CHAPTER 2

MATERIALS AND METHODS

Chapter 2

Materials and Methods

2.1 STOCK AND FACILITIES

2.1.1 Stock

The experiments reported in this thesis were carried out with commercial strains of birds. The two experiments in Chapter 3 used layer-type strains (Hyline) which were genotypically different: Experiment 1 (Section 3.2.1.1), White Leghorn (WL) X Australorp (A); Experiment 2 (Section 3.2.1.2), White Leghorn (WL) X New Hampshire (NH). The stock used for the body composition experiments in Chapter 4 are given in Table 4.1: group codes 1 and 8 were layer-type birds (Hyline, WL X A), and group codes 9, 12 and 13 were broiler breeders (group code 9, Allied Genetic Breeders; group codes 12 and 13, Hyline); birds in group 13 were spares from the experiment reported in Chapter 7, while birds in group 12 were from an experiment not reported in this thesis. These broiler breeder pullets (group 12) were from a commercial dam line (Hyline) and were reared from 42 d to 126 d of age either on *ad libitum* feed intake (diet contained 12.8 MJ ME and 145 g protein/kg) or were quantitatively restricted in energy intake (diet contained 12.2 MJ ME and 250 g protein/kg) to approximately 60% of the intake of the birds allowed *ad libitum* feed intake. Birds (group 12) were housed conventionally (see Section 2.1.2.1) and were in flat-deck cages (see Section 2.1.2.2). Birds sampled from Experiments 1 and 2 in Chapter 3 were used for investigations of alterations in body composition due to restricted feeding during rearing (Chapter 5) and for energy metabolism studies (Chapter 6). Broiler breeders (Hyline) used in Chapter 8 were sampled from a commercial farm (Terrace Farms, Freemans Reach, Sydney) at 84 d of age; these birds could not be collected earlier due to a nationwide petrol strike. Birds in all experiments were numbered with a wing-band.

2.1.2 Facilities

2.1.2.1 Housing

The facilities used to house birds for all experiments except for the energy metabolism studies (see Chapters 7 and 8) were uninsulated, galvanised

iron sheds with side ventilation flaps and an unjoined roof apex which was baffled. The floor was concrete. The room in which the large open-circuit respiration chambers were situated is described in Chapter 7. Birds in Experiment 1 (Chapter 3) were maintained on deep litter in a similar shed at the University's Poultry Research Farm up to 98 d of age. Birds in Experiment 2 (Chapter 3) were maintained in flat-deck cages (see Section 2.2.2.2) up to 98 d of age in a normal experimental shed (see above).

2.1.2.2 Cages

There were two types of cages used which are specified for individual experiments throughout this thesis: (1) flat-deck carry-on wire-mesh cages with three compartments each 61 cm x 61 cm x 38 cm in height with 3.8 cm mesh spacing. Each compartment could be fitted with an individual feeding trough. The young layer-type pullets in Experiment 2 (Chapter 3) were initially (56 d of age) maintained at fifteen birds per compartment, and by 84 d of age at eight to nine birds per compartment. For the studies in which broiler breeders were placed in these cages, each compartment held two or three birds; (2) wire-mesh layer units with six compartments each 48 cm length x 20 cm width and positioned on iron stands approximately 80 cm above ground-level. Each compartment was fitted with an individual feeder, and communal water troughs were positioned at the rear of each cage unit.

2.2 MANAGEMENT AND DISEASE PREVENTION

2.2.1 Debeaking and brooding

Birds were debeaked at one day of age. Normal brooding procedures and equipment were used. Multiple tiered experimental brooders (Multiplo) were maintained at approximately 21°C; birds were brooded at this temperature for two to three weeks with water and feed offered *ad libitum*.

2.2.2 Disease prevention

Disease prevention procedures for the broiler breeders in Chapter 8 were carried out at the commercial farm prior to birds being collected. These procedures are therefore given in Chapter 8, and would have been very similar to those used for the broiler breeders slaughted (Chapter 4). Birds were vaccinated against Marek's disease (injection) and Infectious Bronchitis (eye-drop method) at one day of age. Feed used during rearing contained coccidiostat (see Section 2.3).

2.3 FEED INGREDIENTS AND DIET ANALYSIS

Diets used in all the experiments reported in this thesis were least-cost formulations mixed by a commercial feed milling company (Fielders Stockfeeds, Tamworth). The ingredients used, and the determined chemical composition of the diets, are given in Table 2.1. The inclusion rates of the ingredients given in Table 2.1 for diets 1 and 2 are approximate and were determined by regular inspection of the ingredient sheets provided by the milling company for the diets mixed throughout the experiments. Diet 3 was also a least-cost formulation but was from a single mix and therefore the ingredient compositions are more exact. Composition of the vitamin and mineral premix used in all diets is given in Table 2.2. Feed was usually stored in metal silos.

Metabolisable energy content (MJ ME/kg) of diets 1 and 2 for Experiments 1 and 2 (Chapter 3) was determined at regular intervals by the bio-assay technique of Farrell (1978, 1980). In these experiments (1 and 2 in Chapter 3) representative feed samples were regularly taken to form composite samples which were then used for chemical analyses and metabolisable energy determinations. Birds in the experiment reported in Chapter 8 received diet 1 during rearing and diet 3 during egg production. Small subsamples of feed (*c.* 50 g) were taken daily from the feed which the birds received and bulked over each 7 d period. Analyses were carried out on each of these 7 d feed samples, which were also further bulked, usually over 28 d periods, for determination of metabolisable energy content by the bio-assay technique of Farrell (1978, 1980).

