100	2310	2370	2490	2410	2215	2235	2340	2245
A1	4	ADL	PINK53	1980	2145	2280	2345	2385	2370	2460	2480	2455
A1	4	80	GREEN4	1840	1580	1685	1730	1730	1575	1800	1695	1580
A1	4	80	PINK99	1690	1565	1595	1610	1585	1650	1700	1670	1710
A1	4	80	GREEN1	1540	1685	1685	1585	1655	1630	1690	1615	1670
A3	1	80	YEL2	1625	1565	1705	1710	1720	1720	1705	1645	1610
A3	2	ADL	GREN25	2055	2050	2105	2190	2055	2050	2135	2210	2315
A3	2	ADL	GREN14	2140	2045	2295	2340	2365	2355	2375	2465	2550
A3	2	ADL	GREN15	2015	1820	2025	1900	1970	1950	2150	2415	2445
A3	2	ADL	GREN96	1810	1930	2030	2065	2035	2120	2145	2150	1970
A3	2	ADL	GOLD9	2255	2270	2435	2385	2440	2465	2500	2475	2500
A3	2	ADL	GOLD12	1820	1885	1990	2060	2055	2030	2035	2090	1945
A3	2	ADL	GOLD16	1985	1980	2045	1990	2165	2155	2150	2135	2225
A3	2	80	BLUE5	1600	1585	1630	1730	1655	1660	1720	1685	1765
A3	2	80	BLUE21	1890	1865	1895	2005	1810	1860	1760	1795	1920
A3	2	80	BLUE30	1915	2090	2045	2060	1995	1985	1910	2005	2135
A3	3	ADL	S629	1950	1850	1940	1910	1935	1955	2000	2200	1975
A3	3	ADL	S638	2200	2240	2210	2415	2340	2360	2410	2510	2705
A3	3	ADL	S639	2095	2278	2120	2270	2070	2245	2190	2218	2230
A3	3	ADL	S649	1840	1905	2020	1940	1975	2050	2060	2055	2135
A3	3	ADL	S659	1890	1955	2265	1935	1915	1940	1950	2610	2030
A3	3	ADL	S660	1865	1950	1990	2000	1975	2045	1980	2000	2045
A3	3	ADL	S662	2085	2145	2185	2205	2295	2275	2290	2320	2315
A3	3	80	GOLD69	1865	1695	1640	1815	1740	1630	1660	1625	1690
A3	3	80	GOLD72	1845	1965	1760	1880	1735	1610	1630	1615	1570
A3	3	80	GOLD92	1710	1670	1525	1845	1620	1610	1520	1500	1405
A3	3	80	GOLD93	1810	1795	1730	1860	1630	1695	1555	1650	1645
A3	3	80	S574	1725	1690	1760	1740	1775	1720	1760	1965	1950

Listing of Purebred Data
Body Weights   (Continued)

LINE	GEN	FDLVL	ID	BW17	BW18	BW19	BW20	BW21	BW22	BW23	BW24	BW25
A3	3	80	GREN9J	1900	1840	1915	1795	1750	1765	1715	1800	1875
A3	3	80	GREN95	1850	1765	1800	1775	1705	1720	1740	1830	1910
A3	3	80	S571	1900	1720	1800	1710	1770	1710	1770	1710	1880
A3	3	80	GOLD75	1710	1530	1570	1645	1640	1585	1630	1650	1630
A3	4	ADL	GREN22	2120	2230	2380	2410	2515	2555	2590	2585	2620
A3	4	ADL	GREN24	1875	1935	1980	2055	1995	1930	2005	1960	2030
A3	4	80	GREN16	1855	1805	1770	1750	1785	1740	1745	1655	1730
A3	4	80	GREN17	1885	1750	1745	1710	1715	1730	1690	1715	1795
A3	4	80	GREN31	1600	1835	1760	1790	1710	1800	1785	1880	1885
A4	1	80	YEL3	1747	1745	1700	1680	1840	1760	1765	1610	1740
A4	2	ADL	GREEN3	2100	2055	2285	2295	2280	2360	2325	2355	2390
A4	2	ADL	GREN21	1985	1925	2070	2140	2070	2005	2045	2135	2150
A4	2	ADL	GREN31	2400	2290	2640	2525	2600	2655	2650	2910	3000
A4	2	ADL	GREN68	2000	2280	2175	2085	2225	2250	2155	2200	2045
A4	2	80	BLUE9	1755	1750	1905	1810	1625	1765	1710	1720	1760
A4	2	80	BLUE22	2010	1930	2120	2340	2120	2100	2170	2225	2260
A4	2	80	BLUE24	1705	1685	1755	1915	1655	1960	1840	1960	1855
A4	2	80	BLUE31	1815	1810	1930	1930	1710	1845	1875	1810	1920
A4	2	80	BLUE32	2260	2230	2405	2500	2175	1995	2165	2185	2230
A4	2	80	BLUE38	2100	2130	2375	2370	2135	2110	2180	2125	2105
A4	2	80	BLUE33	1820	1950	1880	2010	2000	1790	1810	1900	1960
A4	3	ADL	GOLD79	1750	1845	1945	1735	1930	1842	1890	1950	1900
A4	3	ADL	S634	2115	2180	2210	2345	2445	2540	2590	1955	2730
A4	3	ADL	BLUE81	2170	2000	2240	2140	2045	2135	2170	1880	2115
A4	3	ADL	S642	2025	2107	2075	2195	2295	2265	2225	2295	2370
A4	3	ADL	S644	2055	2120	2130	2220	2600	2350	2260	2295	2055
A4	3	ADL	S645	1905	1955	1945	2065	2015	2060	2030	2000	2040
A4	3	ADL	S655	1805	1915	1865	1945	1885	1890	1955	2000	2015
A4	3	80	BLUE5J	1720	1815	1620	1500	1555	1700	1530	1565	1615
A4	3	80	BLUE99	1565	1535	1612	1460	1615	1600	1485	1525	1530
A4	3	80	BLU100	1580	1725	1663	1490	1520	1510	1570	1470	1487
A4	3	80	BLUE60	1910	1720	1725	1690	1655	1680	1615	1685	1560
A4	3	80	BLUE74	1580	1490	1442	1390	1530	1490	1610	1585	1395
A4	3	80	BLUE90	1740	1715	1710	1680	1772	1625	1555	1580	1640
A4	3	80	GOLD89	1510	1620	1445	1477	1525	1500	1400	1510	1370
A4	3	80	BLUE86	1555	1625	1590	1580	1640	1625	1555	1535	1650
A4	3	80	GOLD84	1670	1620	1600	1670	1600	1560	1610	1525	1570
A4	3	80	GOLD86	1680	1795	1610	1640	1735	1615	1705	1200	1525
A4	3	80	GOLD88	1765	1835	1820	1640	1730	1700	1825	1725	1750
A4	4	ADL	PINK1	1950	1800	1900	1975	2035	1980	1985	2045	2015
A4	4	ADL	PINK3	1790	1860	1980	2110	2100	2065	2050	2215	2165
A4	4	ADL	PINK8J	1430	1750	1780	1770	1825	1690	1715	1690	1615
A4	4	80	PINK5	1635	1480	1625	1515	1600	1500	1425	1460	1455
A4	4	80	PINK6	1760	1765	1710	1705	1725	1645	1585	1720	1650
A4	4	80	PINK7	1665	1600	1800	1745	1725	1700	1730	1820	1795
C4	1	ADL	YEL4	1697	1730	1755	1775	1665	1700	1765	1790	1815
C4	2	ADL	GREN41	2225	2125	2300	2355	2355	2335	2360	2485	2365
C4	2	ADL	GREN47	2100	2050	2305	2395	2335	2255	2365	2475	2635
C4	2	ADL	GREN55	2000	1910	2025	2120	2060	2095	2135	2150	2100
C4	2	ADL	GOLD11	2165	2210	2340	2355	2305	2305	2365	2405	2355
C4	2	ADL	GOLD14	2000	2065	2195	2190	2160	2135	2160	2155	2280
C4	2	ADL	GOLD15	2160	2230	2250	2280	2280	2340	2340	2350	2490
C4	2	80	BLUE11	1855	1775	1930	1895	1733	1790	1720	1755	1905

Listing of Purebred Data
Body Weights   (Continued)

