

## CHAPTER 9

### GENERAL DISCUSSION AND CONCLUSIONS

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### General Discussion and Conclusions

The experiments reported in this thesis were undertaken with the dual objectives of clarification of the biological responses to feed restriction and of elucidation of the possible reasons for such responses. These objectives were largely achieved by the multidisciplinary nature of the work as detailed, and the results obtained taken as a whole warrant some discussion.

#### 9.1 ENERGY METABOLISM

Investigations of energy metabolism in this thesis centred around three studies:

(1) Serial measurement of starvation heat production with cognisance of both chronological and physiological age for layer-type birds (Chapter 6);

(2) Regression techniques to partition the production data from layer-type birds (Chapter 6); and

(3) Detailed calorimetric measurements on broiler breeder birds in relation to age or stage of egg production and dietary regimen (Chapter 8).

Ideally the experimenter would have liked to carry out calorimetric measurements in conjunction with the regression techniques used in Chapter 6, but this was not possible due to construction and calibration of the large open-circuit respiration chambers described in Chapter 7. These chambers were seen to be central to long-term and practically orientated studies of energy metabolism of poultry for the reasons detailed in Chapter 7, and the normality of production obtained (Chapters 7 and 8) vindicated their construction. However, the techniques used to determine the energetics of poultry here require some comment. The regression techniques employed for the production data on the layer-type birds (Chapter 6) and the calorimetric measurements carried out on the broiler breeders (Chapter 8) were without manipulation of feed intake for measurement of energetics *per se*. Although this approach was desirable because of the nature of the experi-

ments it nonetheless caused problems of data analysis. Regression techniques used to partition the metabolisable energy intake of layer-type birds between maintenance and production failed to account for sufficient variability and as such gave unrealistic estimates of the partial efficiencies. Application of a regression model with assumed partial efficiencies (Chapter 6) clarified the trends but such an approach ignores possible real differences in energetic efficiency between treatments. The techniques used by other workers (Reid *et al.* 1978; Valencia *et al.* 1980a,b), where graded amounts of feed were given to birds, would probably have been more suitable for the present study in retrospect. Similarly, the analysis of the detailed calorimetric study in Chapter 8 presented problems due to the high rate of energy retention which made extrapolation to zero energy balance for estimation of maintenance energy requirements at times tenuous, and also due to the confounding effects of age or stage of egg production on energy metabolism. The best approach to such calorimetric studies is open to debate, but certainly there should be no assumptions made concerning either the linearity of the relationship between energy retention and metabolisable energy intake between maintenance and production (Chapters 6 and 7) or of the constancy of such relationships (Chapter 8).

Serial measurement of starvation heat production for layer-type birds (Chapter 6) showed that there was apparently no alterations due to undernutrition. Recalculation of the results given by Balnave *et al.* (1979) showed that starvation heat production of similar types of birds was increased near cessation of feed restriction in direct relationship to the severity of the liveweight reduction, which was unexpected given that most comparable studies on a range of animal species found the reverse (see Chapter 6). Notwithstanding the arguments proposed in Chapter 6 to account for the differences between these studies, it is possible that the major reason may be due to alterations in physical activity. For example, Blaxter and Wood (1951) concluded that the disproportionate decline in heat production relative to liveweight during undernutrition of young calves was due to a reduction in activity. Similarly, Leveille and O'Hea (1967) found that the physical activity of rats was considerably reduced during periods of undernutrition, and the authors attributed the observed improved feed efficiency to this effect. These findings contrast sharply with those

of Wenk and van Es (1976) who reported that feed restriction of chickens increased the proportion of the maintenance energy required for activity from 15-20% under *ad libitum* feeding to 30%; similar increases were reported for pigs on restriction programmes (Halter *et al.* 1980). However, the large differences in physiology and metabolism between immature pullets and hens in egg production may indicate that differences in a metabolic response to feed or energy restriction are possible; on this basis an increase in starvation heat production during rearing due to undernutrition (Balnave *et al.* 1979) is reconcilable with a decrease during egg production due to undernutrition (MacLeod and Shannon 1978; MacLeod *et al.* 1979). The increased starvation heat production at 20 weeks of age found by Balnave *et al.* (1979) was 9% and 21% for birds restricted to 78% and 66% of the live-weight of birds allowed *ad libitum* feed intake. The procedures used in the present studies (Chapter 6) would have largely eliminated differences between treatments in physical activity. On this assumption, and given that starvation heat production was unaltered in the present study and also that under normal conditions activity would probably be increased for birds on the restriction treatments (Wenk and van Es 1976), then it could be argued that the present results may be in agreement with those reported by Balnave *et al.* (1979). Extrapolation of starvation heat production to the energy required for maintenance is precarious since an assumed efficiency of utilization of metabolisable energy for maintenance is at best only an approximation. Also the procedures and method used to measure starvation heat production and to estimate maintenance energy requirements for the layer-type birds further compound such comparisons.

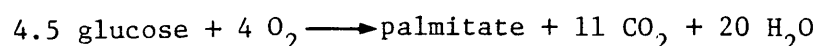
Additionally there were differences in the relative shifts of the maintenance energy requirements estimated by regression techniques (Chapter 6) between treatments in the two production experiments (Chapter 3), so conclusions concerning alterations in starvation heat production in layer-type birds from one experiment must be cautious. The finding that differences in feather cover between birds either allowed *ad libitum* feed intake or restricted during rearing were reversed between the two experiments on layer-type birds (Chapter 3) may be indicative of fundamental, perhaps genotypically based, alterations in activity patterns, although the relationship between activity and feather damage is open to question (Hughes 1978;

1980). Certainly changes in feather cover should be included in more detail in future experiments of this nature than were attempted in the present studies.

Changes in the maintenance energy requirement and/or in the efficiency of utilization of metabolisable energy for production were apparent in broiler breeders during rearing due to undernutrition (Chapter 8). On the assumption that energetic efficiency was the same irrespective of treatment during rearing, marked reductions in the maintenance energy requirement of birds on the restriction treatments were demonstrated. Extrapolation of these results to changes in starvation heat production must be made with caution as indicated previously, but the trends suggest that the results found for broiler breeders calculated in this manner would indicate a reduction in starvation heat production during rearing due to undernutrition. This is apparently not in agreement with the previous conclusions for layer-type birds, but there is good evidence to suggest that there are effects of strain *per se* on alterations in energy metabolism of poultry due to undernutrition (MacLeod and Shannon 1978; MacLeod *et al.* 1979) which are reconcilable with the known influences of genotypic variation on the responses to restriction during rearing (Section 1.4.1, Chapter 1), on energy metabolism (Farrell 1975; Pym and Farrell 1977; Kuenzel and Kuenzel 1977) and on nutrient requirements (Nesheim 1975). In addition, Savory (1975) and Kuenzel and Kuenzel (1977) noted large differences in the activity of layer-type and broiler birds during rearing, with broilers being very inactive. Furthermore, it is difficult to determine the "biological severity" of restricted feeding of broiler breeders because of the gross overconsumption of feed which occurs in birds allowed *ad libitum* feed intake as evidenced by the extent of fat deposition which was apparent during rearing (Chapter 8). Nevertheless, after commencement of egg production for broiler breeders there was good evidence to suggest that a slight increase in the severity of feed restriction imposed during rearing (Treatment 3 versus Treatment 2, Chapter 8) caused major differences in energy metabolism which were partly confirmed by measurements of starvation heat production. These relative changes were apparent without any large alteration in the relative gross energetic efficiency of egg production. These findings lead to two tentative conclusions. The first is that

relatively small variations in the quantities of feed allocated to broiler breeders during rearing may result in differences in energy metabolism which continue during egg production. In certain situations it is therefore possible that such alterations may be detrimental to maximum egg output. The second is that although there were apparently some differences in energy metabolism between treatments which were dependent largely on feeding regimen during rearing, these did not affect the overall egg production or gross efficiency of egg production. Changes in energetics would probably need to be extremely large to directly alter either of these variables.

Alterations in energetics of birds on restricted feeding programmes, and during different physiological stages (*viz.*, of growth and egg production), are probably due to the changing relationships between maintenance and production and due to the changing nature of the production. For example the finding that respiratory quotients were very high (often greater than unity), particularly for the broiler breeders on the restriction treatments (Figures 8.4, 8.5 and 8.6, Chapter 8), correlates well with the measured ( $C^{14}$ -acetate) increases in *de novo* lipogenesis observed after layer-birds on restriction programmes were given their feed allocation (Chapter 5). The reason that high respiratory quotients indicate lipid synthesis from substrates other than fat can be demonstrated by the following simplified equation (McGilveray 1970):



Respiratory quotients greater than unity in birds allowed *ad libitum* feed intake during rearing (see Figure 8.5, Chapter 8) indicates that substantial lipid synthesis occurred even in those birds, which would concur with the extremely high rates of fat deposition measured (Section 8.3.5, Chapter 8). However, the respiratory quotients of the broiler breeders on the quantitative feed restriction programmes were consistently greater than unity for the majority of the 24 h postfeeding period, and whereas with age the respiratory quotients decreased to below unity for birds on the *ad libitum* treatment (see Figure 8.6, Chapter 8), those for birds on the restriction treatments remained elevated. This agrees with the recent finding

by Freeman *et al.* (1981) that young chickens on feed restriction programmes were hyperlipidaemic. Smith *et al.* (1978) found that plasma triglyceride levels increased immediately after feeding in chickens in direct relation with the amount and frequency of feeding. Leveille and O'Hea (1967) showed that the respiratory quotient of rats on meal-feeding regimens increased to about 1.12 within two to four hours after feeding, and decreased to 0.73 within 24 h of feeding. As in Chapter 7, Shannon *et al.* (1969) showed that the respiratory quotient was a direct function of feeding level (over 24 h). Calculations carried out by Armstrong (1969) showed that theoretically the efficiency of lipogenesis from glucose (c. 69%) is less than that with which glucose is used to spare body fat from oxidation (c. 100%). Such considerations may account for apparent shifts in the efficiency of utilization of metabolisable energy for production found for broiler breeders in Chapter 8, and may indicate that, although these differences in efficiency were largely not significant, they may have biological importance.

## 9.2 BODY COMPOSITION

The possibility that body fat content *per se* resulted in suboptimal reproductive performance (Scott *et al.* 1969; Gous 1972; Neil *et al.* 1977) had logical extension as a reason for the beneficial effects on restricted feeding, since a reduction in body fat content was one of the measured effects at cessation of restriction (see Chapter 5). To avoid the obvious problems of relating body composition to subsequent egg production with the usual slaughter techniques, prediction equations were developed in a series of experiments in Chapter 4 using the water isotopes, tritiated water and deuterium oxide. Detailed studies were also undertaken on the body composition relationships in poultry because such relationships are the basis of prediction of body composition. As expected (Section 4.1, Chapter 4) the relationships were dynamic in that they were influenced by age and liveweight, and this caused problems in the derivation of prediction equations. Nevertheless equations with combined data and separate equations for individual groups of birds could be used to predict body composition with good accuracy (Chapter 4).

Consequently these equations proved successful in achieving the specified aims for which they were derived (Chapters 5 and 8). The detailed

body composition experiments reported in this thesis allow certain conclusions to be made concerning the effects of feed restriction; some were known or expected but nevertheless contribute to an area where previously there was little information.