2.4 PREPARATION AND SAMPLING OF CARCASS AND LIVER

2.4.1 Maceration and storage

Birds used in the body composition studies reported in Chapter 4 were killed by cervical dislocation of the neck. For liver composition studies, the liver was removed immediately, rinsed in physiological saline (9 g NaCl/1000 ml H_2O), blotted dry, weighed and stored at -20°C. Carcasses were placed in plastic bags and stored at -20°C. Prior to maceration, carcasses were allowed to partially thaw. They were then chopped into small sections and put through a large mincer. The mincer was cleaned and the collected macerate was run through again to form a fine mince. The macerate was placed in individual plastic bags and stored at -20°C prior to chemical analysis, except that protein determinations were carried out on the fresh mince prior to storage.

TABLE 2.1 Composition (g/kg) and analysis on an air-dry basis of experimental diets.

Diet number:	1	2	3
Period used:	Rearing	Laying	Laying
Age of birds (wks):	6-18 12-22	18-68	22-43
Composition (g/kg)			
Wheat	710	252	390
Sorghum	50	380	150
Barley	-	-	100
Pollard	80	100	90
Wheat bran	40	50	45
Sunflower meal	-	-	50
Soyabean meal	-	-	30
Meat meal	95	139	75
Lucerne meal	-	20	-
Lupins	18	-	-
Limestone	1.5	54	60
Salt (NaCl)	2.1	1.0	2.5
Lysine	-	-	1.33
Methionine	-	0.65	1.15
Coccidiostat	0.13	-	-
Vitamin/mineral premix	1.5	1.3	1.2
Vitamin carrier	1.8	2.0	3.5
Choline	-	-	0.33
Flavomycin	-	0.075	-
Determined analyses (g/kg)			
Dry matter	90.9	91.3	90.3
Metabolisable energy (MJ/kg)*	12.54	12.05	11.46
Ether extractives	37.0	39.8	41.7
Protein (N x 6.25)	169.1	167.8	177.8
Ash content	51.9	86.0	77.6
Amino acids			
Lysine	6.9	-+	6.7
Arginine	11.1	-	10.1
Threonine	4.4	-	6.7
Glutamic acid	32.5	-	43.3
Valine	6.9	-	7.3
Methionine	3.1	-	3.0
Isoleucine	5.2	-	5.9
Leucine	11.7	-	12.3

* Using the rapid method of Farrell (1978, 1980).

+ Not determined.

TABLE 2.2 Level of premix ingredient in mixed feed (per kg feed)

Type of diet	Rearing	Laying
Vitamin A (500 IU)	30 mg	31 mg
Vitamin D_3 (400 IU)	9 mg	9 mg
Vitamin E Adsorbate (50%)	30 mg	39 mg
Vitamin K3 (22.5%)	3 mg	4 mg
Thiamine HCl	--	1 mg
Riboflavin	5 mg	9 mg
Calcium Panthothenate D	14 mg	7 mg
Niacin	15 mg	20 mg
Folic acid	300 µg	3 mg
Pyridoxine HCl	--	5 mg
Vitamin B_{12} (1000 mg/kg)	8 mg	20 mg
Biotin (1%)	--	10 mg
Manganese Oxide	150 mg	130 mg
Zinc Oxide	98 mg	91 mg
Copper Sulphate	30 mg	26 mg
Ferris Sulphate $7H_2O$ (20% Fe)	150 mg	130 mg
Sodium Molybdate (40% Mo)	2 mg	3 mg
EDDI (80% Iodine)	2 mg	1 mg
Ethoxequin (55% material)	2 mg	247 mg
Sodium Selenite (46% Se)	150 µg	260 µg

TABLE 2.3 Metabolisable energy (kJ/g) of the diets given in Table 2.1 at different times throughout the experimental series as determined by the rapid bio-assay technique of Farrell (1978, 1980)

Relevant chapter and experiment	Diet number	Number of determinations*	Metabolisable energy (kJ ME/g)	
			Mean	± SEM
Chapter 3, experiment 1	1	1	12.54	--
Chapter 3, experiment 2	1	1	12.54	--
Chapter 3, experiment 1	2	7	12.40	0.27
Chapter 3, experiment 2	2	6	11.69	0.12
Chapter 7	3	3	11.54	0.39
Chapter 8	1	1	12.37	--
Chapter 8	3	4	11.46	0.16

* Five or six cockerels were used for each determination.

2.4.2 Sampling for chemical analyses

Fresh mince samples for protein determinations were obtained with an open-ended 20 ml plastic syringe which was plunged into the combined macerate to give representative samples (5 g). Samples (20-30 g) for initial dry matter and subsequent ether extract determinations were either obtained by the above procedure on the fresh mince or, after the carcass macerates were frozen, by the use of an open pipe of similar diameter to the 20 ml plastic syringe attached to an electric drill.

2.5 CHEMICAL ANALYSES

All chemical analyses were carried out in duplicate on each feed, excreta or carcass sample according to the methods given below. Feed and dried excreta samples were ground to pass a one mm sieve and thoroughly mixed prior to sampling.

2.5.1 Dry matter

Feed: The method described by the A.O.A.C. (1965, 1980) was used.

Excreta: Drying of the excreta samples for metabolisable energy determinations by the rapid bio-assay techniques was as described by Farrell (1978). In the calorimetric study reported in Chapter 8, excreta samples (500 g) were freeze-dried for approximately 14 d to determine dry matter.