LINE	GEN	FDLVL	ID	BW17	BW18	BW19	BW20	BW21	BW22	BW23	BW24	BW25
C4	2	80	BLUE20	1880	1765	1900	1920	1955	1820	1745	1765	1865
C4	2	80	BLUE26	1875	1920	1920	1865	1855	1785	1795	1810	1870
C4	2	80	BLUE28	1530	1555	1565	1535	1465	1525	1600	1525	1580
C4	2	80	BLUE41	1735	1715	1825	1790	1740	1645	1665	1740	1800
C4	2	80	BLUE44	1925	1910	1925	2030	1890	1840	1895	1840	1850
C4	3	ADL	BLUE67	1770	1795	1790	1770	1860	1860	1905	1995	1910
C4	3	ADL	BLUE87	2050	1850	2195	2050	1975	1930	2045	1895	1990
C4	3	ADL	BLUE88	2050	2045	2070	2075	2045	2115	2040	2260	1920
C4	3	ADL	S551	1775	1830	1880	1785	1860	1645	1785	1930	1870
C4	3	ADL	S575	1760	1860	1920	1835	1825	1885	1850	1890	2115
C4	3	80	GOLD76	1655	1680	1560	1560	1545	1495	1455	1460	1455
C4	3	80	BLUE54	1845	1790	1845	1755	1645	1660	1565	1740	1590
C4	3	80	BLUE96	1525	1510	1460	1540	1380	1415	1458	1385	1370
C4	3	80	GOLD99	1640	1674	1535	1625	1490	1480	1420	1450	1445
C4	3	80	S582	1690	1755	1595	1670	1605	1570	1525	1620	1765
C4	3	80	S680	1445	1454	1355	1540	1370	1417	1380	1500	1445
C4	3	80	S682	1525	1590	1560	1475	1485	1510	1460	1390	1435
C4	3	80	S578	1670	1580	1550	1585	1640	1690	1490	1610	1605
C4	4	ADL	PINK33	1805	1795	1870	1930	1895	1765	1825	1820	1780
C4	4	ADL	PINK34	1815	1795	1870	1850	1980	1830	1870	1830	1800
C4	4	80	PINK44	1685	1565	1615	1615	1675	1555	1515	1600	1635
C4	4	80	PINK45	1705	1820	1700	1865	1770	1710	1690	1665	1840

6. Listing of Breeds Data
Production Variables

BREED	LINE	FDLVL	ID	F18 $\overline{6}{6}$	F22 $\overline{4}{2}$	EGG18 $\overline{6}{6}$	EGG22 $\overline{4}{2}$	FCE18 $\overline{6}{6}$	FCE22 $\overline{4}{2}$	AEW18 $\overline{6}{6}$	AEW22 $\overline{4}{2}$
CROS	A3XA4	ADL	MOR51	115	126	129	99	17.7	29.0	53.3	51.9
CROS	A3XA4	ADL	MOR50	126	128	212	95	31.0	31.0	61.7	58.5
CROS	A3XA4	ADL	MOR61	115	108	176	88	27.1	29.7	59.4	51.1
CROS	A3XA4	100	MOR44	100	100	203	85	36.0	34.8	59.5	57.3
CROS	A3XA4	100	MOR63	100	100	216	99	37.0	39.0	57.6	55.1
CROS	A3XA4	100	GREN95	100	100	180	81	34.2	35.5	63.8	61.3
CROS	A3XA4	80	GREN94	80	80	125	62	23.0	27.2	49.4	49.1
CROS	A3XA4	80	GREN93	80	80	106	49	22.5	23.6	57.0	54.0
CROS	A3XA4	90	MOR53	90	90	166	102	28.7	38.8	52.3	47.9
CROS	A3XA4	90	MOR55	90	90	137	84	25.9	35.7	57.3	53.5
CROS	A3XC4	ADL	GREN50	122	129	231	107	35.4	34.9	62.7	58.8
CROS	A3XC4	ADL	GREN51	135	136	233	103	31.1	31.2	60.5	57.6
CROS	A3XC4	ADL	GREN68	127	136	236	111	30.8	31.0	55.8	53.0
CROS	A3XC4	100	GREN46	100	100	188	80	29.6	29.6	52.8	51.8
CROS	A3XC4	100	GREN66	100	100	137	57	22.3	21.7	54.7	53.2
CROS	A3XC4	100	GREN67	100	100	198	98	32.4	36.7	54.9	52.5
CROS	A3XC4	80	GREN84	80	80	79	35	16.6	17.0	56.6	54.5
CROS	A3XC4	80	GREN89	80	80	101	51	20.6	23.6	54.9	51.9
CROS	A3XC4	80	GREN90	80	80	54	34	10.5	15.5	52.3	51.2
CROS	A3XC4	90	GREN59	90	90	128	64	23.9	27.4	56.5	54.0
CROS	A3XC4	90	GREN61	90	90	98	49	19.0	22.3	58.6	57.3
CROS	A3XC4	90	MOR27	90	90	179	80	31.8	32.4	53.7	51.0
CROS	C4XA1	ADL	MOR1	119	136	159	99	22.5	27.9	56.8	53.6
CROS	C4XA1	100	GREN36	100	100	147	67	26.6	27.5	60.7	57.4
CROS	C4XA1	80	GREN43	80	80	114	65	22.3	29.1	52.7	50.2
CROS	C4XA1	80	MOR8	80	80	85	41	19.9	21.9	63.0	59.8
CROS	C4XA1	80	MOR14	80	80	101	48	20.3	22.0	54.1	51.3
CROS	C4XA1	90	GREN33	90	90	116	51	22.5	22.0	58.7	54.2
CROS	C4XA1	90	GREN35	90	90	118	57	22.0	24.1	56.4	53.3
CROS	C4XA3	ADL	MOR35	134	139	163	100	20.9	27.0	57.9	52.5
CROS	C4XA3	ADL	MOR38	135	141	186	80	26.1	24.1	63.4	59.3
CROS	C4XA3	100	MOR43	100	100	133	63	23.8	25.5	60.3	56.6
CROS	C4XA3	100	MOR64	100	100	154	71	26.6	28.9	58.1	56.9
CROS	C4XA3	100	MOR71	100	100	158	91	26.3	35.0	56.1	53.9
CROS	C4XA3	80	MOR17	80	80	80	32	19.5	16.7	65.4	58.4
CROS	C4XA3	80	MOR32	80	80	81	36	17.1	17.3	56.9	53.7
CROS	C4XA3	80	MOR68	80	80	104	67	22.4	32.4	57.9	54.1
CROS	C4XA3	90	MOR42	90	90	128	78	23.2	32.2	54.8	52.1
CROS	C4XA3	90	MOR39	90	90	148	82	27.9	35.4	56.9	54.5
OUTC	STXA1	ADL	BLUE12	140	141	282	127	35.7	35.6	59.3	55.5
OUTC	STXA1	80	MOR73	80	80	130	77	26.5	35.4	54.8	51.6
OUTC	STXA1	80	MOR74	80	80	62	26	13.2	13.6	59.1	57.0
OUTC	STXA1	90	MOR75	90	90	124	69	22.2	27.9	54.2	51.0
OUTC	STXA1	90	MOR92	90	90	155	78	30.6	34.8	59.8	56.2
OUTC	STXA3	ADL	BLUE59	123	123	278	125	39.0	39.6	57.9	54.5
OUTC	STXA3	80	BLUE53	80	80	130	64	25.5	28.2	52.7	49.3