(1) Alterations in body composition were independent of the two methods of feed restriction in layer-type birds although the results of other studies (R.J. Johnson, unpublished information; Powell and Gehle 1976) showed that this may not be the case when low protein or amino acid deficient diets are used to achieve nutrient restriction. With feed restriction *per se* the alterations are *inter alia* related to the degree of liveweight reduction achieved, which was expected on the basis of previous reports (see Figure 1.4, Chapter 1).

(2) With moderately severe liveweight reduction (*c.* 20%) at cessation of feed restriction relative to birds allowed *ad libitum* feed intake, it can be concluded that the major alterations in body composition were a decrease in body fat with a consequent increase in body water. Given the direct inverse relationship between these two components (Chapter 4), the major physiologic finding here was that the water content of the fat-free mass was increased for birds on the restriction treatments at cessation of restriction. This is an important physiological manifestation of undernutrition since basic changes in the intra- and extra-cellular fluid volume were probably involved (Chapter 5). Recalculation of some previous information on body composition confirmed this effect due to undernutrition (Fuller *et al.* 1969; Powell and Gehle 1976; Gous and Stielau 1976; Connor *et al.* 1977b). Differences in body composition reported here and in previous reports were probably due to feather removal prior to carcass analysis, a practice not used in the present studies.

(3) Although body fat content was reduced due to feed restriction, extrapolation of the results to the expected changes in cellularity and hypertrophy of adipose tissue in poultry (e.g., Pfaff and Austic 1976; R.L. Hood, pers. comm.) indicated that there were no permanent changes in either cell numbers or development due to feed restriction. However, this conclusion is tentative since only gross chemical changes were monitored.



(4) Predicted body composition (Chapter 5) for birds on Experiment 2 (Chapter 3) at sexual maturity (first oviposition) showed that the hyperphagia commonly associated with the allowance of *ad libitum* feed intake at cessation of restriction (Figures 3.2 and 3.5, Chapter 3; Gardiner and MacIntyre 1962; Pym and Dillon 1974; Watson 1976; Connor *et al.* 1977b) caused major chemical gains in the body prior to sexual maturity. Gross efficiency of feed utilization was enhanced during compensatory growth (Chapter 3), probably due to the composition of the liveweight gain and also to the high feed intake relative to maintenance requirement. The latter was found for sheep during compensatory growth (Graham and Searle 1979). For birds in Experiment 2 (Chapter 3) approximately 64% of the liveweight gain between cessation of feed restriction and sexual maturity was estimated to be water (see Chapter 5). Water deposition during this period (12-17 d) was 14-18 g/d. These high rates of water deposition were probably due to the substantial protein deposition (van Es 1977), and the finding that protein deposition was greater than fat deposition may partially explain the greater gross energetic efficiency during this period despite commencement of egg production, although current evidence (Pullar and Webster 1977) suggests that the energy costs of protein and fat deposition are almost identical at 53 kJ/g. However, protein deposition is a function of protein synthesis and breakdown, and it is possible that protein turnover, a process thought to contribute to the lower partial efficiency of protein deposition (c. 50%) compared to fat deposition (c. 70%) (see review by van Es 1977; Edmunds and Buttery 1980), could be reduced during compensatory growth. An increase in the partial efficiency of protein synthesis would result in a lower total quantity of energy required therefore giving a higher gross energetic efficiency of growth during this period.

(5) The substantial protein deposition during compensatory growth for previously restricted birds resulted in equivalent or greater absolute amounts for these birds, relative to birds allowed *ad libitum* feed intake, at sexual maturity (Chapter 5). This concurs with the finding of Connor *et al.* (1977b) that there was little or no change in total lean body mass for birds slaughtered at first oviposition due to prior feed restriction. Bailey and Zobrisky (1968) noted that animals are able to maintain essential protein content regardless of nutrient intake. For poultry near commence-

ment of egg production this may be particularly important because of the continued protein requirement for egg production. Harms *et al.* (1971) carried out experiments on laying hens from which they concluded that there was evidence of protein storage and subsequent utilization during periods of protein inadequacy. Such an argument may partially explain the plateau or loss of liveweight soon after birds commenced egg production (see Figures 3.2 and 3.5, Chapter 3).

(6) There was no demonstrable relationship between body fat content at sexual maturity and subsequent rate of egg production (Chapter 5) in layer-type hens within the range of body fat contents measured and under the conditions of the experiment. The latter two considerations are necessary because other results on body composition of Australian laying hens (Connor *et al.* 1977b) showed that considerably greater body fat contents than were observed in the present studies are possible. Furthermore, egg production here commenced during periods of high but decreasing ambient temperatures (see Figure 3.1, Chapter 3), and the results of some studies (Fuller *et al.* 1969, 1973; Pym and Dillon 1974; Chaney and Fuller 1975) indicated that if egg production occurred during the very hot summer months, with high temperatures and relative humidity, as are found particularly in other areas of Australia, then body fat content or liveweight may be an important determinant of production. Certainly it can be concluded from the studies detailed in Chapter 5, and in Chapter 8 where broiler breeder hens had excellent rates of egg production despite high body fat contents, that body fat content *per se* does not influence egg production within normal genetic and nutritional boundaries. This does not imply that during egg production the birds which inherently or otherwise are low egg producers will not have increased body fat content (Greenberg 1976) associated with depressed energetic efficiency, but simply that the processes of egg production (yolk deposition, ovulation and oviposition) are unaffected by body fat *per se*. From a physiological viewpoint, this is a logical conclusion.

(7) Liver lipogenesis (Chapter 5) was influenced not by feed restriction *per se*, but by the method of feed restriction. This was due to the extent of hyperphagia which was allowed to occur by the

different feed restriction methods, since birds on the limited-time treatment consumed large quantities of feed on days when they were allowed *ad libitum* feed intake; this resulted in an apparent net increase in liver lipid levels. Although liver lipogenesis was increased for birds on the quantitative treatment the argument was advanced that transport of lipid from the liver was sufficient to result in no net increase. The extent and sites of glycogen synthesis require investigation in birds on restriction treatments during rearing, because circumstantial evidence was obtained here to suggest that substantial glycogen synthesis may occur in such birds; this is in accordance with other studies on poultry (Leveille 1966; Yeh and Leveille 1970; Simon and Blum 1972). The recent finding that insulin sensitivity was probably increased during periods of hyperphagia in restricted fed birds and that the birds had a greater glucose tolerance (Simon and Rosselin 1979) may be related to the observed (Hollands and Gowe 1961; Watson 1976) increases in pancreatic weight noted for birds on restricted feeding regimens. The influence of these effects, and their persistence after subsequent realimentation, require further investigation.

### 9.3 PRODUCTION

Two of the most significant findings of the studies reported in this thesis were:

- (a) that actual egg production and output in broiler breeders were not influenced by feed restriction during rearing relative to birds allowed *ad libitum* feed intake when all eggs were collected and included in calculations; and
- (b) that the pattern of development of egg weight in layer-type birds was changed due to feed restriction during rearing.

Feed restriction of broiler breeders (Chapter 8) caused no real biological response in terms of egg production or output when birds were further restricted during the laying period. The magnitude of the production of abnormal eggs for birds allowed *ad libitum* feed intake during rearing, and particularly eggs with shell formation defects which could reasonably be expected to be unrecorded in deep litter trials, would suggest that the

extremely large responses reported for broiler breeders due to feed restriction during rearing (Pym and Dillon 1974; Watson 1976), as considered in Section 1.4.1, Chapter 1, may be due largely to differences in the production of abnormal eggs. Both Pym and Dillon (1974) and Watson (1976) carried out trials on deep litter and were unable to record abnormal eggs. The pattern of development of egg weight was different for the broiler breeders rather than the layer-type birds which were restricted during rearing (see Figures 3.4 and 3.7 in Chapter 3 and Figure 8.3 in Chapter 8). Only after absolute feed intake ( $\text{g/bird d}^{-1}$ ) of the broiler breeders on the restriction treatments exceeded that of those allowed *ad libitum* intake did egg weight for the former become greater than for the latter. This finding reinforces the model given below to explain the production effects of feed restriction during rearing.

Egg weight appears to be a direct function of chronological age (e.g., Williams and Sharp 1978), which means that birds on restricted feeding programmes during rearing would probably have a different pattern of development of egg weight to birds allowed *ad libitum* feed intake. Birds on the restriction treatments which commence egg production after the cessation of restriction were shown to have an increased egg weight (see Figure 3.8, Chapter 3), but on a flock basis initial average egg weight would probably be lower for birds on the restriction treatments due to commencement of egg production of some of these birds whilst still being restricted-fed. This is illustrated in Figure 9.1. Bullock *et al.* (1963) initially advocated these relationships. Reference to the results given in Chapter 3 clearly show that this hypothetical pattern of egg weight development did not occur for birds in the present study. This was attributed to an increased feed intake which resulted in an increased linoleic acid intake. Calculations detailed in Chapter 3 showed that linoleic acid intake was inadequate to maximize egg weight; the reason for the relative differences between egg weights of Experiments 1 and 2 (Chapter 3) may therefore have been related to differences in feed intake. It is hypothesised that the changes in egg weight is directly related to the observed production responses to restricted feeding. Given that feed intake is regulated according to maintenance and production, then the following model of the sequence of events is proposed:

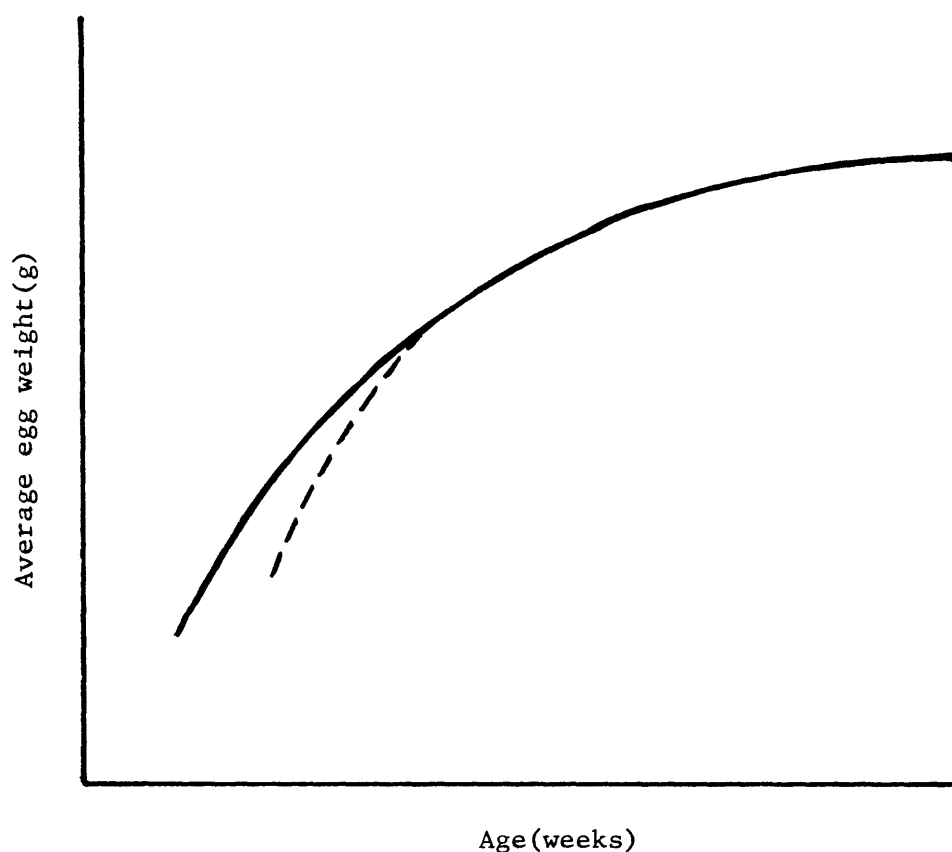


FIGURE 9.1: The probable changes in average egg weight in relation to chronological age for birds which were allowed *ad libitum* feed intake (-) or which were restricted (- -) during rearing.