Carcass: Carcass samples were placed in preweighed cellulose extraction thimbles (single thickness, 30 mm x 80 mm ED, Whatman) and were either oven-dried (force-draught oven at 70°C for 4-5 d) or freeze-dried (14 d). Three experiments were carried out to determine if any differences were apparent between the two methods. Carcass samples from groups 8, 10 and 12 (Table 4.1) were used to determine the dry matter content by either oven-drying or freeze-drying of duplicate samples. The results were as follows: (1) Experiment 1, group 8, 16 birds, mean (±SD) dry matter 44.12 (±2.86%) and 44.66 (±3.68%) for oven-dried and freeze-dried carcass samples respectively ($P > 50\%$); (2) Experiment 2, group 10, 12 birds, mean (±SD) dry matter 43.53 (±1.93%) and 44.16 (±2.97%) respectively ($P > 38\%$); (3) Experiment 3, group 12, 18 birds, mean (±SD) dry matter 42.09 (±4.40%) and 43.28 (±5.19%) respectively ($P > 30\%$), where P is the probability determined in a one-way analysis of variance. Standard

deviations given include the variation between duplicates. All experiments showed a small but non-significant decrease in dry matter contents determined by oven-drying. In the results reported on body composition in this thesis, freeze-dried analyses are given where they could be determined; however on the basis that protein contents were determined on fresh mince samples, there was no distinction made between dry matter contents determined either by oven-drying or by freeze-drying.

Liver: Livers were sectioned into small pieces and placed in preweighed cellulose extraction thimbles and freeze-dried.

2.5.2 Total Nitrogen

Feed and excreta: Nitrogen was determined by micro-Kjeldahl digestion using sulphuric acid (H_2SO_4) and selenium (Se) catalyst followed by steam distillation using the method and equipment described by Ivan *et al.* (1974).

Carcass: Nitrogen was determined on fresh carcass mince samples (5 g) using a macro-Kjeldahl technique and the steam distillation method given above. Mince samples were digested in a 500 ml digestion flask with 30 ml sulphuric acid and four Kjeldahl digestion tablets. Each tablet contained 1.0 g sodium sulphate anhydrous and 10 mg selenium. Glass beads were added to prevent bumping, and anti-foaming agent was added where necessary.

2.5.3 Ether extract

Feed: Ether extract was determined by the loss of weight of a dried feed sample (5 g) in a preweighed extraction thimble after 24 h solvent extraction (petroleum ether, BP 40-60°C) in a Soxhlet apparatus. The solvent extracted feed sample was dried in an oven at 100°C for 24 h prior to reweighing.

Carcass: After dry matter determinations, the extraction thimbles were immediately placed in the Soxhlet apparatus and extracted as above.

2.5.4 Lipid content

Lipid content of freeze-dried liver samples was determined by the method of Folch *et al.* (1957).

2.5.5 Gross energy

Feed and excreta: Gross energy was measured by combustion in a Gallenkamp Adiabatic Bomb calorimeter using 1-2 g samples.

2.5.6 Ash

Feed: Approximately 2 g of sample was weighed into a tared procelain crucible and combusted at 600°C for 4 h in a muffle furnace.

Carcass: Representative 5 g samples were oven-dried at 80°C prior to combustion using the procedure given above.

Crucibles were allowed to cool in a dessicator and weighed to determine ash content by loss of weight.

2.5.7 Carbon

Feed and excreta: Carbon content was determined after combustion of the sample in the bomb calorimeter. The technique was described by Farrell (1972) and involved the slow release of bomb gas through preweighed drying (magnesium perchlorate $Mg(ClO_4)_2$) and carbon dioxide absorbant (Soda asbestos, 6-12 mesh, 'Carbosorb') trains. These trains were reweighed after exhaustion and flushing of the gases contained in the calorimeter bomb container. Initial tests with combustion of benzoic acid (C_6H_5COOH, Ajax Chemicals, Sydney) showed excellent agreement with the theoretical carbon content (68.84 g/100 g): N = 3, Mean = 68.43, SD = 0.27.

2.5.8 Amino acids

Amino acids in feed samples were determined by ion-exchange chromatography (Spackman *et al.* 1958) following protein hydrolysis in hydrochloric acid in sealed, evacuated tubes maintained at 110°C for 21 h. Amino acid concentrations were calculated relative to a standard mixture of amino acids. Nor-leucine was used as an internal standard.

2.6 COMPOSITION OF WHOLE EGGS

The chemical composition of the egg is given in Table 2.4 There are three main factors which influence egg composition, namely diet (Butts and Cunningham 1972; Andersson *et al.* 1978), strain of bird (Marion *et al.* 1965; Andersson *et al.* 1978) and age (Andersson *et al.* 1978; Anderson *et al.* 1978). However the reported changes are usually small and mainly reflect changes in yolk weight.