BREED	LINE	FDLVL	ID	F 1 8 $\overline{6}$ 6	F 2 2 $\overline{4}$ 2	E G G 1 8 $\overline{6}$ 6	E G G 2 2 $\overline{4}$ 2	F C E 1 8 $\overline{6}$ 6	F C E 2 2 $\overline{4}$ 2	A E W 1 8 $\overline{6}$ 6	A E W 2 2 $\overline{4}$ 2
OUTC	STXA4	ADL	BLUE60	138	137	227	116	29.1	33.5	59.2	55.4
OUTC	STXA4	ADL	BLUE64	141	140	233	113	29.6	33.3	60.0	57.6
OUTC	STXA4	80	BLUE55	80	80	67	30	13.0	13.3	52.1	49.6
OUTC	STXA4	80	BLUE58	80	80	65	36	14.2	18.0	58.7	56.0
OUTC	STXA4	90	BLUE66	90	90	160	89	37.3	34.8	54.8	52.8
OUTC	STXA4	90	BLUE68	90	90	128	79	27.4	31.7	53.9	50.6
OUTC	STXC4	ADL	BLUE27	140	141	250	125	31.0	34.4	58.4	54.3
OUTC	STXC4	ADL	BLUE28	122	120	272	127	35.5	38.9	53.7	51.5
OUTC	STXC4	100	MOR86	100	100	259	121	40.3	42.2	52.3	48.8
OUTC	STXC4	100	BLUE30	100	100	230	105	36.8	38.2	53.8	50.9
OUTC	STXC4	80	MOR88	80	80	154	82	29.8	36.2	52.1	49.5
OUTC	STXC4	80	BLUE38	80	80	84	55	18.1	26.7	57.7	54.4
OUTC	STXC4	80	BLUE39	80	80	108	61	22.7	29.8	56.6	54.8
OUTC	STXC4	90	MOR89	90	90	120	69	28.6	21.6	54.5	52.3
OUTC	STXC4	90	BLUE32	90	90	176	81	39.4	34.9	56.4	54.3
OUTC	STXC4	90	BLUE33	90	90	121	51	26.6	20.7	55.5	51.3
PURE	A1	ADL	PINK80	141	142	230	103	28.4	27.7	58.5	53.6
PURE	A1	ADL	PINK52	133	136	168	78	20.1	20.6	53.5	50.3
PURE	A1	ADL	PINK53	132	128	191	84	23.7	23.4	54.9	50.0
PURE	A1	100	PINK77	100	100	133	52	23.1	19.5	58.5	52.6
PURE	A1	100	PINK64	100	100	168	81	27.8	30.0	55.7	51.8
PURE	A1	100	PINK65	100	100	174	64	27.6	22.5	53.3	49.1
PURE	A1	80	GREEN4	80	80	110	55	21.5	24.7	52.4	50.2
PURE	A1	80	PINK99	80	80	71	36	14.2	16.2	53.9	50.5
PURE	A1	80	GREEN1	80	80	102	49	20.5	22.0	54.0	50.3
PURE	A1	90	PINK59	90	90	27	14	4.7	5.7	52.4	51.7
PURE	A1	90	PINK60	90	90	89	35	16.2	14.3	55.2	51.5
PURE	A1	90	PINK61	90	90	150	64	26.2	24.7	52.8	48.7
PURE	A3	ADL	GREN22	110	123	110	87	15.6	27.4	52.2	54.1
PURE	A3	ADL	GREN24	108	112	212	102	32.7	34.4	56.1	53.0
PURE	A3	100	GREN20	100	100	147	62	23.3	22.6	53.2	51.0
PURE	A3	100	GREN21	100	100	158	90	25.9	33.8	55.1	52.6
PURE	A3	100	GREN26	100	100	160	70	30.1	30.2	63.3	60.4
PURE	A3	80	GREN16	80	80	104	53	20.7	23.9	53.5	50.5
PURE	A3	80	GREN17	80	80	83	45	18.2	23.0	59.0	57.2
PURE	A3	80	GREN31	80	80	87	55	17.0	24.9	52.6	50.8
PURE	A3	90	GREN15	90	90	104	37	20.6	16.4	59.8	55.8
PURE	A3	90	GREN28	90	90	7	7	1.2	2.9	52.4	52.4
PURE	A3	90	GREN19	90	90	104	49	18.2	19.1	53.0	49.0
PURE	A4	ADL	PINK1	118	110	163	53	24.9	18.9	59.7	54.9
PURE	A4	ADL	PINK3	119	124	230	96	32.1	30.0	56.3	54.2
PURE	A4	ADL	PINK81	122	108	210	89	33.4	31.9	57.3	54.4
PURE	A4	100	PINK19	100	100	127	47	22.9	18.2	60.6	54.3
PURE	A4	100	PINK26	100	100	152	63	26.8	24.2	59.2	53.9
PURE	A4	80	PINK5	80	80	83	12	17.5	5.8	56.7	53.7
PURE	A4	80	PINK6	80	80	70	17	16.3	8.9	62.7	58.7

BREED	LINE	FDLVL	ID	F18 $\overline{6}$ 6	F22 $\overline{4}$ 2	EGG18 $\overline{6}$ 6	EGG22 $\overline{4}$ 2	FCE18 $\overline{6}$ 6	FCE22 $\overline{4}$ 2	AEW18 $\overline{6}$ 6	AEW22 $\overline{4}$ 2
PURE	A4	80	PINK7	80	80	89	43	17.7	19.1	53.3	49.6
PURE	A4	90	PINK16	90	90	164	71	29.6	29.7	54.6	52.7
PURE	A4	90	PINK18	90	90	84	34	16.8	14.6	60.5	54.1
PURE	C4	ADL	PINK33	125	128	229	92	30.6	27.0	56.2	52.8
PURE	C4	ADL	PINK34	116	114	214	87	31.1	29.0	56.5	53.2
PURE	C4	100	PINK47	100	100	102	33	17.6	12.7	58.1	53.9
PURE	C4	100	PINK48	100	100	167	75	25.8	25.6	52.0	47.7
PURE	C4	80	PINK44	80	80	105	42	20.7	18.5	53.0	49.3
PURE	C4	80	PINK45	80	80	79	33	15.2	14.0	51.7	47.5
PURE	C4	90	PINK86	90	90	125	57	22.7	23.6	55.0	52.2
PURE	C4	90	PINK88	90	90	59	16	11.2	6.8	57.3	53.2
PURE	C4	90	PINK89	90	90	154	65	27.6	26.7	54.2	51.7

7. Listing of Breeds Data
Physiological Variables

BREED	LINE	FDLVL	ID	MR	WTURN	TOTWAT	TSR	PLT4
CROS	A3XA4	ADL	MOR51	296.6	135.2	59.8	0.654	0.851
CROS	A3XA4	ADL	MOR50	301.7	146.3	54.7	0.406	0.923
CROS	A3XA4	ADL	MOR61	317.6	125.9	62.8	0.163	0.490
CROS	A3XA4	100	MOR44	305.9	106.7	60.6	0.310	0.871
CROS	A3XA4	100	MOR63	300.8	120.9	62.9	0.394	0.452
CROS	A3XA4	100	GREN95	282.4	115.6	60.8	0.315	0.710
CROS	A3XA4	80	GREN94	300.4	143.7	61.8	0.375	1.310
CROS	A3XA4	80	GREN93	314.2	140.2	70.1	0.501	0.987
CROS	A3XA4	90	MOR53	333.5	210.4	64.4	0.273	0.832
CROS	A3XA4	90	MOR55	274.5	170.8	64.7	0.332	0.871
CROS	A3XC4	ADL	GREN50	287.9	127.9	58.6	0.391	1.200
CROS	A3XC4	ADL	GREN51	312.5	108.4	58.2	0.358	1.045
CROS	A3XC4	ADL	GREN68	305.4	123.1	58.6	0.272	0.774
CROS	A3XC4	100	GREN46	292.9	127.6	57.1	0.227	0.794
CROS	A3XC4	100	GREN66	276.6	94.0	53.1	0.152	0.768
CROS	A3XC4	100	GREN67	305.4	167.7	65.8	0.292	0.949
CROS	A3XC4	80	GREN84	310.0	145.9	62.0	0.191	1.058
CROS	A3XC4	80	GREN89	317.1	172.6	62.1	0.317	1.084
CROS	A3XC4	80	GREN90	315.1	181.0	62.3	0.459	1.116
CROS	A3XC4	90	GREN59	295.0	159.2	65.8	0.294	0.818
CROS	A3XC4	90	GREN61	328.0	161.3	65.5	0.266	0.858
CROS	A3XC4	90	MOR27	342.3	140.1	63.5	0.280	1.019
CROS	C4XA1	ADL	MOR1	310.5	130.2	54.0	0.420	1.348
CROS	C4XA1	100	GREN36	381.2	101.7	54.7	0.268	1.006
CROS	C4XA1	80	GREN43	336.0	157.7	61.9	0.417	1.264
CROS	C4XA1	80	MOR8	300.4	126.4	63.1	0.493	1.723
CROS	C4XA1	80	MOR14	285.8	122.4	66.8	0.227	1.361
CROS	C4XA1	90	GREN33	303.8	96.1	58.0	0.500	1.110
CROS	C4XA1	90	GREN35	323.0	128.7	62.9	0.286	0.935
CROS	C4XA3	ADL	MOR35	308.8	136.3	53.0	0.201	1.206
CROS	C4XA3	ADL	MOR38	321.7	126.6	52.2	0.254	1.000
CROS	C4XA3	100	MOR43	266.9	128.6	61.6	0.262	0.955
CROS	C4XA3	100	MOR64	287.4	107.8	62.3	0.285	1.222
CROS	C4XA3	100	MOR71	272.4	155.4	64.0	0.462	0.671
CROS	C4XA3	80	MOR17	295.8	157.7	59.2	0.365	1.613
CROS	C4XA3	80	MOR32	287.0	150.6	60.6	0.370	1.381
CROS	C4XA3	80	MOR68	306.3	150.8	63.6	0.542	1.097
CROS	C4XA3	90	MOR42	324.7	121.7	63.2	0.249	0.916
CROS	C4XA3	90	MOR39	303.8	164.5	65.6	0.291	0.762
OUTC	STXA1	ADL	BLUE12	338.1	141.1	57.3	0.232	0.916
OUTC	STXA1	80	MOR73	304.2	219.5	60.8	0.200	1.142
OUTC	STXA1	80	MOR74	312.5	187.7	58.4	0.290	1.626
OUTC	STXA1	90	MOR75	300.0	232.9	61.3	0.396	0.923
OUTC	STXA1	90	MOR92	308.4	128.3	66.8	0.274	0.916
OUTC	STXA3	ADL	BLUE59	318.4	157.9	69.1	0.819	0.839
OUTC	STXA3	80	BLUE53	272.0	166.4	71.1	0.399	1.509
OUTC	STXA4	ADL	BLUE60	255.6	123.0	58.4	0.159	1.161
OUTC	STXA4	ADL	BLUE64	311.3	111.3	62.6	0.143	0.761
OUTC	STXA4	80	BLUE55	265.3	220.5	68.7	0.438	1.406
OUTC	STXA4	80	BLUE58	290.0	202.4	63.9	0.289	1.587
OUTC	STXA4	90	BLUE66	281.6	113.3	62.4	0.175	0.993
OUTC	STXA4	90	BLUE68	286.6	159.7	69.7	0.332	0.839
OUTC	STXC4	ADL	BLUE27	304.2	150.3	64.4	0.266	0.877