- (a) there is a marked increase in feed intake upon cessation of restriction, corresponding to compensatory growth and with a consequent elevated feed intake due to a large liveweight gain near commencement of egg production;
- (b) because of chronological age and a greater dietary linoleic acid supply, the previously restricted birds commence egg production with greater egg weights;
- (c) with a more synchronised rate of ovulation and oviposition due to delayed sexual maturity (Gilbert 1969), egg numbers are increased and with a greater egg weight and consequently egg output;

- (d) feed intake is increased because of this which in turn supplies more linoleic acid which still remains inadequate to maximise egg weight;
- (e) egg weight increases again, and assuming that rate of yolk deposition is sufficient (Watson 1976) then egg output once again increases;
- (f) this "snowball" effect continues causing egg weights of birds previously on the restriction treatments to eventually exceed those of birds allowed *ad libitum* feed intake during rearing.

The factors likely to influence the stages in the proposed model are:

- (i) *Type of restriction.* Some types of restriction, particularly those that affect feed intake *per se* (e.g., low protein diets, amino acid deficient diets), may not be conducive to adequate hyperphagia after cessation of restriction. Birds on limited-time and quantitative restriction programmes develop the ability to consume large quantities of feed extremely quickly;
- (ii) *Severity and duration of restriction.* Severity of restriction is important for the initiation of hyperphagia after cessation of restriction. Duration is similarly important because if restriction is terminated for too long a period prior to sexual maturity then the hyperphagia and compensatory growth will have ceased and feed intake would be similar to birds allowed *ad libitum* feed intake during rearing at a similar stage;
- (iii) *Lighting pattern.* This has obvious importance during the period between cessation of restriction and commencement of production. Ideally, for results in terms of the proposed model, sexual maturity should occur within 7 d after cessation of restriction, and the longer birds are maintained on the restriction programme then the greater the likelihood that this will occur;

- (iv) *Type of diet.* The nutrient density and ingredient composition of the diet will influence the outcome of the proposed model, since if the energy content is very high then feed intake may be depressed which would reduce the supply of linoleic acid. Thus linoleic acid content has obvious importance, and this is an area where geographical and experimental differences in the responses to restricted feeding may be important. For example, wheat-based diets low in linoleic acid are common in Canada and Australia, whereas maize-based diets with a high linoleic acid content are common in the United States of America. Such considerations may at least partially explain variances between published reports (see Table 1.1, Chapter 1);
- (v) *Synchronisation of ovulation and oviposition.* Gilbert (1969) discussed this and cited studies which showed that up to 30% of all ova are missed during the initial stages of egg production. There was good evidence that this was an important factor for birds allowed *ad libitum* feed intake during rearing in the studies reported in Chapter 3. The probable better synchronisation of ovulation and oviposition of the birds previously restricted due to a delayed sexual maturity may explain the greater peaks of egg production found in the present studies (Chapter 3) and which were often reported in other studies. This effect may also at least partially explain the greater peaks of egg production reported for birds reared with decreasing light (see Section 1.4.4, Chapter 1). Peak rate of egg production, on a flock basis, is due to the rate of egg production of individual birds and to the spread of sexual maturity between birds. Maclachlan *et al.* (1977a) stated that the greater uniformity in sexual maturity of birds previously restricted was responsible for the higher peaks of egg production which were observed for these birds. However, the relative differences

between treatments in the two experiments reported in Chapter 3 for sexual maturity would suggest that peak of egg production was higher not primarily due to this reason;

- (vi) *Relationship between egg output and egg numbers.* This may influence the continued increase in egg weight and therefore output as proposed in the model. Perhaps if egg output approaches some maximum genetic potential then there is a negative feedback which depresses egg numbers.

The overall model as proposed is shown in Figure 9.2. If this model is validated, at least partially, then it has important ramifications regarding the practice of feed restriction for broiler breeders. These are:

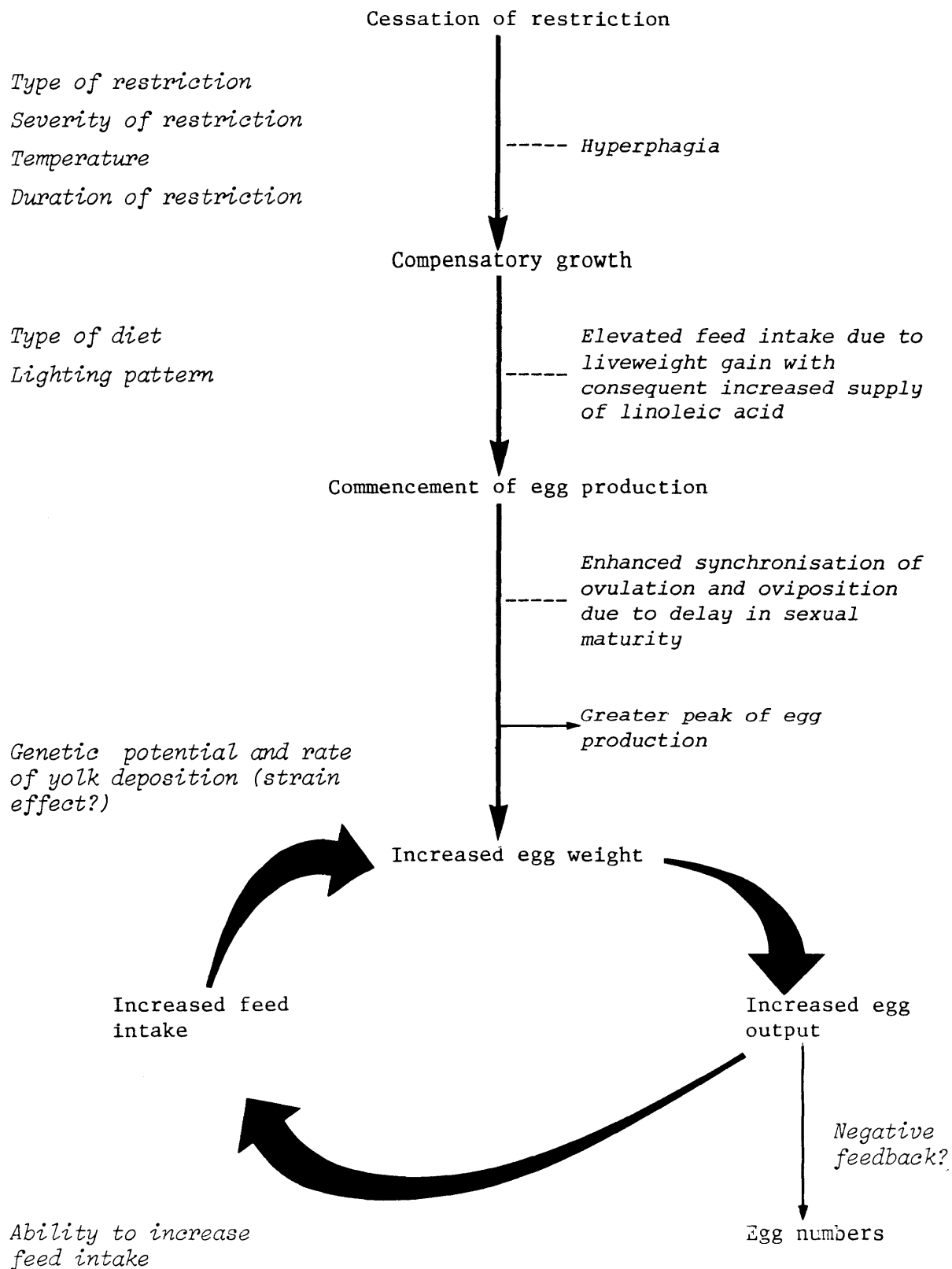
- (a) the empirical allocation of set amounts of feed is extremely tenuous up to and including peak of egg production; and
- (b) the sequence of events as proposed cannot occur in broiler breeders which are restricted during egg production because hyperphagia and compensatory growth are not allowed to occur. Because of the large overconsumption of broiler breeders allowed *ad libitum* feed intake during rearing (Chapter 8), then feed savings with the practice of restricted feeding are essentially guaranteed during this period. The results from the study reported in Chapter 8 would indicate that the reduction in feed intake over the egg production period with continued restriction may be small, and may be substantially negated by a lack of biological response by the restricted birds. The allowance of *ad libitum* feed intake from the period after cessation of restriction to after peak of egg production may give greater production responses. Restriction could then be re-imposed.

Clearly, further research is required to completely validate the proposed model, and to investigate further the practice of feed restric-



FIGURE 9.2: A hypothetical model proposed to explain the enhanced production of birds restricted in feed intake during rearing, and the factors most likely to influence the response in terms of the model.

## EXTERNAL FACTORS



tion for broiler breeders. Such research could certainly result in a greater ability to manipulate the beneficial effects of feed restriction.

#### 9.4 GENERAL COMMENT

Finally, some comment is warranted concerning the apparent confusion regarding the practice of restriction during rearing of poultry. Much of this uncertainty, particularly for layer-type stock, is for three main reasons:

- (1) Different methods of restriction;
- (2) Analysis of results on the basis of chronological age;  
and
- (3) Insufficient information on the biological effects of  
restricted feeding.

The main methods of restriction were outlined in Section 1.4.3, Chapter 1, as quantitative, time limitation, and the use of low protein or amino acid-deficient diets.

Studies on layer-type birds which received low-protein or amino acid-deficient diets during rearing in Australia seem to be largely concerned with demonstrating that such diets did not have a deleterious effect on subsequent productive performance, and most have indeed come to this conclusion (Abu-Serewa 1977, 1978; Connor *et al.* 1977a; Polkinghorne and Mannion 1978). There are two aspects of this which require consideration. The first is that although the above-mentioned studies which used low protein or low lysine diets found no depression in subsequent production, the emphasis was shifted from cost reduction during rearing and/or increased monetary returns during egg production to the maintenance of the *status quo* relative to birds allowed *ad libitum* feed intake of adequate diets. Certainly cost reduction during rearing due to the consumption of less or cheaper feed is an equivocal area irrespective of the method of restriction. Results of the studies in Chapter 3 and previous reports (Pym and Dillon 1974; Watson 1976; Connor *et al.* 1977b; Polkinghorne and Mannion 1978; Brody 1980) showed conclusively that there is a period of compensatory growth when birds are allowed *ad libitum* feed intake after cessation of restriction.

Many factors will influence liveweight gain during this period (see Chapter 3), but calculations carried out in Chapter 3 indicated that feed consumption was directly correlated with energy requirement. Nevertheless the achievement of an actual reduction in feed intake during rearing up to sexual maturity is precariously balanced.