TABLE 2.4 Chemical composition (%) of the egg*

Component	Composition		
	Water	Protein	Lipid
White	88.5	10.5	--
Yolk	47.5	17.4	33.0
Shell	1.0	4.0	--
TOTAL	66.6	12.1	10.6

* Gilbert (1971)

Many workers determined the gross energy content of the fresh, whole (with shell) egg: Brody (1945), 6.7 kJ/g; Leeson and Porter-Smith (1970), 6.4 kJ/g; Grimbergen (1970), 6.2 kJ/g; Tasaki and Sasa (1970), 6.7 kJ/g; Hoffmann and Schiemann (1973), 6.7 kJ/g; Sibbald (1979), 5.9 kJ/g. Both Hoffmann and Schiemann (1973) and Sibbald (1979) reported an effect of egg weight on the gross energy content, and the values reported by Sibbald (1979) for egg from White Leghorn strains of birds were substantially below the normally accepted values. Two experiments were therefore carried out to determine the gross energy content of eggs for birds in the studies reported in this thesis. Twelve eggs were collected from the birds in Experiment 2 which is described in Chapter 3 (layer-type, Hyline, WL X NH) and ten eggs from the broiler breeders used for the preliminary experiment in the newly constructed respiration chambers (Chapter 7). Age of birds at the time of sampling was 398 d and 308 d for the two samplings respectively. Eggs were placed in a coldroom (4°C) for 24 h, weighed and individual eggs broken and shell mashed, freeze-dried and ground prior to determination of gross energy in an adiabatic bomb calorimeter.

There was a significant ($P < 0.001$) inverse relationship between gross energy content (kJ/g) and egg weight (g) for the layer-type birds. The derived relationship was

$$Y = 8.84 - 0.035X$$

$$N = 12; \quad R^2 = 0.45; \quad RSD = 0.34$$

where Y is gross energy (kJ/g), and

X is egg weight (g).

Mean (±SD) gross energy (kJ/g) was 6.6 (±0.5) (range 7.1-5.7) and egg weight (g) was 64.5 (±9.6) (range 53.4-84.1). For the broiler breeder birds there was not a significant relationship between gross energy (kJ/g) and egg weight (g). Mean (±SD) gross energy (kJ/g) was 7.0 (±0.3) (range 7.4-6.8) and egg weight was 67.7 (±6.7) (range 58.7-76.9).

For the studies reported in this thesis, a mean gross energy content of 6.7 kJ/g was used.

2.7 CALCULATION OF RATE OF EGG PRODUCTION

Hen-day rate of egg production is used throughout this thesis, and is calculated over specified time periods by the following formula:

$$\text{Egg production (number/100 hen d)} = \frac{\text{Total number of eggs}}{\text{Number of bird days}}$$

$$= \frac{\sum_{i}^{b}\sum_{j}^{d} N_{ij} \times 100}{\sum_{i}^{b}\sum_{j}^{d} U_{ij}}$$

where N_{ij} = 0, 1 or 2 according to the number of eggs produced on a particular day,

U_{ij} = 0 or 1 according to survival of a particular bird,

b = birds, and

d = days.

2.8 EGG CLASSIFICATION

Where indicated, eggs were classified according to the scheme given in Table 2.5. This scheme was derived by personal observation of the types of eggs produced.

TABLE 2.5 Classification scheme for eggs

Classification	Description
Normal	Adequate shell calcification and size. No shell deformities.
Shell-less	Devoid or nearly devoid of shell calcification around shell membrane.
Partially weak shell	Minor lack of complete shell calcification.
Double yolk	Adequate shell calcification, normal shape, two yolks.
Cracked shell	Adequate shell calcification but shell cracked.
Deformed	Compressed side.

2.9 STATISTICAL ANALYSES

2.9.1 Analyses of variance

Analyses of variance, with designs and models appropriate to the experiment, were carried out using Fortran statistical packages on a digital computer (DECsystem 2060). Statistical packages were either NEVA (Burr 1976) or BMDP (BMDP Biomedical Computer Programs P-Series 1979). Comparison procedures for means were based on the least significant difference (Steel and Torrie 1960). Residual mean squares were examined to determine appropriate transformations (where necessary) to stabilize the variance.

2.9.2 Analyses of covariance

Analysis of covariance (Steel and Torrie 1960) was used as a statistical technique primarily to adjust treatment means of dependent variables for differences in sets of values of corresponding independent variables. Adjusted treatment means are estimates of treatment means at a common mean of the independent variable. Homogeneity of slopes was tested also by covariance analysis. BMDP computer programs were used (BMDP1V) in the above analysis.

2.9.3 Linear and multiple linear regression

Linear and multiple linear regression techniques were carried out using BMDP computer programs (BMDP1R). Differences between pairs of regression coefficients were tested by a t-test (Steel and Torrie 1960) of the form

$$t_{n-k-1} = \frac{\hat{\beta}_1 - \hat{\beta}_2}{\sqrt{(SE\hat{\beta}_1)^2 + (SE\hat{\beta}_2)^2}}$$

where n = number of observations,

k = number of variables,

$\hat{\beta}_1$ = estimate of the partial regresion of Y on X for one treatment or data set,

$\hat{\beta}_2$ = estimate of the partial regression of Y on X for another treatment or data set, and

SE = standard error of the estimates.

2.9.4 Significance levels

Significance levels attained in statistical analyses are given in Table 2.6. In tables throughout this thesis where appropriate, superscripts have been included to indicate the significance of differences between means. Means with superscripts not containing the same letter are significantly different minimally at probability less than five percent ($P < 0.05$). Where important, the exact level of significance of differences is specified in the text.