Listing of Breeds Data
Physiological Variables   (Continued)

BREED	LINE	FDLVL	ID	MR	WTURN	TOTWAT	TSR	PLT4
OUTC	STXC4	ADL	BLUE28	349.4	162.1	61.8	0.287	0.877
OUTC	STXC4	100	MOR86	320.9	150.2	64.2	0.439	1.064
OUTC	STXC4	100	BLUE30	298.7	143.0	67.5	0.565	1.090
OUTC	STXC4	80	MOR88	328.0	237.2	60.8	0.190	1.039
OUTC	STXC4	80	BLUE38	298.3	133.9	58.4	0.272	1.342
OUTC	STXC4	80	BLUE39	318.8	151.7	62.2	0.412	1.587
OUTC	STXC4	90	MOR89	328.4	129.5	60.4	0.386	1.207
OUTC	STXC4	90	BLUE32	287.0	145.8	65.1	0.267	1.174
OUTC	STXC4	90	BLUE33	270.3	120.0	63.0	0.280	1.174
PURE	A1	ADL	PINK80	336.0	153.6	60.2	0.487	1.290
PURE	A1	ADL	PINK52	326.4	137.3	60.4	0.567	1.116
PURE	A1	ADL	PINK53	325.5	173.8	59.1	0.519	0.948
PURE	A1	100	PINK77	360.2	155.0	61.5	0.269	1.078
PURE	A1	100	PINK64	319.7	96.6	65.7	0.464	1.471
PURE	A1	100	PINK65	356.1	201.6	61.7	0.272	1.200
PURE	A1	80	GREEN4	343.9	183.2	63.9	0.302	1.355
PURE	A1	80	PINK99	312.5	84.3	62.8	0.668	1.755
PURE	A1	80	GREEN1	322.6	148.1	62.1	0.590	1.322
PURE	A1	90	PINK59	338.9	183.6	60.2	0.504	1.432
PURE	A1	90	PINK60	335.1	112.4	59.6	0.561	1.122
PURE	A1	90	PINK61	350.2	104.9	66.5	0.434	1.432
PURE	A3	ADL	GREN22	303.3	109.8	56.5	0.337	0.922
PURE	A3	ADL	GREN24	319.7	116.2	57.1	0.675	1.168
PURE	A3	100	GREN20	313.8	120.4	57.0	0.287	1.084
PURE	A3	100	GREN21	336.4	119.0	56.8	0.335	1.026
PURE	A3	100	GREN26	300.4	109.5	62.3	0.221	0.826
PURE	A3	80	GREN16	284.9	136.9	59.5	0.235	1.219
PURE	A3	80	GREN17	309.6	121.6	61.1	0.300	1.213
PURE	A3	80	GREN31	283.7	154.0	60.2	0.392	1.116
PURE	A3	90	GREN15	324.3	139.2	69.5	0.314	1.116
PURE	A3	90	GREN28	281.2	110.9	67.3	0.328	0.600
PURE	A3	90	GREN19	271.5	114.8	56.5	0.292	0.916
PURE	A4	ADL	PINK1	340.6	167.5	64.1	0.589	1.220
PURE	A4	ADL	PINK3	359.0	167.1	58.1	0.354	1.574
PURE	A4	ADL	PINK81	349.4	147.1	63.5	0.534	0.839
PURE	A4	100	PINK19	335.1	113.4	67.9	0.421	1.503
PURE	A4	100	PINK26	331.4	102.4	65.5	0.350	1.116
PURE	A4	80	PINK5	313.8	94.7	63.4	0.894	1.555
PURE	A4	80	PINK6	327.2	123.5	63.4	0.648	1.265
PURE	A4	80	PINK7	322.2	97.0	64.3	0.767	1.678
PURE	A4	90	PINK16	341.8	135.6	67.2	0.483	0.884
PURE	A4	90	PINK18	331.4	111.3	67.0	0.558	1.032
PURE	C4	ADL	PINK33	362.3	148.2	64.2	0.433	0.948
PURE	C4	ADL	PINK34	344.8	134.7	63.4	0.366	0.845
PURE	C4	100	PINK47	300.4	93.8	71.0	0.371	1.426
PURE	C4	100	PINK48	357.3	123.0	61.5	0.327	1.342
PURE	C4	80	PINK44	328.9	111.8	66.8	0.567	1.548
PURE	C4	80	PINK45	336.4	103.3	65.0	0.535	1.613
PURE	C4	90	PINK86	327.6	137.0	71.5	0.444	1.071
PURE	C4	90	PINK88	333.9	121.9	61.1	0.380	1.071
PURE	C4	90	PINK89	348.5	125.1	64.5	0.602	1.071

8. Listing of Breeds Data
Egg Shell Variables

BREED	LINE	FDLVL	ID	SHELL	SWSA	STHICK	POR	ECON
CROS	A3XA4	ADL	MOR51	5.93	82.3	363	4.2	1.37
CROS	A3XA4	ADL	MOR50	6.30	84.3	376	4.0	1.37
CROS	A3XA4	ADL	MOR61	5.39	78.9	350	2.9	1.39
CROS	A3XA4	100	MOR44	6.05	85.0	380	4.3	1.38
CROS	A3XA4	100	MOR63	5.99	86.3	396	4.4	1.38
CROS	A3XA4	100	GREN95	6.18	81.7	352	4.9	1.51
CROS	A3XA4	80	GREN94	5.23	81.7	346	3.4	1.37
CROS	A3XA4	80	GREN93	5.95	85.9	391	4.6	1.44
CROS	A3XA4	90	MOR53	5.30	82.2	361	4.5	1.30
CROS	A3XA4	90	MOR55	5.05	73.1	322	4.0	1.34
CROS	A3XC4	ADL	GREN50	5.69	77.6	347	4.1	1.33
CROS	A3XC4	ADL	GREN51	5.40	75.1	336	5.1	1.31
CROS	A3XC4	ADL	GREN68	5.10	73.1	323	5.0	1.32
CROS	A3XC4	100	GREN46	4.98	77.1	351	4.3	1.29
CROS	A3XC4	100	GREN66	5.07	75.8	354	4.7	1.39
CROS	A3XC4	100	GREN67	6.00	85.4	378	4.0	1.38
CROS	A3XC4	80	GREN84	5.61	79.7	355	3.8	1.32
CROS	A3XC4	80	GREN89	5.68	80.6	362	3.8	1.40
CROS	A3XC4	80	GREN90	5.69	82.7	374	3.6	1.38
CROS	A3XC4	90	GREN59	5.97	86.2	389	4.2	1.38
CROS	A3XC4	90	GREN61	5.67	81.3	366	4.1	1.29
CROS	A3XC4	90	MOR27	5.55	82.4	370	3.3	1.33
CROS	C4XA1	ADL	MOR1	6.16	86.9	399	4.5	1.39
CROS	C4XA1	100	GREN36	5.50	77.3	349	3.9	1.37
CROS	C4XA1	80	GREN43	5.38	79.8	362	4.2	1.33
CROS	C4XA1	80	MOR8	5.56	75.9	339	4.2	1.31
CROS	C4XA1	80	MOR14	5.16	77.3	344	4.6	1.28
CROS	C4XA1	90	GREN33	5.56	77.8	351	4.1	1.41
CROS	C4XA1	90	GREN35	5.70	83.6	374	4.0	1.33
CROS	C4XA3	ADL	MOR35	5.57	78.3	341	4.3	1.31
CROS	C4XA3	ADL	MOR38	6.02	80.0	368	4.8	1.36
CROS	C4XA3	100	MOR43	5.54	78.3	347	4.2	1.20
CROS	C4XA3	100	MOR64	5.63	80.7	365	4.8	1.26
CROS	C4XA3	100	MOR71	5.66	82.3	353	4.8	1.34
CROS	C4XA3	80	MOR17	5.99	79.8	348	3.9	1.33
CROS	C4XA3	80	MOR32	6.15	84.3	384	3.6	1.45
CROS	C4XA3	80	MOR68	5.79	76.2	354	4.0	1.33
CROS	C4XA3	90	MOR42	5.29	77.5	340	4.4	1.29
CROS	C4XA3	90	MOR39	5.59	79.5	366	4.8	1.30
OUTC	STXA1	ADL	BLUE12	6.34	87.8	394	4.4	1.21
OUTC	STXA1	80	MOR73	5.01	72.2	329	4.2	1.42
OUTC	STXA1	80	MOR74	5.50	78.5	359	4.2	1.40
OUTC	STXA1	90	MOR75	5.47	78.4	343	4.1	1.31
OUTC	STXA1	90	MOR92	5.71	80.3	356	3.6	1.40
OUTC	STXA3	ADL	BLUE59	5.39	76.1	355	4.0	1.34
OUTC	STXA3	80	BLUE53	4.81	72.3	321	3.9	1.38
OUTC	STXA4	ADL	BLUE60	5.81	83.0	363	4.4	1.32
OUTC	STXA4	ADL	BLUE64	5.66	79.4	353	3.9	1.33
OUTC	STXA4	80	BLUE55	5.26	80.3	363	3.3	1.33
OUTC	STXA4	80	BLUE58	5.32	75.6	336	3.9	1.36
OUTC	STXA4	90	BLUE66	5.26	79.1	359	3.9	1.27
OUTC	STXA4	90	BLUE68	4.84	81.7	375	4.3	1.35
OUTC	STXC4	ADL	BLUE27	5.39	76.2	346	4.7	1.31