Given that nutrient reduction during rearing up to sexual maturity is uncertain, at least with current types of birds and under conventional management and housing conditions, then the practice of restriction during rearing necessitates that such programmes enhance subsequent egg production or efficiency. This is the major area which segregates methods of restriction, because quantitative and time limitation methods have consistently given greater physiological or chronological egg production (see Table 1.1, Chapter 1), whereas low protein or low lysine diets have not been as consistent (Couch and Trammell 1970; Luther *et al.* 1976; Connor *et al.* 1977a; Abu-Serewa 1977, 1978; Polinghorne and Mannion 1978). The experiments reported by Connor *et al.* (1977a,b) illustrate the difference. With low lysine diets fed during rearing, Connor *et al.* (1977a) found no effect on either chronological or physiological egg production or output, while with time limitation methods used with the same strain of bird (Connor *et al.* 1977b) there was a significant improvement in egg production.

Chronological age analysis of production data from experiments on restricted feeding was initially identified as a major factor which contributed to the confusion regarding the responses obtained (see Chapter 1), and subsequent studies here (Chapter 3) provided quantitative evidence of the large differences between methods of analysis which were due to a simple delay in sexual maturity. Published reports on restricted feeding should be encouraged to contain both methods of analysis, particularly with regard to egg production and output. The third reason for the confusion regarding the practice of nutrient restriction is the acknowledged (Lee *et al.* 1971a; Robinson 1976; Pearson and Shannon 1979) lack of information on the biological effects of restricted feeding during rearing. Although the variability of the responses obtained between published reports on restriction was clearly illustrated in Chapter 1, there is a vast body of

evidence which shows that enhanced egg production and gross energetic efficiency may occur (Gowe *et al.* 1960; Strain *et al.* 1965; McMahon *et al.* 1974; Pym and Dillon 1974; Peter *et al.* 1976; Watson 1976; Connor *et al.* 1977b; J.K. Connor, pers. comm.; R.B. Cumming, pers. com.). To study these effects and the probable reasons for their occurrence, the fundamental prerequisite is to obtain the effects experimentally. Both experiments carried out here on layer-type birds showed that the two feed restriction methods used resulted in the desired response in terms of egg production and gross energetic efficiency. There was, however, some evidence that the two different restriction methods caused a varied response in the different types of birds used between experiments (Chapter 3). Conclusions regarding strain effects on the response to feed restriction cannot be made from the results reported here, but the known differences between strains (Proudman and Gowe 1967, 1973; Patchell 1977) are sufficiently large, and the emerging new strains sufficiently numerous (e.g., SIRO-CT bird), that the practice of feed restriction for layer-type birds will depend on strain responses. These should therefore be determined, since it is possible that some types of birds will require optimum growth during rearing for optimum egg production.

The model proposed, and the results reported in this thesis, should allow an improved orientation to be placed on the practice of feed restriction of poultry on a research basis. Undoubtedly this will further clarify the biological basis of feed restriction, but considerably more research in this area is still required.

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## APPENDICES

APPENDIX TABLE A3.1 Two-way analyses of variance for the production parameters measured in eleven 28 d periods after commencement of egg production on a chronological basis.<sup>+</sup> (Experiment 1)

Production parameter	Source of variation	Degrees of freedom (df)	Mean squares (MS)	Significance <sup>1</sup>
Feed intake (g/bird d <sup>-1</sup> )	Treatment (T)	2	7169.0	***
	Age (A)	10	129957.7	***
	T x A	20	6764.7	***
	Error	4673	258.0	***
Egg production (no./100 hen d)	Treatment (T)	2	12094.0	***
	Age (A)	10	148575.4	***
	T x A	20	15545.6	***
	Error	4673	555.0	***
Egg mass output (g/bird d <sup>-1</sup> )	Treatment (T)	2	5942.9	***
	Age (A)	10	62622.3	***
	T x A	20	4020.8	***
	Error	4673	178.2	***

+ Number of hen d for the three treatment groups were 1587, 1580 and 1539 for the *ad libitum* (A), limited-time restriction (TR) and quantitative restriction (QR) treatments respectively.

1 See Table 2.6, Chapter 2 for significance levels.

APPENDIX TABLE A3.2 Two-way analyses of variance for comparison of liveweights (W, g) between treatments during the egg production periods after prior logarithmic transformation.

Experiment	Source of variation	Degrees of freedom (df)	Mean Squares (MS)	Significance <sup>1</sup>
Experiment 1	Treatment (T)	2	0.026	***
	Age (A)	15	0.076	***
	T x A	30	0.002	NS
	Error	1741	0.002	
Experiment 2	Treatment (T)	2	0.038	***
	Age (A)	10	0.085	***
	T x A	20	0.0002	NS
	Error	1496	0.0023	

<sup>1</sup> See Table 2.6, Chapter 2 for significance levels.

APPENDIX TABLE A3.3 Two-way analyses of variance for the production parameters measured in twelve 28 d periods after commencement of egg production on a chronological basis. (Experiment 2)

Production parameter	Source of variation	Degrees of freedom (df)	Mean squares (MS)	Significance <sup>1</sup>
Feed intake (g/bird d <sup>-1</sup> )	Treatment (T)	2	6904.5	***
	Age (A)	11	174308.2	***
	T x A	22	10054.4	***
	Error	6636	317.7	
Egg production (no./100 hen d)	Treatment (T)	2	20133.9	***
	Age (A)	11	347797.7	***
	T x A	22	30448.4	***
	Error	6636	363.6	
Egg mass output (g/bird d <sup>-1</sup> )	Treatment (T)	2	1198.2	***
	Age (A)	11	152306.6	***
	T x A	22	8853.5	***
	Error	6636	140.0	
Average egg weight (g/bird)	Treatment (T)	2	1132.7	***
	Age (A)	10	8278.0	***
	T x A	20	75.6	***
	Error	5639	20.1	

<sup>1</sup> See Table 2.6, Chapter 2 for significance levels.

APPENDIX TABLE A3.4 The effect of feeding regimen during rearing on the gross energetic efficiency of egg production (kJ egg energy/kJ ME, %) in nine 28 d periods after peak of egg production for individual treatments. Standard deviations are given in parentheses below each mean (Experiment 1).

Period	Treatment <sup>+</sup>			Significance <sup>1</sup>
	<i>Ad libitum</i>	Limited-time	Quantitative	
1	19.2 <sup>a</sup> (7.0)	20.7 <sup>b</sup> (6.1)	20.6 <sup>b</sup> (5.4)	*
2	19.5 <sup>a</sup> (6.6)	21.8 <sup>b</sup> (3.2)	20.7 <sup>b</sup> (4.7)	***
3	19.7 <sup>a</sup> (6.3)	22.1 <sup>b</sup> (3.2)	21.0 <sup>b</sup> (4.6)	***
4	19.4 <sup>a</sup> (5.8)	22.0 <sup>b</sup> (3.8)	20.2 <sup>ab</sup> (6.0)	***
5	19.0 <sup>a</sup> (6.1)	20.3 <sup>b</sup> (4.0)	18.7 <sup>ab</sup> (6.0)	*
6	17.0 <sup>a</sup> (6.7)	20.5 <sup>b</sup> (4.0)	19.6 <sup>c</sup> (8.2)	***
7	16.2 <sup>a</sup> (7.4)	20.0 <sup>b</sup> (4.0)	18.5 <sup>c</sup> (4.9)	***
8	17.2 <sup>a</sup> (6.7)	20.0 <sup>b</sup> (4.6)	17.3 <sup>a</sup> (8.8)	**
9	15.8 (7.7)	17.6 (6.4)	16.1 (7.4)	NS
Overall	18.1 <sup>a</sup>	20.7 <sup>b</sup>	19.4 <sup>c</sup>	***

<sup>1</sup> See Table 2.6, Chapter 2 for significance levels.

<sup>+</sup> See Section 3.2.2, Chapter 3 for details of treatments.



APPENDIX TABLE A3.5 The effect of feeding regimen during rearing on the gross energetic efficiency of egg production (kJ egg energy/kJ ME, %) in ten 28 d periods after peak of egg production for individual treatments. Standard deviations are given in parentheses below each mean (Experiment 2).

Period	Treatment <sup>+</sup>			Significance <sup>1</sup>
	<i>Ad libitum</i>	Limited-time	Quantitative	
1	22.3 <sup>a</sup> (6.4)	23.9 <sup>b</sup> (5.0)	24.2 <sup>b</sup> (4.4)	**
2	23.4 (5.2)	23.6 (4.7)	24.0 (3.5)	NS
3	22.8 (5.0)	23.3 (5.2)	23.5 (3.3)	NS
4	22.0 <sup>a</sup> (5.6)	23.3 <sup>b</sup> (6.3)	23.7 <sup>b</sup> (4.0)	**
5	22.7 <sup>a</sup> (4.8)	24.1 <sup>b</sup> (6.0)	23.6 <sup>ab</sup> (4.8)	*
6	22.4 (6.1)	23.4 (6.6)	23.5 (4.9)	NS
7	22.5 <sup>a</sup> (6.1)	23.9 <sup>b</sup> (6.6)	24.2 <sup>b</sup> (4.6)	*
8	22.8 <sup>a</sup> (6.8)	24.3 <sup>b</sup> (6.4)	23.8 <sup>ab</sup> (4.5)	*
9	22.6 <sup>a</sup> (6.4)	24.8 <sup>b</sup> (7.2)	24.4 <sup>b</sup> (4.9)	**
10	24.0 (6.5)	23.6 (8.9)	23.9 (6.8)	NS
Overall	22.8 <sup>a</sup>	23.8 <sup>b</sup>	23.9 <sup>b</sup>	***

1 See Table 2.6, Chapter 2 for significance levels.

+ See Section 3.2.2, Chapter 3 for details of treatments.

APPENDIX TABLE A4.1 Linear regressions of total body water (TBW, g) on tritiated water space (T, g) for birds in individual groups.

Group	No. of birds	Constants in the equation: TBW = a + dT		R <sup>2</sup>	RSD	Equation * Number
		a	d			
1	16	277.4	0.645	0.764	36.25	4a
2	6	95.1	0.622	0.867	1.47	4b
3	12	71.7	0.814	0.934	11.61	4c
4	12	88.1	0.808	0.895	17.01	4d
5	18	-63.4	0.974	0.957	22.94	4e
6	18	-149.6	1.054	0.845	40.53	4f
7	18	-254.6	1.123	0.852	52.79	4g
8	15	193.0	0.779	0.704	63.83	4h
9	10	-369.0	1.076	0.878	76.40	4i
10	12	-101.5	0.994	0.894	24.47	4j
11	12	-834.9	1.595	0.897	57.56	4k
12	12	27.6	0.863	0.900	67.03	4l
13	8	-58.8	0.937	0.608	150.76	4m

\* Equation number relative to equation in Table 4.10 with all birds combined.

APPENDIX TABLE A4.2 Allometric regressions of total body water (TBW, g) on tritiated water space (T, g) for birds in individual groups.

Group	No. of birds	Constants in the equation: $TBW = aT^d$		$R^2$	RSD <sup>+</sup>	Equation * Number
		a	d			
1	16	5.636	0.737	0.779	-	11a
2	6	5.888	0.678	0.867	-	11b
3	12	2.109	0.873	0.941	-	11c
4	12	2.158	0.872	0.900	-	11d
5	18	0.600	1.060	0.957	-	11e
6	18	0.418	1.112	0.860	-	11f
7	18	0.191	1.220	0.842	-	11g
8	15	3.289	0.823	0.739	-	11h
9	10	0.195	1.200	0.883	-	11i
10	12	0.413	1.111	0.898	-	11j
11	12	0.007	1.688	0.893	-	11k
12	12	0.968	0.987	0.897	-	11l
13	8	0.519	1.073	0.649	-	11m

+ Residual standard deviations not calculated for individual group allometric regression equations

\* See Appendix Table A4.1.