TABLE 2.6 The statistical notation with the appropriate symbol used to designate the significance level attained in statistical analyses

Significance level (%)	Symbol	Statistical notation
10	-	$0.05 < P < 0.100$
5	*	$0.010 < P < 0.050$
1	**	$0.001 < P < 0.010$
0.1	***	$P < 0.001$

CHAPTER 3

THE PRODUCTION RESPONSES OF LAYER-TYPE POULTRY TO FEED RESTRICTION DURING REARING

Chapter 3

The Production Responses of Layer-Type Poultry to Feed Restriction During Rearing

3.1 INTRODUCTION

There are many reports on the influence of undernutrition during the growth of egg producing poultry on productive performance (see Lee *et al.* 1971a). Frequently found responses were summarized by Pearson and Shannon (1979). Dietary intake manipulation during rearing of poultry destined to be retained for egg production, particularly broiler breeders, is one of the most practically applied techniques in the livestock industries. Consequently, the majority of the studies conducted on restricted feeding of poultry historically have been, and currently are, directed towards the attainment and optimization of commercially orientated responses *viz.* a feed intake reduction and an increased egg production. Certain factors are known to have the potential, either singularly or together, to determine the consistency of the responses obtained to restricted feeding programmes. These were discussed in detail in Chapter 1 (Section 1.6). Of the responses obtained to restricted feeding during rearing, probably the most important, in the biological interpretation of results and for experimental planning, is delayed sexual maturity. MacIntyre and Aitken (1959) initially showed the large influence which a delayed sexual maturity in birds subjected to restricted feeding could exert on the conclusions reached concerning differences between treatments in production. Subsequent studies verified this effect (Walter and Aitken 1961; Gardiner and MacIntyre 1962; MacIntyre and Gardiner 1964) and many authors recognized and considered its influence on their results (e.g. Hollands and Gowe 1961; Connor *et al.* 1977b; Polkinghorne and Mannion 1978).

Because of the delayed sexual maturity associated with restricted feeding of poultry it is appropriate to use more specialized terminology in the presentation of experimental details on which calculations can be based. Most reports which discussed sexual maturity as a factor in data interpretation referred to an "age" and a "maturity" basis of measurement (see for example Lee *et al.* 1971a). The concept that the age of an animal can be considered on both a strict chronological age basis and on a more obtuse

physiological age basis is not new (Carrell 1931). Within individual animals, physiological changes may not occur on a strict chronological age basis. Bailey *et al.* (1960) discussed this in relation to the effect of nutrition on the chemical composition of mice. However for birds the concept of physiological age is used to delineate only the gross alterations in the pattern of egg production caused by appropriate feed restriction during rearing. This was considered in Section 1.2.6, Chapter 1, where the terms chronological and physiological age were defined. For individual birds the major physiological stage is the attainment of sexual maturity (first oviposition). However logistically such physiological stages as the attainment of certain rates of egg production (number/100 hen d) within each treatment (e.g. 10, 50 and approximate peak) are acceptable for biological between treatment comparisons, given that the duration of measurement from each is the same for all treatments. There is no study which has examined in detail the effect of a restricted feeding programme on subsequent feed intake, egg production and egg weight over specified times on a physiological age basis.

Prior to sexual maturity in the normally reared, *ad libitum* fed bird there are marked changes in both carbohydrate and lipid metabolism (Heald and Badman 1963; Pearce 1971; Jensen 1979), and a reduction in feed intake (Foster 1968a; Meyer *et al.* 1970; Hurwitz *et al.* 1971). This latter effect may have major ramifications to the energy balance and rate of increase in egg production of birds during the transition from pullet to laying hen. There is no information on the pattern of feed intake in relation to sexual maturity for birds which were on restricted feeding programmes. Many reports showed that there is a marked increase in feed intake and considerable compensatory growth in birds immediately after cessation of an adequate feed restriction programme (Osbourn and Wilson 1960; Pym and Dillon 1974; Watson 1976; Brody *et al.* 1980). Polin and Wolford (1973) postulated that the observed increase in initial egg weights for birds previously on restricted feeding programmes (see Lee *et al.* 1971a) may be due to an increased feed intake.

Regulation of feed intake in birds is complex (see Sturkie 1976), and is compounded in egg producing birds by various short-term regulatory mechanisms (Morris and Taylor 1967; Wood-Gush and Horne 1970; Nys *et al.* 1976; Savory 1977) and behavioural factors (Davis and Sykes 1977). Feed

intake is determined primarily, but not wholly, by energy requirements for maintenance and production. However, the excessive deposition of fat which may occur during growth and when birds are in egg production implies excessive energy intake. The effect of prior feed restriction on subsequent feed intake is unclear although Pym and Dillon (1974) concluded that there was a significant increase in feed intake during the egg production period of broiler breeders which had been restricted-fed during rearing. No account was taken of factors such as liveweight, liveweight gain, egg output or feather cover in reaching this conclusion (Pym and Dillon 1974).

The experiments to be reported in this chapter examined the biological responses in layer-type birds to feed restriction during growth. Attempts are made to consider in detail the production on a physiological age basis in order to determine the true biological responses. Further studies on the influence of restricted feeding on body composition (Chapter 5) and energy requirements (Chapter 6) were undertaken on the layer-type birds used in the experiments to be reported in this chapter. The results on the production parameters are therefore an integral prerequisite for interpretation of the studies presented in Chapters 5 and 6.

3.2 MATERIALS AND METHODS

3.2.1 Birds and management

3.2.1.1 Experiment 1

Nine hundred and sixty-five layer-type pullets (White Leghorn X Australorp, Hyline) were hatched in September 1977. After normal brooding procedures (see Section 2.2.1, Chapter 2) the pullets were placed in deep-litter pens at the University of New England Poultry Research Farm at Laureldale. Rearing treatments commenced when the pullets were 42 d of age. Due to an unexpected housing shortage, selected birds could not be transferred to individual wire-mesh cages until they were 98 d of age. During this period (42-98 d of age) only two of the planned rearing treatments could be applied (see Section 3.2.2). These difficulties were beyond the control of the author.