Listing of Breeds Data
Egg Shell Variables   (Continued)

BREED	LINE	FDLVL	ID	SHELL	SWSA	STHICK	POR	ECON
OUTC	STXC4	ADL	BLUE28	4.72	71.9	327	4.4	1.32
OUTC	STXC4	100	MOR86	4.73	72.8	349	4.8	1.34
OUTC	STXC4	100	BLUE30	5.60	83.6	390	4.1	1.39
OUTC	STXC4	80	MOR88	5.63	85.1	394	3.9	1.40
OUTC	STXC4	80	BLUE38	5.62	77.0	348	3.4	1.28
OUTC	STXC4	80	BLUE39	4.92	72.8	321	3.9	1.31
OUTC	STXC4	90	MOR89	6.05	85.1	384	4.0	1.34
OUTC	STXC4	90	BLUE32	6.07	85.5	385	3.5	1.42
OUTC	STXC4	90	BLUE33	5.48	82.6	382	4.1	1.31
PURE	A1	ADL	PINK80	5.57	79.3	354	5.4	1.20
PURE	A1	ADL	PINK52	5.73	83.1	365	4.6	1.34
PURE	A1	ADL	PINK53	5.70	83.3	373	5.1	1.33
PURE	A1	100	PINK77	6.15	89.1	382	4.5	1.28
PURE	A1	100	PINK64	5.80	82.9	364	4.7	1.24
PURE	A1	100	PINK65	5.01	76.3	340	5.3	1.27
PURE	A1	80	GREEN4	5.63	85.1	396	4.2	1.25
PURE	A1	80	PINK99	5.80	83.5	377	4.5	1.32
PURE	A1	80	GREEN1	5.97	81.5	380	4.2	1.33
PURE	A1	90	PINK59	5.14	77.1	337	4.6	1.28
PURE	A1	90	PINK60	5.88	86.0	380	4.7	1.26
PURE	A1	90	PINK61	5.51	79.8	355	4.7	1.27
PURE	A3	ADL	GREN22	5.74	81.0	361	5.0	1.44
PURE	A3	ADL	GREN24	5.35	76.8	348	5.9	1.32
PURE	A3	100	GREN20	5.25	78.4	355	4.4	1.38
PURE	A3	100	GREN21	5.65	79.9	360	4.3	1.38
PURE	A3	100	GREN26	6.44	85.3	390	3.7	1.45
PURE	A3	80	GREN16	5.31	79.2	353	5.1	1.31
PURE	A3	80	GREN17	5.77	81.2	360	4.6	1.41
PURE	A3	80	GREN31	5.49	79.9	364	4.5	1.41
PURE	A3	90	GREN15	5.84	79.9	373	4.9	1.34
PURE	A3	90	GREN28	.	.	.	.	.
PURE	A3	90	GREN19	5.09	76.2	335	4.5	1.36
PURE	A4	ADL	PINK1	6.01	83.6	382	4.7	1.40
PURE	A4	ADL	PINK3	6.32	89.6	400	4.3	1.35
PURE	A4	ADL	PINK81	5.59	78.6	346	4.5	1.40
PURE	A4	100	PINK19	6.19	86.0	387	3.7	1.34
PURE	A4	100	PINK26	6.25	87.3	396	4.7	1.41
PURE	A4	80	PINK5	5.73	80.3	356	4.7	1.51
PURE	A4	80	PINK6	5.74	78.3	356	4.5	1.39
PURE	A4	80	PINK7	5.71	83.6	377	4.5	1.38
PURE	A4	90	PINK16	5.86	84.0	377	4.2	1.37
PURE	A4	90	PINK18	5.48	76.9	352	4.5	1.39
PURE	C4	ADL	PINK33	5.68	81.1	374	4.8	1.30
PURE	C4	ADL	PINK34	5.86	82.0	379	4.1	1.35
PURE	C4	100	PINK47	5.84	78.2	367	4.1	1.29
PURE	C4	100	PINK48	5.16	79.7	365	5.3	1.33
PURE	C4	80	PINK44	5.98	84.6	378	4.3	1.40
PURE	C4	80	PINK45	5.87	86.3	398	3.7	1.38
PURE	C4	90	PINK86	5.26	79.4	357	4.4	1.34
PURE	C4	90	PINK88	5.62	78.2	368	4.1	1.30
PURE	C4	90	PINK89	5.43	79.5	361	4.7	1.38

9. Listing of Breeds Data
Body Weights

BREED	LINE	FDLVL	ID	BW1	BW2	BW3	BW4	BW5	BW6	BW7	BW8
CROS	A3XA4	ADL	MOR51	48	58	97	163	230	331	445	655
CROS	A3XA4	ADL	MOR50	48	65	110	165	241	341	440	635
CROS	A3XA4	ADL	MOR61	41	57	103	170	255	315	394	630
CROS	A3XA4	100	MOR44	39	54	86	136	206	274	390	614
CROS	A3XA4	100	MOR63	48	52	90	150	235	295	409	625
CROS	A3XA4	100	GREN95	38	66	125	194	270	360	464	665
CROS	A3XA4	80	GREN94	44	66	117	189	255	365	465	700
CROS	A3XA4	80	GREN93	38	53	107	160	225	310	399	595
CROS	A3XA4	90	MOR53	38	49	84	148	231	330	435	640
CROS	A3XA4	90	MOR55	38	41	65	120	195	270	380	590
CROS	A3XC4	ADL	GREN50	42	70	124	200	275	352	440	625
CROS	A3XC4	ADL	GREN51	42	64	117	180	268	330	460	715
CROS	A3XC4	ADL	GREN68	45	71	120	186	250	340	450	685
CROS	A3XC4	100	GREN46	46	70	126	205	283	385	495	656
CROS	A3XC4	100	GREN66	44	71	130	202	270	380	504	745
CROS	A3XC4	100	GREN67	46	65	115	188	265	364	475	715
CROS	A3XC4	80	GREN84	43	63	115	169	240	325	400	595
CROS	A3XC4	80	GREN89	40	61	110	165	230	325	404	595
CROS	A3XC4	80	GREN90	39	62	112	178	249	334	446	655
CROS	A3XC4	90	GREN59	45	70	132	200	265	385	480	720
CROS	A3XC4	90	GREN61	45	49	85	146	200	280	340	540
CROS	A3XC4	90	MOR27	43	56	100	160	232	305	377	566
CROS	C4XA1	ADL	MOR1	49	70	120	185	251	355	430	640
CROS	C4XA1	100	GREN36	45	72	124	189	250	320	405	591
CROS	C4XA1	80	GREN43	37	57	94	150	205	245	360	570
CROS	C4XA1	80	MOR8	40	60	100	154	215	305	381	575
CROS	C4XA1	80	MOR14	41	66	112	182	240	350	449	670
CROS	C4XA1	90	GREN33	47	75	127	195	275	340	440	640
CROS	C4XA1	90	GREN35	47	63	116	189	260	330	435	615
CROS	C4XA3	ADL	MOR35	39	62	111	185	256	365	465	710
CROS	C4XA3	ADL	MOR38	42	61	115	175	246	340	440	595
CROS	C4XA3	100	MOR43	49	66	114	186	246	373	500	750
CROS	C4XA3	100	MOR64	39	44	80	139	220	270	375	575
CROS	C4XA3	100	MOR71	41	62	118	200	290	355	460	740
CROS	C4XA3	80	MOR17	37	58	107	174	235	324	375	555
CROS	C4XA3	80	MOR32	49	67	116	191	261	375	480	705
CROS	C4XA3	80	MOR68	40	56	114	190	290	355	450	735
CROS	C4XA3	90	MOR42	49	68	115	186	240	351	445	655
CROS	C4XA3	90	MOR39	41	60	101	158	230	300	380	550
OUTC	STXA1	ADL	BLUE12	34	61	115	179	282	355	471	760
OUTC	STXA1	80	MOR73	40	61	114	193	275	325	415	650
OUTC	STXA1	80	MOR74	40	62	116	190	285	356	431	655
OUTC	STXA1	90	MOR75	42	65	116	199	295	386	476	710
OUTC	STXA1	90	MOR92	36	40	67	99	158	210	280	530
OUTC	STXA3	ADL	BLUE59	46	65	121	205	254	390	515	700
OUTC	STXA3	80	BLUE53	34	55	116	180	269	415	535	725
OUTC	STXA4	ADL	BLUE60	54	74	132	225	240	395	515	715
OUTC	STXA4	ADL	BLUE64	50	70	121	210	232	400	535	800
OUTC	STXA4	80	BLUE55	42	64	138	200	265	415	540	765
OUTC	STXA4	80	BLUE58	45	60	135	194	285	415	520	745
OUTC	STXA4	90	BLUE66	49	74	130	214	220	385	525	730
OUTC	STXA4	90	BLUE68	38	60	105	183	220	365	485	690
OUTC	STXC4	ADL	BLUE27	43	70	131	205	310	400	490	730