APPENDIX TABLE A4.3 Linear regressions of total body water (TBW, g) on deuterium oxide space (D, g) for birds in individual groups.

Group	No. of birds	Constants in the equation: TBW = a + gD		R <sup>2</sup>	RSD	Equation* Number
		a	d			
5	18	49.16	0.929	0.925	30.20	15a
6	18	-145.19	1.049	0.806	45.34	15b
7	18	-140.9	1.041	0.880	47.40	15c
8	15	157.9	0.801	0.654	69.06	15d
9	10	-475.2	1.180	0.886	73.85	15e
10	12	-50.6	0.941	0.804	33.31	15f
11	12	188.3	0.741	0.509	125.73	15g
12	12	-98.3	0.939	0.932	55.19	15h

\* See Appendix Table A4.1.

APPENDIX TABLE A4.4 Allometric regressions of total body water (TBW, g) on deuterium oxide space (D, g) for birds in individual groups.

Group	No. of birds	Constants on the equation: TBW = aD <sup>g</sup>		R <sup>2</sup>	RSD <sup>+</sup>	Equation <sup>*</sup> Number
		a	g			
5	18	1.469	0.941	0.923	-	19a
6	18	0.420	1.111	0.818	-	19b
7	18	0.471	1.095	0.863	-	19c
8	15	2.979	0.836	0.676	-	19d
9	10	0.137	1.254	0.898	-	19e
10	12	0.545	1.071	0.804	-	19f
11	12	1.811	0.900	0.580	-	19g
12	12	0.555	1.062	0.934	-	19h

+ See footnote in Appendix Table A4.2.

\* See Appendix Table A4.1.

APPENDIX TABLE A4.5 Multiple linear regressions of total body water (TBW, g) on liveweight (W, g) and tritiated water space (T, g) for birds in individual groups.

Group	No. of birds	Constants in the equation: TBW = a + bW + dT			R <sup>2</sup>	RSD	Equation * Number
		a	b	d			
1	16	200.6	0.100	0.540	0.795	35.02	5a
2	6	133.8	-0.206	0.775	0.889	1.55	5b
3	12	41.6	0.360	0.345	0.978	7.15	5c
4	12	70.1	0.148	0.623	0.908	16.80	5d
5	18	7.8	0.248	0.513	0.980	16.19	5e
6	18	-34.3	0.350	0.367	0.917	30.65	5f
7	18	-65.6	0.377	0.350	0.920	40.10	5g
8	15	250.2	0.320	0.195	0.954	26.22	5h
9	10	-3.3	0.288	0.424	0.964	44.60	5i
10	12	-14.5	0.185	0.622	0.938	19.67	5j
11	12	-306.4	0.434	0.446	0.977	29.00	5k
12	12	197.1	0.136	0.561	0.934	57.41	5l
13	8	-63.4	0.700	-0.225	0.929	70.56	5m

See Appendix Table A4.1.

APPENDIX TABLE A4.6 Allometric regressions of total body water (TBW, g) on liveweight (W, g) and tritiated water space (T, g) for birds in individual groups.

Group	No. of birds	Constants in the equation: $TBW = aW^b T^d$			$R^2$	RSD <sup>+</sup>	Equation * Number
		a	b	d			
1	16	3.048	0.626	0.184	0.805	-	12a
2	6	13.428	0.841	-0.292	0.889	-	12b
3	12	1.180	0.361	0.570	0.980	-	12c
4	12	1.722	0.681	0.214	0.911	-	12d
5	18	0.759	0.577	0.422	0.981	-	12e
6	18	0.573	0.478	0.550	0.915	-	12f
7	18	0.420	0.379	0.683	0.920	-	12g
8	15	3.266	0.225	0.558	0.954	-	12h
9	10	0.622	0.472	0.540	0.968	-	12i
10	12	0.637	0.685	0.342	0.941	-	12j
11	12	0.094	0.474	0.789	0.976	-	12k
12	12	2.323	0.617	0.249	0.931	-	12l
13	8	0.383	-0.239	1.267	0.938	-	12m

+ See footnote in Appendix Table A4.2.

\* See Appendix Table A4.1.

APPENDIX TABLE A4.7 Multiple linear regressions of total body water (TBW, g) on liveweight (W, g) and deuterium oxide space (D, g) for birds in individual groups.

Group	No. of birds	Constants in the equation: TBW = a + bW + gD			R <sup>2</sup>	RSD	Equation* Number
		a	b	g			
5	18	79.2	0.326	0.341	0.967	20.76	16a
6	18	-35.4	0.375	0.328	0.918	30.53	16b
7	18	-35.3	0.341	0.387	0.920	39.94	16c
8	15	294.3	0.352	0.103	0.941	29.70	16d
9	10	-42.5	0.284	0.471	0.962	45.44	16e
10	12	52.4	0.254	0.449	0.904	24.55	16f
11	12	-60.8	0.570	0.020	0.967	34.63	16g
12	12	60.7	0.100	0.696	0.948	50.93	16h

\* See Appendix Table A4.1.



APPENDIX TABLE A4.8 Allometric regressions of total body water (TBW, g) on liveweight (W, g) and deuterium oxide space (D, g) for birds in individual groups.

Group	No. of birds	Constants in the equation: TBW = aW <sup>b</sup> D <sup>g</sup>			R <sup>2</sup>	RSD <sup>+</sup>	Equation <sup>*</sup> Number
		a	b	g			
5	18	1.237	0.559	0.363	0.966	-	20a
6	18	0.581	0.624	0.396	0.911	-	20b
7	18	0.590	0.664	0.351	0.917	-	20c
8	15	4.131	0.625	0.121	0.939	-	20d
9	10	0.570	0.527	0.501	0.964	-	20e
10	12	0.927	0.479	0.485	0.907	-	20f
11	12	0.349	1.023	0.039	0.965	-	20g
12	12	1.119	0.171	0.787	0.948	-	20h

+ See footnote in Appendix Table A4.2.

\* See Appendix Table A4.1.

APPENDIX TABLE A4.9 Covariance probability matrix of adjusted means for differences between individual groups of birds in the relationship  $TBW(q) = a + dT$ .

[illegible]

APPENDIX TABLE A4.10 Covariance probability matrix of adjusted means for differences between individual groups of birds in the allometric relationship  $TBW(g) = aT^d$ .

[illegible]

APPENDIX TABLE A4.11 Covariance probability matrix of adjusted means for differences between individual groups of birds in the relationship  $TBW(g) = a + bw + dT$ .

[illegible]

APPENDIX TABLE A4.12 Covariance probability matrix of adjusted means for differences between individual groups of birds in the relationship  $TBW(g) = aw^b T^d$ .

Covariance probability matrix of adjusted means for differences between individual groups of birds in the relationship  $TBW(g) = aW^b T^d$ .

[illegible]

APPENDIX TABLE A4.13 Covariance probability matrix of adjusted means for differences between individual groups of birds in the relationship  $TBW(g) = a + gD$ .

Group	5	6	7	8	9	10	11	12
5		**	*	*	NS	***	***	**
6			NS	NS	NS	NS	NS	NS
7				NS	NS	NS	NS	*
8					NS	NS	NS	*
9						NS	NS	***
10							NS	NS
11								NS
12								

APPENDIX TABLE A4.14 Covariance probability matrix of adjusted means for differences between individual groups of birds in the allometric relationship  $TBW(g) = -aD^g$ .

Group	5	6	7	8	9	10	11	12
5		***	**	*	NS	***	***	**
6			NS	NS	NS	NS	NS	NS
7				NS	NS	NS	NS	NS
8					NS	NS	*	NS
9						NS	NS	**
10							NS	NS
11								NS
12								

APPENDIX TABLE A4.15 Covariance probability matrix of adjusted means  
for differences between individual groups of birds  
in the relationship  $TBW(g) = a + bW + gD$ .

Group	5	6	7	8	9	10	11	12
5		*	NS	NS	NS	NS	*	NS
6			NS	NS	*	NS	NS	NS
7				NS	NS	NS	NS	NS
8					NS	NS	NS	NS
9						*	*	NS
10							NS	NS
11								*
12								



APPENDIX TABLE A4.16 Covariance probability matrix of adjusted means for differences between individual groups of birds in the relationship  $TBW(g) = aW^{b_g}D^g$ .

Group	5	6	7	8	9	10	11	12
5		***	*	NS	NS	*	**	NS
6			NS	NS	*	NS	NS	*
7				NS	NS	NS	NS	NS
8					NS	NS	NS	NS
9						NS	*	NS
10							NS	NS
11								*
12								

APPENDIX TABLE A4.17

Linear, multiple linear and allometric regression equations established to predict total body water (TBW, g) from liveweight (W, g) and tritiated water space (T, g) for groups of birds classified on the basis of age and type into pullets (aged less than 162 d), newlayers (aged 162 to 280 d), oldlayers (aged 280 to 476 d) and broilers (broiler breeders).

Model and Independent Variables	Category	Number of birds	Constants in the equation <sup>+</sup>			R <sup>2</sup>	RSD <sup>‡</sup>	CoV (%)	Equation code*
			a	b	d				
a + bW	Pullets	48	108.5	0.519		0.979	33.3	0.69	A1
	Newlayers	46	333.0	0.365		0.671	49.3	0.72	A2
	Oldlayers	45	132.1	0.490		0.913	40.9	0.55	A3
	Broilers	30	424.1	0.425		0.906	83.3	0.83	A4
a + dT	Pullets	48	14.0		0.900	0.993	18.6	0.38	A5
	Newlayers	46	106.2		0.806	0.782	40.2	0.59	A6
	Oldlayers	45	-212.8		1.095	0.769	66.6	0.89	A7
	Broilers	30	-206.6		0.997	0.881	93.7	0.93	A8
a + bW + dT	Pullets	48	31.6	0.113	0.708	0.995	17.0	0.35	A9
	Newlayers	46	103.8	0.137	0.581	0.816	37.3	0.54	A10
	Oldlayers	45	6.6	0.401	0.251	0.923	38.9	0.52	A11
	Broilers	30	94.5	0.257	0.433	0.931	72.7	0.72	A12
aW <sup>b</sup> T <sup>d</sup>	Pullets	48	1.140	0.731	0.223	0.997	-	-	A13
	Newlayers	46	1.609	0.232	0.669	0.835	-	-	A14
	Oldlayers	45	0.682	0.731	0.259	0.918	-	-	A15
	Broilers	30	1.114	0.550	0.396	0.936	-	-	A16

<sup>+</sup> Dependent variable is total body water (TBW, g) and independent variables are as specified.

\* Appendix equations are denoted by the prefix A.

<sup>‡</sup> See footnote in Appendix Table A4.2.

APPENDIX TABLE A4.18 Linear, multiple linear and allometric regression equations established to predict total body water (TBW, g) from liveweight (W, g) and deuterium oxide space (D, g) from groups of birds classified on the basis of age.