3.2.1.2 Experiment 2

Two hundred and thirty-seven layer-type pullets (White Leghorn X New Hampshire, Hyline) were hatched in October 1978. After normal

brooding procedures (see Section 2.2.1, Chapter 2) birds were placed in flat-deck carry-on cages (see Section 2.1.2.2, Chapter 2 for details). At 42 d of age individual birds were weighed and randomly allocated to each of three groups on the basis of stratified liveweights. Rearing treatments commenced at 56 d of age. At 98 d of age fifty-three birds from each group were selected (stratified randomisation) and placed in single wire-mesh cages.

The type of layer cages used and the housing conditions, which were common to both experiments, are described in Chapter 2, Section 2.1.2. Management and disease prevention procedures which were carried out in both experiments are given in Chapter 2, Section 2.2. Lighting patterns, both natural and artificial, the average Armidale temperature variation and the stage of development of the birds used in the experiments in relation to the above environmental parameters are given in Figure 3.1. Artificial fluorescent lighting was commenced at 140 d of age and was progressively increased to 17 h/d by the following schedule: (a) 14.25 h increased by 15 min/7 d for 42 d; (b) increased by 12 min/7 d for the following 28 d; (c) increased by 10 min/7 d for the following 42 d; (d) increased by 5 min/7 d thereafter until 17 h/d was attained when the birds were approximately 280 d of age (see Figure 3.1). When feed restriction programmes were terminated, coarse iron grids were placed in feeders to minimize feed spillage.

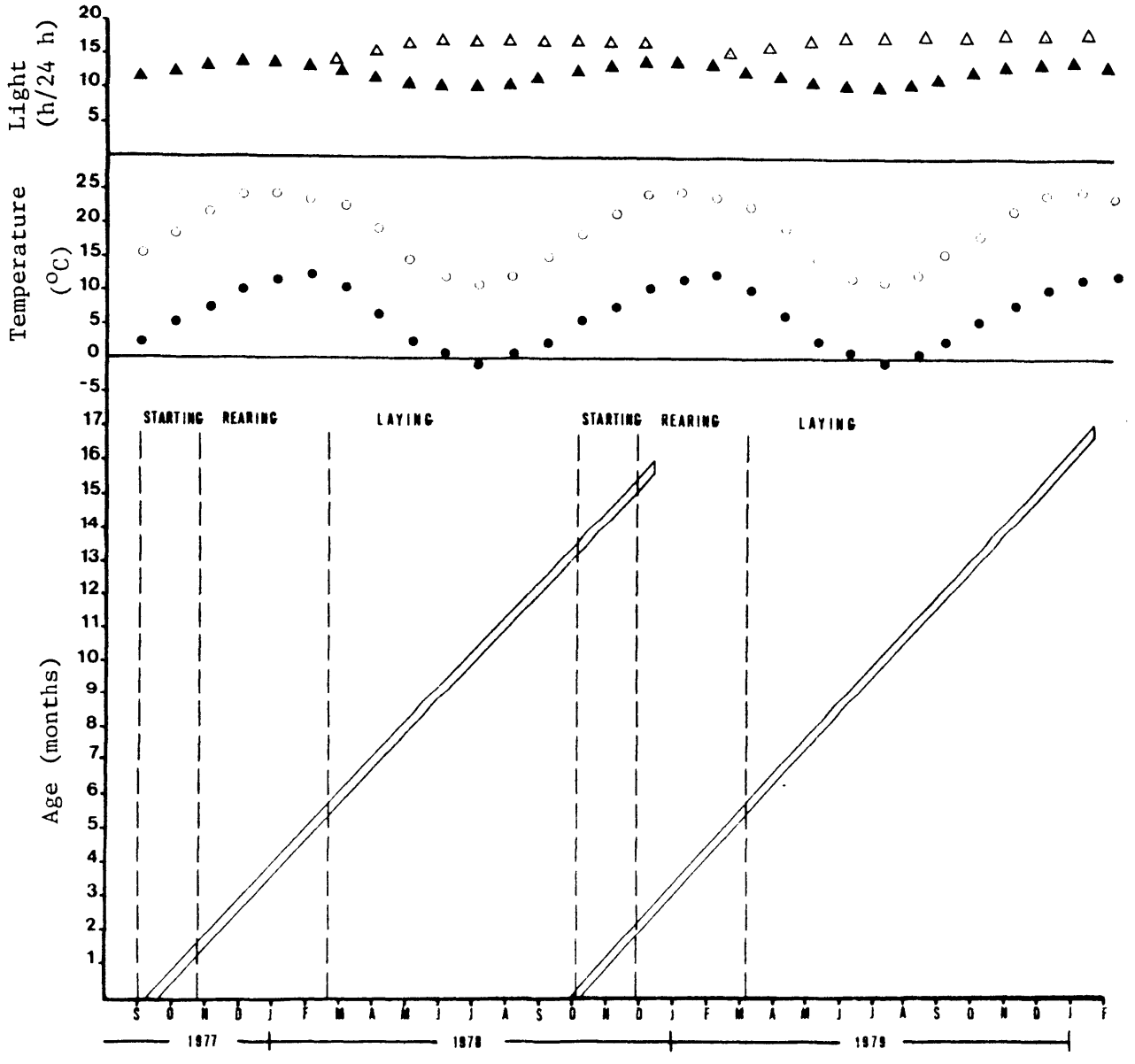
3.2.2 Treatments and diets

Diets of normal commercial ingredient composition were purchased from Fielders Stockfeeds, Tamworth. A standard starter diet which contained coccidiostat and was of determined composition 12.31 MJ ME and 190 g crude protein/kg, was offered *ad libitum* in both experiments to the birds between hatching and 42 d of age. From 42 d to 126 d of age birds were offered a rearing diet (Diet 1, Table 2.1, Chapter 2). A diet appropriate for egg production (Diet 2, Table 2.1, Chapter 2) was offered until the termination of each experiment. Details relevant to these diets are given in Section 2.3, Chapter 2.