Listing of Breeds Data
Body Weights (Continued)

BREED	LINE	FDLVL	ID	BW1	BW2	BW3	BW4	BW5	BW6	BW7	BW8
OUTC	STXC4	ADL	BLUE28	42	68	121	182	275	375	450	670
OUTC	STXC4	100	MOR86	46	70	125	192	270	345	445	625
OUTC	STXC4	100	BLUE30	40	63	120	179	270	320	420	625
OUTC	STXC4	80	MOR88	41	65	116	180	250	295	395	655
OUTC	STXC4	80	BLUE38	40	70	130	187	280	345	422	705
OUTC	STXC4	80	BLUE39	39	66	110	157	245	295	374	590
OUTC	STXC4	90	MOR89	42	61	112	177	251	325	425	630
OUTC	STXC4	90	BLUE32	36	61	122	180	280	335	430	650
OUTC	STXC4	90	BLUE33	40	66	125	185	264	328	425	680
PURE	A1	ADL	PINK80	48	64	114	191	285	375	514	765
PURE	A1	ADL	PINK52	46	72	127	209	296	341	455	680
PURE	A1	ADL	PINK53	46	73	130	205	289	351	406	600
PURE	A1	100	PINK77	39	73	136	210	296	380	485	705
PURE	A1	100	PINK64	40	66	120	198	294	360	437	664
PURE	A1	100	PINK65	36	63	119	196	280	339	443	660
PURE	A1	80	GREEN4	37	65	119	196	275	390	508	780
PURE	A1	80	PINK99	39	66	124	190	264	354	455	635
PURE	A1	80	GREEN1	37	69	129	205	275	390	500	710
PURE	A1	90	PINK59	38	66	124	199	292	354	488	676
PURE	A1	90	PINK60	38	63	115	193	266	345	470	695
PURE	A1	90	PINK61	38	62	115	190	264	322	387	581
PURE	A3	ADL	GREN22	36	60	115	193	285	385	510	720
PURE	A3	ADL	GREN24	39	62	117	185	245	325	425	640
PURE	A3	100	GREN20	39	60	119	202	294	405	530	755
PURE	A3	100	GREN21	40	57	110	181	255	376	510	790
PURE	A3	100	GREN26	42	60	111	186	274	325	460	710
PURE	A3	80	GREN16	43	61	120	197	278	387	515	775
PURE	A3	80	GREN17	40	64	117	195	280	408	545	755
PURE	A3	80	GREN31	38	61	110	165	235	302	410	634
PURE	A3	90	GREN15	39	46	90	165	250	369	485	730
PURE	A3	90	GREN28	46	65	120	200	280	400	510	695
PURE	A3	90	GREN19	37	59	116	199	280	380	505	745
PURE	A4	ADL	PINK1	47	71	133	205	276	365	386	606
PURE	A4	ADL	PINK3	45	67	115	190	255	315	305	505
PURE	A4	ADL	PINK81	36	46	76	131	181	237	305	505
PURE	A4	100	PINK19	48	67	116	180	245	330	405	635
PURE	A4	100	PINK26	42	63	115	180	250	330	400	590
PURE	A4	80	PINK5	43	61	105	182	252	320	393	595
PURE	A4	80	PINK6	43	57	101	156	244	322	426	665
PURE	A4	80	PINK7	39	52	92	150	215	286	385	605
PURE	A4	90	PINK16	35	58	110	180	260	352	435	635
PURE	A4	90	PINK18	38	59	107	170	250	332	447	685
PURE	C4	ADL	PINK33	44	66	104	115	230	315	400	605
PURE	C4	ADL	PINK34	46	70	125	210	277	365	454	655
PURE	C4	100	PINK47	46	74	131	205	280	375	480	710
PURE	C4	100	PINK48	44	66	117	185	245	316	425	650
PURE	C4	80	PINK44	36	63	116	190	270	344	446	680
PURE	C4	80	PINK45	36	60	107	172	250	325	426	665
PURE	C4	90	PINK86	36	67	119	180	255	332	434	640
PURE	C4	90	PINK88	38	66	109	169	239	301	401	625
PURE	C4	90	PINK89	35	55	100	160	245	301	375	565

Listing of Breeds Data
Body Weights   (Continued)

BREED	LINE	FDLVL	ID	BW9	BW10	BW11	BW12	BW13	BW14	BW15	BW16
CROS	A3XA4	ADL	MOR51	875	1075	1250	1370	1485	1750	1735	1690
CROS	A3XA4	ADL	MOR50	840	1025	1220	1380	1515	1805	2000	1940
CROS	A3XA4	ADL	MOR61	855	1050	1210	1340	1360	1765	1920	1820
CROS	A3XA4	100	MOR44	860	1135	1350	1475	1595	1760	2120	1890
CROS	A3XA4	100	MOR63	820	1000	1165	1295	1350	1755	1745	1685
CROS	A3XA4	100	GREN95	885	1100	1230	1400	1575	1780	2015	2030
CROS	A3XA4	80	GREN94	905	1095	1225	1445	1605	1535	1700	1825
CROS	A3XA4	80	GREN93	755	890	1005	1125	1215	1285	1570	1600
CROS	A3XA4	90	MOR53	907	1135	1365	1520	1710	1950	1835	1700
CROS	A3XA4	90	MOR55	820	1135	1230	1315	1475	1720	1735	1585
CROS	A3XC4	ADL	GREN50	775	1025	1240	1410	1610	1690	1995	2000
CROS	A3XC4	ADL	GREN51	930	1180	1400	1580	1745	1880	2100	2110
CROS	A3XC4	ADL	GREN68	885	1065	1235	1395	1575	1730	1860	2010
CROS	A3XC4	100	GREN46	865	1145	1360	1465	1675	1815	2035	2055
CROS	A3XC4	100	GREN66	970	1230	1410	1620	1760	1935	2230	2500
CROS	A3XC4	100	GREN67	935	1175	1332	1545	1790	1930	1825	1875
CROS	A3XC4	80	GREN84	795	964	1110	1240	1330	1435	1570	1700
CROS	A3XC4	80	GREN89	830	1060	1235	1465	1620	1730	1815	1820
CROS	A3XC4	80	GREN90	845	1045	1185	1380	1605	1725	1840	1975
CROS	A3XC4	90	GREN59	925	1107	1270	1480	1670	1720	1950	1865
CROS	A3XC4	90	GREN61	731	920	1070	1285	1440	1585	1780	1980
CROS	A3XC4	90	MOR27	700	855	950	1150	1315	1540	1710	1595
CROS	C4XA1	ADL	MOR1	855	985	1125	1365	1595	1740	1885	2015
CROS	C4XA1	100	GREN36	745	970	1190	1365	1470	1690	2015	1915
CROS	C4XA1	80	GREN43	740	950	1130	1265	1395	1550	1545	1635
CROS	C4XA1	80	MOR8	735	915	1050	1255	1450	1595	1440	1490
CROS	C4XA1	80	MOR14	880	1040	1140	1300	1440	1570	1645	1790
CROS	C4XA1	90	GREN33	815	1035	1220	1350	1470	1570	1675	1710
CROS	C4XA1	90	GREN35	745	950	1165	1300	1455	1670	1740	1690
CROS	C4XA3	ADL	MOR35	990	1280	1445	1575	1695	1995	2205	2070
CROS	C4XA3	ADL	MOR38	780	1005	1150	1315	1295	1685	2105	1870
CROS	C4XA3	100	MOR43	1015	1280	1520	1690	1800	1965	2125	1970
CROS	C4XA3	100	MOR64	760	975	1150	1350	1390	1710	1950	2000
CROS	C4XA3	100	MOR71	935	1145	1325	1405	1495	2000	1965	1870
CROS	C4XA3	80	MOR17	714	855	955	1140	1320	1455	1570	1745
CROS	C4XA3	80	MOR32	935	1130	1235	1355	1495	1585	1745	1735
CROS	C4XA3	80	MOR68	950	1165	1335	1420	1460	1735	1640	1590
CROS	C4XA3	90	MOR42	890	1100	1295	1440	1545	1720	1800	1640
CROS	C4XA3	90	MOR39	785	990	1165	1290	1420	1720	1735	1530
OUTC	STXA1	ADL	BLUE12	970	1150	1365	1485	1735	2005	2030	2115
OUTC	STXA1	80	MOR73	860	1060	1275	1415	1435	1620	1565	1500
OUTC	STXA1	80	MOR74	890	1105	1285	1405	1450	1525	1605	1735
OUTC	STXA1	90	MOR75	930	1125	1280	1405	1460	1855	1805	1860
OUTC	STXA1	90	MOR92	730	960	1170	1290	1390	1735	1925	1680
OUTC	STXA3	ADL	BLUE59	865	1105	1260	1410	1620	1825	1900	1755
OUTC	STXA3	80	BLUE53	910	1105	1275	1375	1585	1685	1470	1475
OUTC	STXA4	ADL	BLUE60	855	1090	1250	1400	1535	2110	2175	2095
OUTC	STXA4	ADL	BLUE64	960	1230	1400	1510	1675	2125	2210	2070
OUTC	STXA4	80	BLUE55	970	1110	1310	1405	1615	1670	1550	1610
OUTC	STXA4	80	BLUE58	945	1095	1315	1410	1680	1770	1965	1785
OUTC	STXA4	90	BLUE66	865	1090	1205	1355	1450	1690	1845	1650
OUTC	STXA4	90	BLUE68	820	1075	1210	1380	1495	1610	1570	1490
OUTC	STXC4	ADL	BLUE27	970	1055	1325	1365	1555	1790	1765	1905