Model and Independent Variables	Category	Number of birds	Constants in the equation <sup>+</sup>			R <sup>2</sup>	RSD <sup>‡</sup>	CoV (%)	Equation code*
a + bW	Pullets	-	-	-	-	-	-	-	-
	Newlayers	-	-	-	-	-	-	-	A17
	Oldlayers	56	-296.4	0.342	0.831	40.2	0.49	0.49	A18
	Broilers	22	-630.3	0.396	0.799	125.5	1.51	1.51	A19
a + gD	Pullets	-	-	-	-	-	-	-	-
	Newlayers	-	-	-	-	-	-	-	A20
	Oldlayers	56	47.2	0.873	0.681	74.5	0.91	0.91	A21
	Broilers	22	-425.7	1.14	0.906	78.9	0.95	0.95	A22
a + bW + gD	Pullets	-	-	-	-	-	-	-	-
	Newlayers	-	-	-	-	-	-	-	A23
	Oldlayers	56	88.4	0.431	0.920	37.7	0.46	0.46	A24
	Broilers	22	-2.15	0.210	0.948	60.1	0.72	0.72	A25
a <sup>b</sup> D <sup>g</sup>	Pullets	-	-	-	-	-	-	-	-
	Newlayers	-	-	-	-	-	-	-	A26
	Oldlayers	56	1.419	0.763	0.971	-	-	-	A27
	Broilers	22	0.710	0.326	0.948	-	-	-	A28

<sup>+</sup> Dependent variable is total body water (TBW, g) and independent variables are as specified.

\* See Appendix Table A4.17.

<sup>‡</sup> See footnotes in Appendix Table A4.2.

APPENDIX TABLE A4.19 Differences between actual body water (TBW) and that predicted from the equation  $TBW(g) = a + bW + dT$  derived after birds were classified according to pullets (aged less than 162 d), newlayers (162-280 d), oldlayers (280-476 d) and broilers (broiler breeders) (See Appendix Table A4.26 for data used.)

Category <sup>+</sup>	Mean total body water (TBW) <sup>1</sup>		Total body water (g) predicted using:		Difference (%) <sup>4</sup>	
	(g)	(±SD)	Category equations <sup>2</sup>	Combined equation <sup>3</sup>	Category equations	Combined equation
Pullets	698.4	226.0	698.3	685.6	-0.01	-1.83
Newlayers	1012.2	85.1	1011.5	1038.8	-0.07	2.44
Oldlayers	1110.1	136.9	1110.2	1102.3	0.01	-0.52
Broiler breeders	1841.7	267.0	1841.9	1836.7	0.01	-0.27

+ See text for details.

1. Actual total body water determined by desiccation.
2. Relevant equations are given in Appendix Table A4.17.
3. Equation 5 in Table 4.10.
4. Percentage difference between predicted and actual total body water.

APPENDIX TABLE A4.20 Differences between actual total body water (TBW) and that predicted from the equation  $TBW(g) = a + bw + gD$  derived after birds were classified according to newlayers, oldlayers and broiler breeders (See Appendix Table A4.27 for data used.)

Category <sup>+</sup>	Mean total body water (TBW) <sup>1</sup>		Total body water predicted using:		Difference (%) <sup>4</sup>	
	(g)	(±SD)	Category equations <sup>2</sup>	Combined equation	Category equations	Combined equation
Newlayers						
Oldlayers	1094.3	130.6	1094.8	1102.2	0.05	0.72
Broiler breeders	1771.9	250.6	1769.9	1758.9	-0.11	-0.73

+ See text for details.

Notes 1 and 4, see Appendix Table A4.19 for explanation.

2. Relevant equations are given in Appendix Table A4.18.

3. Equation 16 in Table 4.10.

APPENDIX TABLE A4.21

Linear, multiple linear and allometric regression equations established to predict total body water (TBW, g) from liveweight (W, g) and tritiated water space (T, g) for groups of birds classified on the basis of liveweight into (a) liveweight less than or equal to 1500 g, (b) liveweight greater than 1500 g but less than 2200 g, and (c) liveweight greater than 2200 g.

Model and Independent Variables	Category <sup>+</sup>	Number of birds	Constants in the equation			R <sup>2</sup>	RSD	CoV (%)	Equation code
			a	b	d				
a + BW	1	38	77.0	0.556		0.971	31.6	0.83	A29
	2	89	234.8	0.428		0.693	49.4	0.51	A30
	3	42	153.9	0.498		0.933	90.8	0.83	A31
a + dT	1	38	25.7		0.880	0.992	16.7	0.44	A32
	2	89	166.4		0.754	0.771	42.6	0.44	A33
	3	42	165.0		0.824	0.931	92.0	0.85	A34
a + BW + dT	1	38	30.4	0.072	0.769	0.992	16.5	0.43	A35
	2	89	99.1	0.191	0.503	0.824	37.6	0.39	A36
	3	42	106.1	0.261	0.421	0.965	66.8	0.61	A37
aW <sup>b</sup> T <sup>d</sup>	1	38	1.122	0.224	0.733	0.996	-	-	A38
	2	89	1.479	0.345	0.561	0.826	-	-	A39
	3	42	1.306	0.416	0.509	0.966	-	-	A40

+ Categories were: 1. Liveweight less than or equal to 1500 g; 2. Liveweight greater than 1500 g and less than or equal to 2200 g; 3. Liveweight greater than 2200 g.

APPENDIX TABLE A4.22 Linear, multiple linear and allometric regression equations established to predict total body water (TBW, g) from liveweight (W, g) and deuterium oxide space (D, g) for groups of birds classified on the basis of liveweight into (a) liveweight greater than 1500 g but less than 2200 g and (b) liveweight greater than 2200 g.

Model and Independent Variables	Category <sup>+</sup>	Number of birds	Constants in the equation			R <sup>2</sup>	RSD <sup>‡</sup>	CoV (%)	Equation code
a + gD	1	33	235.2		0.702	0.811	47.1	0.82	A41
	2	82	110.5		0.865	0.897	100.7	0.69	A42
a + bW + gD	1	33	115.6	0.337	0.264	0.899	34.7	0.60	A43
	2	82	106.4	0.275	0.404	0.963	61.6	0.42	A44
a <sup>b</sup> D <sup>g</sup>	1	33	1.663	0.616	0.256	0.903	-	-	A45
	2	82	1.259	0.494	0.431	0.957	-	-	A46

+ Categories were: 1. Liveweight 1500 - 2200 g.  
2. Liveweight >2200 g.

‡ See footnotes in Appendix Table A4.2.

APPENDIX TABLE A4.23 Differences between actual total body water (TBW) and that predicted from the equation  $TBW(g) = a + bW + dT$  derived after birds were classified according to liveweight into (a) liveweight less than or equal to 1500 g; (b) liveweight greater than 1500 g but less than or equal to 2200 g and, (c) liveweight greater than 2200 g.

Category <sup>+</sup>	Mean total body water (TBW) <sup>1</sup>		Total body water (g) predicted using:		Difference (%) <sup>4</sup>	
	(g)	(SD)	Category equations <sup>2</sup>	Combined equation <sup>3</sup>	Category equations	Combined equation
1	620.3	183.7	620.5	606.9	0.03	-2.16
2	1024.3	88.6	1024.1	1037.5	-0.02	1.29
3	1679.9	346.1	1679.4	1666.6	-0.03	-0.79

+ Categories were on the basis of liveweight. See text for details.

Notes 1 and 4, see Appendix Table A4.19.

2. Relevant equations are given in Appendix Table A4.21.

3. Equation (5) given in Table 4.10.



APPENDIX TABLE A4.24 Differences between actual total body water (TBW) and that predicted from the equation  $TBW(g) = a + bw + gd$  derived after birds were classified according to liveweight into (a) liveweight greater than 1500 g and less than or equal to 2200 g and (b) liveweight greater than 2200 g.

Category <sup>+</sup>	Mean total body water (TBW) <sup>1</sup>		Total body water (g) predicted using:		Difference (%) <sup>4</sup>	
	(g)	(SD)	Category <sub>2</sub> equations <sub>2</sub>	Combined <sub>3</sub> equation <sub>3</sub>	Category equation	Combined equation
1	1003.7	107.5	1004.5	1007.2	0.08	0.35
2	1612.7	308.0	1614.0	1601.6	0.08	-0.69

+ Categories were on the basis of liveweight. See text for details.

Notes 1 and 4, see Appendix Table A4.19.

2. Relevant equations are given in Appendix Table A4.22.

3. Equation (16) given in Table 4.10.

APPENDIX TABLE A4.25 Values of liveweight (W), tritiated water space (T) and deuterium oxide space (D) used to predict total body water in Tables 4.11 and 4.12.

Group	Liveweight (g)	Total body water (TBW) (g)	Tritiated water space (T) (g)	Deuterium oxide space (D) (g)
1	1980.5	1028.7	1164.7	-
2	429.2	297.8	325.7	-
3	822.5	533.3	567.2	-
4	1128.3	737.8	803.7	-
5	1587.1	915.6	1004.9	932.9
6	1780.8	985.1	1077.1	1077.4
7	1951.7	1088.3	1195.6	1180.6
8	2046.5	1140.9	1216.2	1227.5
9	3581.3	1935.4	2140.9	2043.0
10	1818.1	1030.9	1139.1	1149.2
11	1999.9	1104.3	1215.7	1235.6
12	2886.9	1635.7	1863.8	1846.2
13	3710.6	2033.6	2232.0	-

APPENDIX TABLE A4.26 Values of liveweight (W, g), total body water (TBW, g), tritiated water space (T, g), protein (P, g), fat (F, g) and energy (E, kJ) for birds after classification into pullets, newlayers, oldlayers and broiler breeders for the equations given in Appendix Table A4.17.

Parameter	Category <sup>+</sup>			
	Pullets (48) <sup>‡</sup>	Newlayers (46)	Oldlayers (45)	Broilers (30)
Liveweight (W)	1136.5	1860.0	1996.2	3338.0
Total body water (TBW)	698.4	1012.2	1110.1	1841.7
Tritiated water space (T)	760.3	1123.7	1207.8	2054.3
Protein (P)	242.5	381.3	382.7	636.8
Fat (F)	128.1	378.5	390.6	688.9
Energy (E)	10878.4	24137.2	24651.4	42572.8

<sup>‡</sup> Numbers of birds in each category given in parentheses.

APPENDIX TABLE A4.27      Values of liveweight (W), total body water (TBW) and deuterium oxide space (D) used to derive predicted total body water for categories newlayers, oldlayers and broiler breeders from the equations given in Appendix Table A4.18.

Category	Number of birds	W (g)	TBW (g)	D (g)
Newlayers	-	-	-	-
Oldlayers	56	1962.3	1094.3	1198.9
Broilers	22	3202.5	1771.9	1935.7

APPENDIX TABLE A4.28

Linear, multiple linear and allometric equations established to determine the appropriate model for the prediction of protein (P, g) from liveweight (W, g), age (A, d), tritiated water space (T, g) or deuterium oxide space (D, g) in poultry.<sup>+</sup>

Dependent Variable	Model and Independent Variables	Constants in the equation							(R <sup>2</sup> ) <sup>1</sup>	(RSD) <sup>2</sup>	Equation Number
		a	b	c	d	e	f	g	h		
Protein (g)	a + cA	251.6		0.515						128.0	A47
	a + h(TBW)	17.6							0.337	0.952	A48
	a + bW + h(TBW)	31.4	0.091						0.164	0.957	A49
	a + h(TBW) + fN	0.85					41.5		0.323	0.954	A50
	aW <sup>b</sup>	0.397	0.909							0.968	A51
	aW <sup>b</sup> (TBW) <sup>h</sup>	0.344	0.630							0.970	A52
	a + dT	19.4			0.305				0.322	0.954	A53
	a + bW + dT	29.8	0.084		0.160					0.962	A54
	a + bW + dT + cA	28.3	0.081	0.012	0.164					0.962	A55
	aT <sup>d</sup>	0.272			1.023					0.964	A56
	aW <sup>b</sup> T <sup>d</sup>	0.326	0.540		0.422					0.972	A57
	a + gD	38.6						0.298		0.921	A58
	a + bW + gD	47.4	0.093					0.137		0.943	A59
	aD <sup>g</sup>	0.828						0.871		0.910	A60
	aW <sup>b</sup> D <sup>g</sup>	0.679	0.447					0.421		0.928	A61

<sup>+</sup> N = 169 for tritiated water space (T) and N = 115 for deuterium oxide space (D).