There were three rearing treatments applied in both experiments. These were:

(1) Treatment 1 - allowed *ad libitum* feed intake;

FIGURE 3.1: The chronological age (months) of layer-type birds in two experiments on the effects of feed restriction during rearing in conjunction with average (1949-1976) Armidale maximum (○) and minimum (●) temperatures (°C) and natural (▲) or artificial (△) light (h/24 h) during both experiments.


Light (h/24 h)
Temperature (°C)
Age (months)
STARTING
REARING
LAYING
STARTING
REARING
LAYING
S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F
1977
1978
1979
Experiment 1
Experiment 2

(2) Treatment 2 - restricted in feed intake by limitation of the amount of time allowed for feeding;

(3) Treatment 3 - restricted in feed intake by offering, daily, a proportion of the quantity consumed by Treatment 1.

For convenience, these treatments will be referred to as *ad libitum* (A), limited-time restriction (TR) and quantitative restriction (QR) for treatments 1, 2 and 3 respectively. Birds on the limited-time restriction programme (TR) were initially allowed approximately 30 h of continuous *ad libitum* feed intake in every 72 h. However, during the course of both experiments it became apparent that continuation of this schedule would not result in the planned 20 to 25% liveweight reduction at 140 to 154 d of age. Therefore it was necessary to progressively reduce the amount of time allowed for feeding, such that by 126 d of age the schedule was 24 h feed/72 h. In Experiment 1 birds were reared at the University of New England Poultry Farm at which only Treatments 1 and 2 were applied (see Section 3.2.1.1). At 98 d of age, 50 of the *ad libitum* birds (Treatment 1) and 100 of the limited-time birds (Treatment 2) were randomly selected from a cross-section of the deep-litter floor pens and transferred to individual wire-mesh cages in a separate housing facility (see Section 2.1.2, Chapter 2, for details). Half of the selected limited-time birds were randomly allocated to the quantitative feed restriction programme (Treatment 3). Feed intake of the birds on Treatment 1 was measured daily in Experiment 1 from 98 to 210 d of age and over 7 d periods in Experiment 2 (see Section 3.3.1). Birds on the quantitative feed restriction programme in Experiment 1 were allocated a daily feed allowance which was approximately 60-70% of the observed mean daily feed intake of the *ad libitum* birds, the exact proportion depending on relative liveweight. Birds on the quantitative feed restriction programme in Experiment 2 were similarly allocated a daily feed allowance which was approximately 60-70% of the observed mean feed intake over the previous 7 d period of the *ad libitum* birds. Feed restriction programmes were terminated at 162 d of age in Experiment 1, and 168 d of age in Experiment 2. The total periods of feed restriction were therefore 42 to 162 d and 56 to 168 d of age for Experiments 1 and 2 respectively. No treatments were imposed during the laying period

during which time all birds were allowed *ad libitum* feed intake. Tap water was available at all times from a communal trough positioned at the rear of each layer unit (6 cages/unit).

3.2.3 Measurements

3.2.3.1 Feed intake

3.2.3.1.1 Experiment 1

Feed intake of individual birds was measured daily at approximately 0900 h from 98 d to 210 d of age. This duration of measurement facilitated the detailed analysis of the effect of initial oviposition (sexual maturity) on feed intake of individual birds for suitable periods, both prior to and subsequent to sexual maturity. Due to circumstances beyond the author's control there were no feed intake records available for the period during which the birds were reared at the University of New England Poultry Farm (42 to 98 d of age). Feed intake for each bird on all treatment groups was measured over 7 d periods after 210 d of age to the completion of the experiment (437 d of age).

3.2.3.1.2 Experiment 2

Feed intake of individual birds was measured over 7 d periods from 56 d of age to the completion of the experiment (476 d of age).

3.2.3.2 Liveweights

3.2.3.2.1 Experiment 1

Birds were weighed in groups of four at 42 d of age at the University of New England Poultry Farm; mean liveweight (N = 965) at this time was 438 g. The birds could not be weighed again until they were sub-sampled and transferred to individual cages at 98 d of age, after which liveweights were recorded at 114, 123, 129, 142, 151 and 162 d of age, then every 7 d to 206 d of age, and then every 28 d to the completion of the experiment at 437 d of age.

3.2.3.2.2 Experiment 2

Birds were weighed individually at 42 d of age; mean (±SD) liveweight (N = 237) was 569 (±62) g. The birds were weighed at the commencement of the rearing treatments (56 d of age), every 14 d to 224 d of age and then every 28 d to the completion of the experiment at 476 d of age.