Listing of Breeds Data
Body Weights - (Continued)

BREED	LINE	FDLVL	ID	BW9	BW10	BW11	BW12	BW13	BW14	BW15	BW16
OUTC	STXC4	ADL	BLUE28	895	1075	1205	1280	1480	1720	1685	1730
OUTC	STXC4	100	MOR86	840	990	1010	1140	1220	1570	1575	1515
OUTC	STXC4	100	BLUE30	875	1070	1235	1315	1545	1600	1900	1585
OUTC	STXC4	80	MOR88	825	1030	1235	1345	1420	1490	1520	1560
OUTC	STXC4	80	BLUE38	905	1100	1210	1345	1500	1670	1590	1525
OUTC	STXC4	80	BLUE39	855	1045	1235	1310	1495	1610	1730	1680
OUTC	STXC4	90	MOR89	820	980	1185	1340	1410	1720	1790	1820
OUTC	STXC4	90	BLUE32	910	1090	1265	1330	1600	1705	1725	1755
OUTC	STXC4	90	BLUE33	970	1170	1355	1400	1615	1735	1660	1700
PURE	A1	ADL	PINK80	1000	1265	1470	1397	1610	2075	2175	2245
PURE	A1	ADL	PINK52	900	1135	1320	1530	1720	1915	2180	2200
PURE	A1	ADL	PINK53	820	1050	1245	1410	1600	2010	1940	1990
PURE	A1	100	PINK77	895	1125	1280	1410	1595	1820	1790	1925
PURE	A1	100	PINK64	885	1125	1320	1455	1675	1916	1955	1915
PURE	A1	100	PINK65	880	1115	1315	1465	1510	1795	1760	1970
PURE	A1	80	GREEN4	1035	1225	1350	1580	1735	1810	2055	1855
PURE	A1	80	PINK99	845	1030	1180	1345	1390	1580	1710	1645
PURE	A1	80	GREEN1	920	1125	1260	1460	1535	1730	1765	1750
PURE	A1	90	PINK59	870	1085	1270	1395	1535	1795	1885	2050
PURE	A1	90	PINK60	895	1090	1295	1445	1625	1870	1835	2065
PURE	A1	90	PINK61	780	975	1175	1365	1525	1765	1755	1895
PURE	A3	ADL	GREN22	990	1220	1375	1490	1635	1830	1915	1925
PURE	A3	ADL	GREN24	845	1060	1190	1315	1415	1710	1845	1775
PURE	A3	100	GREN20	965	1225	1385	1530	1620	1940	2085	2065
PURE	A3	100	GREN21	1020	1270	1420	1540	1720	1925	2065	1870
PURE	A3	100	GREN26	930	1170	1305	1415	1590	1780	2120	1825
PURE	A3	80	GREN16	1010	1250	1375	1465	1610	1740	1960	1735
PURE	A3	80	GREN17	1020	1240	1360	1455	1625	1690	1870	1955
PURE	A3	80	GREN31	780	1065	1310	1470	1710	1775	1950	1820
PURE	A3	90	GREN15	1000	1140	1295	1490	1600	1820	1850	2110
PURE	A3	90	GREN28	865	1095	1265	1405	1525	1725	1860	1890
PURE	A3	90	GREN19	960	1205	1385	1545	1805	1930	2140	2095
PURE	A4	ADL	PINK1	892	1105	1315	1510	1615	1825	1950	1725
PURE	A4	ADL	PINK3	790	935	1120	1345	1465	1745	1760	1560
PURE	A4	ADL	PINK81	720	945	1145	1300	1385	1505	1630	1585
PURE	A4	100	PINK19	855	1060	1200	1390	1470	1585	1675	1625
PURE	A4	100	PINK26	802	990	1185	1365	1455	1675	1885	1735
PURE	A4	80	PINK5	780	960	1120	1235	1270	1405	1440	1510
PURE	A4	80	PINK6	840	990	1150	1295	1335	1580	1632	1680
PURE	A4	80	PINK7	810	1110	1170	1355	1420	1565	1800	1640
PURE	A4	90	PINK16	854	1030	1165	1315	1395	1530	1670	1575
PURE	A4	90	PINK18	878	1055	1235	1445	1510	1740	1850	1795
PURE	C4	ADL	PINK33	814	1005	1195	1355	1490	1715	1765	1655
PURE	C4	ADL	PINK34	855	1045	1210	1325	1465	1775	1715	1670
PURE	C4	100	PINK47	930	1165	1250	1503	1560	1830	2060	1905
PURE	C4	100	PINK48	870	1085	1280	1425	1490	1870	1835	1690
PURE	C4	80	PINK44	930	1125	1305	1502	1610	1785	1615	1695
PURE	C4	80	PINK45	889	1130	1360	1545	1640	1830	1765	1770
PURE	C4	90	PINK86	835	1045	1205	1340	1445	1630	1560	1605
PURE	C4	90	PINK88	835	1015	1132	1300	1425	1660	1795	1815
PURE	C4	90	PINK89	755	975	1150	1310	1385	1670	1605	1630

Listing of Breeds Data
Body Weights (Continued)