Notes 1 and 2, see Table 4.10.

APPENDIX TABLE A4.29 Linear, multiple linear and allometric regression equations established to determine the appropriate model for the prediction of fat (F, g) from the variables given in poultry.<sup>+</sup>

Dependent Variable	Model and Independent Variables	Constants in the equation							Equation Number
		a	b	c	d	e	f	g	
Fat (g)	a + bw	-148.9	0.264						A62
	a + h(TBW)	-163.0							A63
	a + bw + h(TBW)	-39.2	0.814						A64
	a + bw + h(TBW) + cA	-28.3	0.838	-0.083					A
	aW <sup>b</sup>	0.0009	1.693						A65
	a(TBW) <sup>h</sup>	0.0009							A66
	aW <sup>b</sup> (TBW) <sup>h</sup>	0.005	5.046						A67
	a + dT	-155.2			0.431				A68
	a + bw + dT	-80.2	0.604		-0.607				A69
	a + bw + dT + cA	-71.3	0.622	-0.070	-0.629				A70
	aT <sup>d</sup>	0.0008			1.818				A71
	aW <sup>b</sup> T <sup>d</sup>	0.0032	4.070		-2.714				A72
	aW <sup>b</sup> T <sup>d</sup> A <sup>c</sup>	0.0037	3.718	0.113	-2.446				A73
	a + gD	-155.1						0.284	A74
	a + bw + gD	-109.1	0.484					-0.403	A75
	a + bw + gD + cA	-110.0	0.484	0.004					A76
	aD <sup>g</sup>	0.0266							A77
	aW <sup>b</sup> D <sup>g</sup>	0.0084	2.592						A78
	aW <sup>b</sup> D <sup>g</sup> A <sup>c</sup>	0.0058	2.508	0.120					A79

<sup>+</sup> See Appendix Table A4.28.

Notes 1 and 2, see Table 4.10.

APPENDIX TABLE A4.30 Linear, multiple linear and allometric regression equations established to determine the appropriate model for the prediction of ash (A, g) from the variables given in poultry.<sup>+</sup>

Dependent Variable	Model and Independent Variables	Constants in the equation							Equation Number
		a	b	c	d	e	f	g	
Ash (g)	a + cA	40.3	0.112						A80
	a + h(TBW)	12.1							A81
	a + bW + h(TBW)	17.2	0.034						A82
	a + bW + h(TBW) + cA	12.1	0.022	0.039					A83
	aW <sup>b</sup>	0.137	0.821						A84
	aW <sup>b</sup> (TBW) <sup>h</sup>	0.150	1.001						A85
	aW <sup>b</sup> (TBW) <sup>h</sup> A <sup>c</sup>	0.165	0.649	0.095					A86
	a + dT	12.4			0.048				A87
	a + bW + dT	15.5	0.025		0.005				A88
	a + bW + dT + cA	10.2	0.014	0.042	0.018				A89
	aT <sup>d</sup>	0.103			0.915				A90
	aW <sup>b</sup> T <sup>d</sup>	0.135	0.794		0.031				A91
	aW <sup>b</sup> T <sup>d</sup> A <sup>c</sup>	0.154	0.469	0.279	0.104				A92
	a + gD	11.7						0.048	A93
	a + bW + gD	13.0	0.014					0.024	A94
	a + bW + gD + cA	3.5	0.009	0.043				0.029	A95
	aD <sup>g</sup>	0.187						0.831	A96
	aW <sup>b</sup> D <sup>g</sup>	0.153	0.456					0.372	A97
	aW <sup>b</sup> D <sup>g</sup> A <sup>c</sup>	0.111	0.385	0.102				0.412	A98

+ See Appendix Table A4.28.

Notes 1 and 2, see Table 4.10.

APPENDIX TABLE A4.31 Linear, multiple linear and allometric regression equations established to determine the appropriate model for the prediction of gross energy (E, kJ) from the variables given in poultry.<sup>+</sup>

Dependent Variable	Model and Independent Variables	Constants in the equation								Equation Number		
		a	b	c	d	e	f	g	h		(R <sup>2</sup> ) <sup>1</sup>	(RSD) <sup>2</sup>
Energy (kJ)	a + bw	-4777.0	14.62							0.949	2788.0	A99
	a + h(TBW)	-6059.0							27.22	0.872	4422.0	Al00
	a + bw + h(TBW)	-810.0	34.53						-39.08	0.989	1311.0	Al01
	a + bw + h(TBW) + cA	-383.0	35.47	-3.24					-40.36	0.990	1257.0	Al02
	aW <sup>b</sup>	1.086	1.315							0.964	3286.6	Al03
	a(TBW) <sup>h</sup>	0.869							1.453	0.899	5179.9	Al04
	aW <sup>b</sup> (TBW) <sup>h</sup>	2.565	2.991						-1.936	0.994	1348.5	Al05
	aW <sup>b</sup> (TBW) <sup>h</sup> A <sup>c</sup>	2.582	2.967	0.007					-1.915	0.994	1397.2	Al06
	a + dT	-5706.0			24.41					0.862	4598.0	Al07
	a + bw + dT	-2474.0	26.01		-20.32					0.971	2117.0	Al08
	a + bw + dT + cA	-2160.0	26.65	-2.47	-21.08					0.971	2103.0	Al09
	aT <sup>d</sup>	0.877			1.432					0.899	5253.3	Al10
	aW <sup>b</sup> T <sup>d</sup>	1.991	2.450		-1.296					0.982	2485.3	Al11
	aW <sup>b</sup> T <sup>d</sup> A <sup>c</sup>	2.089	2.330	0.038	-1.205					0.983	2498.4	Al12
	a + gD	-5243.0						24.33		0.791	4501.0	Al13
	a + bw + gD	-3207.0	21.46					-12.76		0.941	2401.0	Al14
	a + bw + gD + cA	-3038.0	21.55	-0.76				-12.85		0.940	2410.0	Al15
	aD <sup>g</sup>	6.368						1.159		0.783	3688.0	Al16
aW <sup>b</sup> D <sup>g</sup>	2.979	1.713					-0.568		0.921	2032.3	Al17	
aW <sup>b</sup> D <sup>g</sup> A <sup>c</sup>	2.600	1.682	0.044				-0.550		0.924	2201.0	Al18	

+ See Appendix Table A4.28.

Notes 1 and 2, see Table 4.10.



APPENDIX TABLE A5.1 Factorial analyses of variance for the determined carcass composition of birds in Experiment 1 for three ages designated rearing (R, 162 d of age) or laying (L<sub>1</sub>, 218 d; L<sub>2</sub>, 337 d of age) with the source of variation partitioned accordingly.

Source of Variation	Degrees of freedom	Source of Variation	Degrees of freedom	Carcass Component							
				Total body water (g/kgW)		Fat (g/kgW)		Protein (g/kgW)		Water content of the fat-free mass (g/100g)	
				Mean Squares	Sig-nificance	Mean Squares	Sig-nificance	Mean Squares	Sig-nificance	Mean Squares	Sig-nificance
Age (A)	2	L <sub>1</sub> v L <sub>2</sub>	1	173	NS	7	NS	1354	**	1.9	NS
		R v (L <sub>1</sub> L <sub>2</sub> )	1	5919	***	40137	***	1350	**	49.9	***
Treatment (T)	2			1984	-	2778	**	909	NS	0.8	NS
T x A	4	T x (L <sub>1</sub> v L <sub>2</sub> )	2	304	NS	95	NS	59	NS	2.2	NS
		T x R v (L <sub>1</sub> L <sub>2</sub> )	2	872	NS	278	NS	105	NS	6.3	*
Error	45			328		432		216		1.8	

APPENDIX TABLE A6.1 Mean squares and significance levels attained in split plot analyses of variance for the parameters measured during starvation heat production (SHP) determination of representative birds from each of the three rearing treatments in Experiment 1 (see Chapter 3) over three chronologic and three physiologic stages.

Stage <sup>+</sup>	Source of variation	Degrees of freedom	Liveweight (W, g)			Respiratory quotient (RQ)			Starvation heat production (SHP, kJ)		
			Mean Squares	Signif- icance*	Mean Squares	Signif- icance	Mean Squares	Signif- icance	per bird d	per kW d	per kgW <sup>0.75</sup> d
Chronologic	Treatment (T)	2	67141	NS	0.00022	NS	4900	NS	31	NS	46
	Error (a)	15	140531		0.00050		12064		618		939
	Period (P)	2	1948834	***	0.00284	**	292574	***	6502	***	25101
	T x P	4	91161	**	0.00035	NS	7607	**	514	NS	693
	Error (b)	27	16200		0.00047		1289		454		472
Physiologic	Treatment (T)	2	39355	NS	0.00042	NS	15401	NS	1411	NS	2702
	Error (a)	15	104249		0.00031		9765		764		1069
	Period (P)	2	132732	***	0.00092	*	42994	***	4751	***	8361
	T x P	4	6869	NS	0.00006	NS	1565	NS	335	NS	439
	Error (b)	27	3323		0.00019		1540		443		587

+ See Section 6.2.1.3 for details of stages during which measurements were carried out.

\* See Chapter 2, Table 2.6 for significance levels.

APPENDIX TABLE A6.2 Means of the parameters from individual bird data over 7 d periods from 10 eggs/100 hen d for nine (Experiment 1) and ten (Experiment 2) 28 d periods in each treatment.

Experiment	Treatment <sup>1</sup>	Parameters <sup>2</sup>						N <sup>+</sup>
		ME	W	$\Delta W$	E	T	A	
1	1	1445 (256)*	1968 (249)	1.6 (4.5)	38.2 (16.7)	13.4 (5.2)	267 (81)	1467
	2	1516 (231)	1936 (309)	2.6 (7.7)	44.0 (14.6)	12.8 (4.7)	290 (81)	1409
	3	1443 (263)	1941 (237)	2.5 (6.5)	39.0 (17.3)	13.0 (4.9)	281 (80)	1385
	Overall	1468 (253)	1949 (267)	2.2 (6.4)	40.0 (16.4)	13.1 (5.0)	279 (81)	4261
2	1	1410 (207)	1935 (252)	2.1 (4.1)	45.5 (15.9)	13.3 (4.6)	275 (81)	1840
	2	1482 (203)	1930 (240)	1.9 (5.2)	51.2 (15.3)	13.7 (5.1)	317 (81)	1960
	3	1520 (204)	1928 (219)	2.3 (6.2)	51.5 (13.6)	13.6 (4.9)	310 (81)	1760
	Overall	1470 (209)	1931 (238)	2.1 (5.2)	49.4 (15.3)	13.6 (4.8)	300 (83)	5560

1. See Table 6.6.

2. Parameters were:

ME, Metabolisable energy intake (kJ/bird d<sup>-1</sup>);  
W, Liveweight (g/bird<sup>-1</sup>);  
 $\Delta W$ , Liveweight change (g/bird d<sup>-1</sup>);  
E, Egg mass output (g/bird d<sup>-1</sup>);  
T, Average shed temperature (°C) and  
A, Age (d).

+ N is number of observations (bird d) in each mean.

\* Standard deviations given in parentheses.

APPENDIX TABLE A8.1 Egg production parameters of broiler breeders  
(N = 15/treatment) in respiration chambers as  
influenced by feeding regimen

Period	Age (d)	Egg production (no./100 hen d)			Egg weight (g/bird)			Egg output (g/bird d <sup>-1</sup> )		
Treatment:		1	2	3	1	2	3	1	2	3
1	112									
2	119									
3	126									
4	133									
5	140	3.8			41.8			1.6		
6	147	36.2			42.1			15.2		
7	154	66.7			44.9			29.9		
8	161	89.5			48.9			43.7		
9	168	88.6	1.9	2.9	48.6	42.9	50.1	43.0	0.8	1.4
10	175	88.6	5.7	6.7	53.0	46.6	48.7	47.0	2.7	3.2
11	182	81.0	15.2	17.1	53.5	48.5	47.6	43.3	7.4	8.2
12	189	80.2	41.0	36.2	54.1	51.8	52.2	43.4	21.2	18.9
13	196	77.1	61.0	48.6	54.2	55.4	53.7	41.8	33.8	26.1
14	203	76.2	72.4	67.6	55.8	54.8	53.6	42.5	39.6	36.2
15	210	71.4	82.9	67.6	57.2	57.6	56.4	40.9	47.7	38.2
16	217	77.1	86.7	83.8	57.3	59.5	57.4	44.2	51.5	48.1
17	224	68.6	83.8	77.1	57.4	58.7	58.9	39.4	49.2	45.4
18	231	71.4	88.6	84.8	58.3	60.7	60.0	41.6	53.8	50.8
19	238	68.6	81.9	81.9	60.2	61.5	60.8	41.3	50.4	49.8
20	245	65.7	75.2	81.0	58.7	62.1	60.9	38.6	46.7	49.3
21	252	65.7	71.4	79.0	59.7	63.2	61.5	39.2	45.1	48.6
22	259	67.6	78.1	81.0	60.1	60.6	62.7	40.6	47.4	50.7
23	266	48.6	74.3	78.1	60.4	63.3	62.7	29.3	47.0	49.0
24	273	59.0	75.2	71.4	61.7	63.7	61.9	36.4	48.0	44.2
28	301	59.0	65.7	68.7	62.4	64.2	63.5	36.8	42.2	44.2

APPENDIX TABLE A8.2 Numbers of eggs classified as abnormal\* or which were broken produced by broiler breeder hens in respiration chambers

Treatment 1: *ad libitum*

Period	Age	Without shells		Partially shell-less	Cracked shell	Double yolk	Other <sup>+</sup>	Broken
		Weighed	Broken					
5	140	0	0	0	0	0	0	0
6	147	5	2	2	0	4	0	1
7	154	4	6	5	0	8	1	7
8	161	5	7	4	6	7	2	11
9	168	5	4	2	4	3	4	6
10	175	1	9	2	1	13	2	1
11	182	2	7	0	0	10	1	3
12	189	2	5	1	1	5	1	6
13	196	2	7	1	1	4	2	9
14	203	0	7	3	2	1	1	5
15	210	0	1	1	1	1	1	5
16	217	0	0	0	0	0	0	0
17	224	2	0	1	2	2	0	3
18	231	0	3	0	1	0	1	3
19	238	1	0	0	1	2	0	6
20	245	0	5	1	1	0	1	3
21	252	1	1	1	6	1	0	5
22	259	0	2	0	2	0	1	11
23	266	0	1	0	4	0	0	3
24	273	0	2	0	2	0	0	3
25	280	0	1	1	2	0	0	3
26	287	0	0	0	3	0	1	1
27	294	0	2	0	0	0	0	1
28	301	0	4	0	3	0	0	3

\* See Chapter 2, Section 2.8 for classification scheme.

+ Includes flat-sided and pee-wee eggs.

APPENDIX TABLE A8.3 Numbers of eggs classified as abnormal\* or which were broken produced by broiler breeder hens in respiration chambers

Treatment 2: restricted (R1)

Period	Age	Without shells		Partially shell-less	Cracked shell	Double yolk	Other <sup>+</sup>	Broken
		Weighed	Broken					
9	168	0	0	0	0	0	0	0
10	175	0	0	0	0	0	0	0
11	182	0	0	0	0	0	0	1
12	189	0	1	1	0	0	0	1
13	196	0	2	0	2	2	0	1
14	203	2	6	2	3	1	0	1
15	210	1	1	2	1	0	1	0
16	217	0	2	0	6	2	1	3
17	224	2	1	0	2	1	3	1
18	231	0	1	0	4	1	1	5
19	238	0	1	0	3	0	1	4
20	245	1	2	0	3	0	2	5
21	252	1	1	0	1	0	0	4
22	259	0	1	0	5	0	3	2
23	266	1	0	0	5	0	0	4
24	273	0	1	1	4	0	2	0
25	280	1	1	0	7	0	0	1
26	287	1	1	0	4	0	2	2
27	294	0	0	0	0	0	0	1
28	301	1	0	1	2	0	1	4

\* and + See Appendix Table A8.2.

APPENDIX TABLE A8.4 Numbers of eggs classified as abnormal\* or which were broken produced by broiler breeder hens in respiration chambers

Treatment 3: restricted (R2)

Period	Age	Without shells		Partially shell-less	Cracked shell	Double yolk	Other <sup>+</sup>	Broken
		Weighed	Broken					
9	168	0	0	0	2	0	0	0
10	175	0	0	0	0	0	0	0
11	182	0	0	1	0	0	0	0
12	189	0	0	0	1	3	0	0
13	196	0	1	0	0	0	0	2
14	203	1	9	0	0	0	0	3
15	210	1	4	2	0	1	0	4
16	217	1	4	0	2	1	0	5
17	224	0	0	0	3	0	1	6
18	231	1	1	3	4	0	0	6
19	238	0	1	0	2	0	1	2
20	245	1	3	0	3	1	2	4
21	252	0	1	1	3	0	0	7
22	259	0	0	0	0	0	0	3
23	266	1	0	0	3	0	0	3
24	273	0	2	0	2	0	0	1
25	280	0	0	0	4	0	0	1
26	287	0	0	0	4	0	0	3
27	294	0	1	0	0	0	0	0
28	301	0	1	0	0	0	0	1

\* and + See Appendix Table A8.2.

APPENDIX TABLE A8.5 Split plot analyses of variances which examined treatment and period effects, and their interaction, for egg production, gross energetic efficiency and liveweight of groups of broiler breeders in respiration chambers

(1) Liveweight (W, g) from 112 d to 266 d of age

Source of variation	df	Mean Squares	Significance
Treatments (T)	2	151100830	***
Error (a)	42	975166	
Periods (P)	23	22953219	***
T x P	46	189395	***
Error (b)	965	15115	

(2) Egg output (g/bird d<sup>-1</sup>) and gross efficiency of egg production (kJ egg/kJ ME%) from commencement of egg production in each treatment for twenty 7 d periods

Source of variation	df	Egg output		Gross efficiency	
		Mean Squares	Significance	Mean Squares	Significance
Treatments (T)	2	132	NS	63	NS
Error (a)	42	552		101	
Periods (P)	19	8672	***	1224	***
T x P	38	632	***	85	***
Error (b)	797	130		20	

(3) Egg output (g/bird d<sup>-1</sup>) and gross efficiency of egg production (kJ egg 100/kJ ME) from attainment of 65 eggs/100 hen d for each treatment for fifteen 7 d periods

Source of variation	df	Egg output		Gross efficiency	
		Mean Squares	Significance	Mean Squares	Significance
Treatments (T)	2	1888	*	515	**
Error (a)	42	449		83	
Periods (P)	14	546	***	64	***
T x P	28	92	NS	13	NS
Error (b)	587	104		15	



APPENDIX TABLE A8.6 Mean squares, and significance levels attained in factorial analyses of variance for parameters measured on three groups of broiler breeders in respiration chambers which were on three feeding treatments for twenty-five 7 d periods which were divided into 3 d and 4 d subperiods (replications).

Source of variation	Degrees of freedom	Metabolisable					
		Metabolisability		Metabolisable energy (ME, kJ/g)		Metabolisable energy intake (ME, kJ/kgW d <sup>-1</sup> )	
		Mean	Sig- Squares	Mean	Sig- Squares	Mean	Sig- Squares
			nificance		nificance		nificance
Treatments (T)	2	164.9	***	5.21	***	56808	***
Period (P)	24	9.8	***	1.17	***	19017	***
Replications (R) x P	25	1.8	NS	0.05	NS	443	***
T x P	48	5.8	***	0.18	***	4827	***
Error	50	1.8		0.05		305	0.0002
						0.0047	***
						0.0109	***
						0.0009	***
						0.0008	***
						0.0002	

		Feed intake (g/kgW d <sup>-1</sup> )		Heat production (HE(RQ), kJ/kgW d <sup>-1</sup> )		Retained energy (RE(RQ), kJ/kgW d <sup>-1</sup> )		Retained nitrogen (RN, mg/kgW d <sup>-1</sup> )	
		Mean	Sig- Squares	Mean	Sig- Squares	Mean	Sig- Squares	Mean	Sig- Squares
			nificance		nificance		nificance		nificance
Treatments (T)	2	194.9	***	12624	***	18848	***	335044	***
Period (P)	24	85.8	***	4490	***	5813	***	65000	***
Replications (R) x P	25	2.5	NS	137	***	335	NS	1924	NS
T x P	48	41.9	***	1303	***	1675	***	9379	***
Error	50	1.6		37		241		2752	

APPENDIX TABLE A8.7 Mean squares (MS), and significance levels (S) attained in factorial analyses of variance for parameters measured on three groups of broiler breeders in respiration chambers which were on three feeding treatments (see Appendix Table A8.6).

Source of variation	Degrees of freedom	Feed intake (g/kgW <sup>0.75</sup> d <sup>-1</sup> )		Metabolisable energy intake (ME, kJ/kgW <sup>0.75</sup> d <sup>-1</sup> )		Heat production (HE, kJ/kgW <sup>0.75</sup> d <sup>-1</sup> )		Retained energy (RE, kJ/kgW <sup>0.75</sup> d <sup>-1</sup> )		Retained nitrogen (RN, mg/kgW <sup>0.75</sup> d <sup>-1</sup> )	
		MS	S	MS	S	MS	S	MS	S	MS	S
Treatments (T)	2	8.2	-	9398	***	1861	***	17983	***	403575	***
Period (P)	24	69.5	***	12452	***	1609	***	7125	***	85052	***
Replications (R) x P	25	3.7	NS	622	NS	148	**	572	NS	3015	NS
T x P	48	100.6	***	12128	***	3614	***	3550	***	20527	***
Error	50	2.8		524		64		411		5823	