BREED	LINE	FDLVL	ID	BW17	BW18	BW19	BW20	BW21	BW22	BW23	BW24	BW25
CROS	A3XA4	ADL	MOR51	1885	1870	1945	1945	2115	2185	2360	2335	2420
CROS	A3XA4	ADL	MOR50	2195	2125	2230	2240	2250	2425	2400	2385	2350
CROS	A3XA4	ADL	MOR61	1885	1780	1875	1910	1995	2055	2040	2010	2025
CROS	A3XA4	100	MOR44	2015	1790	1850	1820	1825	1875	1890	1845	1840
CROS	A3XA4	100	MOR63	1645	1595	1645	1650	1640	1700	1680	1720	1710
CROS	A3XA4	100	GREN95	1990	1920	1845	1790	1915	1890	1905	1910	1895
CROS	A3XA4	80	GREN94	1575	1610	1535	1550	1655	1475	1500	1635	1760
CROS	A3XA4	80	GREN93	1475	1585	1525	1505	1460	1560	1545	1600	1535
CROS	A3XA4	90	MOR53	1755	1560	1590	1715	1775	1540	2000	1865	1780
CROS	A3XA4	90	MOR55	1655	1545	1500	1580	1720	1705	1625	1700	1790
CROS	A3XC4	ADL	GREN50	1955	2120	2230	2230	2270	2320	2390	2385	2365
CROS	A3XC4	ADL	GREN51	2025	2190	2340	2235	2225	2320	2355	2325	2325
CROS	A3XC4	ADL	GREN68	2045	2100	1950	2070	2135	2080	2145	2175	2270
CROS	A3XC4	100	GREN46	1935	2030	1935	1895	1800	1895	1900	1920	1905
CROS	A3XC4	100	GREN66	2455	2410	2335	2390	2375	2380	2430	2365	2560
CROS	A3XC4	100	GREN67	1820	1790	1700	1745	1805	1740	1820	1760	1785
CROS	A3XC4	80	GREN84	1740	1640	1655	1595	1585	1555	1670	1885	1685
CROS	A3XC4	80	GREN89	1640	1615	1675	1810	1580	1665	1775	1755	1740
CROS	A3XC4	80	GREN90	1645	1595	1775	1600	1660	1630	1680	1840	1895
CROS	A3XC4	90	GREN59	1815	1790	1760	1665	1790	1695	1760	1890	1825
CROS	A3XC4	90	GREN61	1845	1780	1645	1610	1690	1640	1675	1850	1950
CROS	A3XC4	90	MOR27	1685	1570	1600	1460	1555	1555	1695	1650	1640
CROS	C4XA1	ADL	MOR1	2105	2225	2190	2215	2250	2240	2315	2280	2260
CROS	C4XA1	100	GREN36	1900	2005	2000	1980	2025	2055	2060	2150	2145
CROS	C4XA1	80	GREN43	1480	1575	1520	1635	1505	1585	1565	1645	1620
CROS	C4XA1	80	MOR8	1575	1570	1530	1570	1565	1700	1605	1740	1585
CROS	C4XA1	80	MOR14	1720	1540	1670	1580	1550	1680	1670	1760	1760
CROS	C4XA1	90	GREN33	1705	1845	1770	1825	1795	1755	1970	2085	2050
CROS	C4XA1	90	GREN35	1550	1555	1725	1555	1640	1615	1625	1775	1800
CROS	C4XA3	ADL	MOR35	2315	2325	2440	2390	2635	2740	2860	2950	2935
CROS	C4XA3	ADL	MOR38	1995	1955	2130	2090	2130	2260	2165	2115	2055
CROS	C4XA3	100	MOR43	2175	1805	2010	1885	2005	2035	1980	1970	1990
CROS	C4XA3	100	MOR64	1900	1880	1790	1875	1930	1940	2110	1910	1875
CROS	C4XA3	100	MOR71	1840	1875	1850	1845	1840	1980	2025	2050	2110
CROS	C4XA3	80	MOR17	1720	1630	1755	1520	1730	1550	1565	1700	1680
CROS	C4XA3	80	MOR32	1760	1515	1790	1720	1700	1660	1745	1690	1850
CROS	C4XA3	80	MOR68	1530	1665	1510	1665	1530	1515	1685	1595	1525
CROS	C4XA3	90	MOR42	1635	1745	1600	1680	1745	1820	1835	1825	1995
CROS	C4XA3	90	MOR39	1635	1485	1550	1555	1690	1540	1740	1650	1725
OUTC	STXA1	ADL	BLUE12	1945	2075	2010	2140	2185	2240	2205	2170	2345
OUTC	STXA1	80	MOR73	1500	1615	1490	1690	1505	1490	1545	1645	1545
OUTC	STXA1	80	MOR74	1825	1710	1755	1905	1750	1815	1810	1810	1765
OUTC	STXA1	90	MOR75	1690	1650	1610	1750	1645	1775	1920	1875	1780
OUTC	STXA1	90	MOR92	1855	1720	1540	1660	1515	1645	1750	1710	1615
OUTC	STXA3	ADL	BLUE59	1885	1810	1995	2080	2075	2120	2160	2150	2175
OUTC	STXA3	80	BLUE53	1470	1450	1475	1465	1545	1600	1565	1575	1415
OUTC	STXA4	ADL	BLUE60	2260	2245	2440	2500	2650	2665	2570	2575	2630
OUTC	STXA4	ADL	BLUE64	2170	2170	2265	2400	2345	2425	2530	2445	2535
OUTC	STXA4	80	BLUE55	1675	1645	1600	1465	1615	1720	1695	1540	1585
OUTC	STXA4	80	BLUE58	1925	1670	1825	1730	1920	1765	1810	1635	1725
OUTC	STXA4	90	BLUE66	1655	1635	1595	1545	1700	1600	1665	1700	1785
OUTC	STXA4	90	BLUE68	1520	1625	1685	1520	1650	1725	1615	1655	1700
OUTC	STXC4	ADL	BLUE27	1750	1860	1835	1930	1930	2045	2015	1975	2130

Listing of Breeds Data
Body Weights   (Continued)

BREED	LINE	FDLVL	ID	BW17	BW18	BW19	BW20	BW21	BW22	BW23	BW24	BW25
OUTC	STXC4	ADL	BLUE28	1610	1665	1565	1670	1790	1750	1775	1740	1860
OUTC	STXC4	100	MOR86	1485	1515	1515	1575	1425	1550	1530	1495	1500
OUTC	STXC4	100	BLUE30	1455	1615	1575	1645	1655	1690	1605	1615	1505
OUTC	STXC4	80	MOR88	1525	1565	1510	1580	1515	1595	1575	1675	1570
OUTC	STXC4	80	BLUE38	1415	1530	1605	1625	1630	1775	1670	1865	1745
OUTC	STXC4	80	BLUE39	1475	1580	1445	1570	1520	1585	1595	1650	1485
OUTC	STXC4	90	MOR89	1635	1750	1550	1725	1620	1815	1765	1795	1730
OUTC	STXC4	90	BLUE32	1645	1570	1645	1740	1700	1710	1655	1625	1470
OUTC	STXC4	90	BLUE33	1630	1710	1800	1685	1655	1815	1735	1660	1625
PURE	A1	ADL	PINK80	2035	2275	2470	2405	2400	2355	2280	2480	2145
PURE	A1	ADL	PINK52	2100	2310	2370	2490	2410	2215	2235	2340	2245
PURE	A1	ADL	PINK53	1980	2145	2280	2345	2385	2370	2460	2480	2455
PURE	A1	100	PINK77	1740	1990	1715	1825	1685	1785	1795	1625	1760
PURE	A1	100	PINK64	1765	2070	1910	1840	1905	1975	1945	1975	2010
PURE	A1	100	PINK65	1740	1960	1910	1925	1915	1775	1895	1900	1905
PURE	A1	80	GREEN4	1840	1580	1685	1730	1730	1575	1800	1695	1580
PURE	A1	80	PINK99	1690	1565	1595	1610	1585	1650	1700	1670	1710
PURE	A1	80	GREEN1	1540	1685	1685	1585	1655	1630	1690	1615	1670
PURE	A1	90	PINK59	1975	2140	2045	1835	1785	1730	1785	1660	1790
PURE	A1	90	PINK60	1950	2100	1925	1915	1930	1840	1990	2005	2080
PURE	A1	90	PINK61	1795	2040	1835	1730	1835	1735	1705	1745	1870
PURE	A3	ADL	GREN22	2120	2230	2380	2410	2515	2555	2590	2585	2620
PURE	A3	ADL	GREN24	1875	1935	1980	2055	1995	1930	2005	1960	2030
PURE	A3	100	GREN20	2175	2200	2135	2010	2045	2105	2070	2130	2120
PURE	A3	100	GREN21	2040	1995	1975	1895	1835	1860	1910	1955	2080
PURE	A3	100	GREN26	2040	1915	1820	1665	1680	1725	1710	1835	1780
PURE	A3	80	GREN16	1855	1805	1770	1750	1785	1740	1745	1655	1730
PURE	A3	80	GREN17	1885	1750	1745	1710	1715	1730	1690	1715	1795
PURE	A3	80	GREN31	1600	1835	1760	1790	1710	1800	1785	1880	1885
PURE	A3	90	GREN15	2175	1835	1915	1900	1750	1875	1840	1790	1790
PURE	A3	90	GREN28	1975	2025	2050	2050	2025	2220	2190	2240	2200
PURE	A3	90	GREN19	2220	2075	1940	1890	1875	1900	1800	1940	2135
PURE	A4	ADL	PINK1	1950	1800	1900	1975	2035	1980	1985	2045	2015
PURE	A4	ADL	PINK3	1790	1860	1980	2110	2100	2065	2050	2215	2165
PURE	A4	ADL	PINK81	1430	1750	1780	1770	1825	1690	1715	1690	1615
PURE	A4	100	PINK19	1725	1725	1735	1750	1705	1885	1825	1790	1795
PURE	A4	100	PINK26	1795	1730	1840	1930	1925	1850	1875	1940	1900
PURE	A4	80	PINK5	1635	1480	1625	1515	1600	1500	1425	1460	1455
PURE	A4	80	PINK6	1760	1765	1710	1705	1725	1645	1585	1720	1650
PURE	A4	80	PINK7	1665	1600	1800	1745	1725	1700	1730	1820	1795
PURE	A4	90	PINK16	1515	1485	1485	1610	1545	1390	1410	1495	1510
PURE	A4	90	PINK18	1830	1835	1720	1785	1810	1790	1785	1880	1980
PURE	C4	ADL	PINK33	1805	1795	1870	1930	1895	1765	1825	1820	1780
PURE	C4	ADL	PINK34	1815	1795	1870	1850	1980	1830	1870	1830	1800
PURE	C4	100	PINK47	1855	1810	1970	1780	2050	1875	1800	2035	1945
PURE	C4	100	PINK48	1890	1770	1690	1825	1770	1720	1680	1790	1745
PURE	C4	80	PINK44	1685	1565	1615	1615	1675	1555	1515	1600	1635
PURE	C4	80	PINK45	1705	1820	1700	1865	1770	1710	1690	1665	1840
PURE	C4	90	PINK86	1470	1700	1565	1575	1605	1575	1665	1505	1670
PURE	C4	90	PINK88	1655	1740	1810	1745	1715	1645	1715	1630	1755
PURE	C4	90	PINK89	1635	1635	1585	1580	1655	1520	1655	1650	1700

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