Birds in both experiments were deprived of feed (not water) for varying times to minimize differences in liveweight between treatments due to feed residues in the crop and stomach ("gut-fill"). Young birds (42 d to 112 d of age) were deprived of feed for relatively short intervals (1-3 h) prior to measurement of liveweight. From 112 d of age to the cessation of feed restriction, birds were deprived of feed for approximately 24 h prior to measurement of liveweight. Throughout the remainder of the experiments birds were deprived of feed for 2 h prior to measurement of liveweight. All liveweight measurements were carried out on an electric Metler P3000 balance with minimal disturbance to the birds at approximately 1200 h. Birds were forced to sit in a tared plastic bucket by pressing on their back; this allowed liveweight to be recorded without major movement of the scale.

3.2.3.3 Egg production and classification

Eggs produced were recorded, weighed (±0.2 g) daily for individual birds and were classified according to the scheme given in Section 2.8, Chapter 2. The weights of the shell-less eggs which were broken were estimated by calculating the average egg weight (excluding double yolk eggs) over the 7 d period in which this occurred and subtracting 5 g for shell weight. There was no correction to the assumed energy content (6.7 kJ/g) of the whole egg (see Section 2.6, Chapter 2) in the calculation of total egg energy output when shell-less eggs were recorded.

3.2.3.4 Chronological and physiological age measurements

In this chapter results are presented on both a chronological and physiological age basis to facilitate comparisons with the published literature. The following describes the periods over which analyses were carried out to accommodate both methods of calculation.

3.2.3.4.1 Experiment 1

Chronologic: Egg production commenced in the *ad libitum* treatment at approximately 127 d of age. The chronological age periods began at 141 d of age to facilitate analysis. This allowed eleven 28 d periods for each treatment for analysis of the production parameters for equal chronological age periods.

Physiologic: Three physiologic stages were considered important enough for inclusion:

(a) Egg production greater than or equal to 10 eggs/100 hen d for each treatment. This gave ten 28 d periods of analyses between the following ages: *ad libitum*, 141 to 414 d of age; limited-time restriction, 162 to 435 d of age; quantitative restriction, 155 to 428 d of age.

(b) Egg production greater than or equal to 50 eggs/100 hen d for each treatment. This gave nine 28 d periods for analyses between the following ages: *ad libitum*, 155 to 400 d of age; limited-time restriction, 176 to 421 d of age; quantitative restriction, 176 to 421 d of age.

(c) Egg production greater than or equal to peak of egg production for nine 28 d periods for each treatment: *ad libitum*, 162 to 407 d of age; limited-time restriction, 183 to 428 d of age; quantitative restriction, 183 to 428 d of age.

3.2.3.4.2 Experiment 2

Chronologic: Egg production commenced in the *ad libitum* treatment at 124 d of age. Similar to Experiment 1, this allowed eleven 28 d periods for each treatment for analysis of production for equal chronological age periods.

Physiologic: The same three physiological stages were selected for analyses:

(a) Egg production greater than or equal to 100 eggs/100 hen d for each treatment. This gave ten 28 d periods for analyses between the following ages: *ad libitum*, 138 to 411 d of age; limited-time restriction, 180 to 453 d of age; quantitative restriction, 173 to 446 d of age.

(b) Egg production greater than or equal to 50 eggs/100 hen d for each treatment. This gave ten 28 d periods for analyses between the following ages: *ad libitum*, 152 to 425 d of age; limited-time restriction, 187 to 460 d of age; quantitative restriction, 187 to 460 d of age.

(c) Egg production greater than or equal to peak of egg production for ten 28 d periods for each treatment between the following ages: *ad libitum*, 166 to 439 d of age; limited-time restriction, 201 to 474 d of age; quantitative restriction, 194 to 467 d of age.

3.2.3.5 Temperature

Maximum and minimum shed temperatures (±0.5°C) were recorded daily (0900 h) Mean shed temperature was calculated as the average of these extremes.

3.2.3.6 Feather cover

Degree of feather cover was regularly assessed by subjective measurement. The scoring system used was essentially similar to that used by Hughes (1980):

Feather cover score	*Prerequisite*
1	Perfect feather cover
2	Minor feather loss
3	Moderate feather loss in the ventral and dorsal *or* tail and wing regions
4	Moderate feather loss in the ventral and dorsal *or* tail and wing regions but with extensive feather breakage or damage in conjunction
5	Extensive denudation of feathers

Birds were scored for feather cover using the above guidelines by two persons working independently in Experiment 1 at 280 d, 350 d and 434 d of age, and in Experiment 2 at 276 d, 289 d, 303 d, 331 d, 359 d, 387 d, 415 d and 443 d of age.

3.2.3.7 Body composition

Birds were sampled from the two experiments described in this chapter for the body composition experiments reported in Chapter 4.

3.2.3.7.1 Experiment 1

Six birds per treatment were randomly selected at 39 d (*ad libitum* treatment only), 70 and 101 d (A and TR treatments), 162, 218 and 337 d (A, TR and QR) of age. After appropriate starvation and injection with water isotope, blood samples were taken and birds were slaughtered to determine body composition. Details are given in Chapters 4 and 5.

3.2.3.7.2 Experiment 2

Four birds per treatment were randomly selected at 280 d and 476 d of age and slaughtered as above (Section 3.2.6.1). All birds were injected with deuterium oxide and blood sampled at sexual maturity for the prediction of body composition. Samples of birds were similarly injected and blood sampled after production of a specified number of eggs

at 364 d of age and at the same time after sexual maturity. Details are given in Chapters 4 and 5.

3.2.4 Statistical procedures

There were three rearing treatments which were randomly distributed throughout the housing facilities. For preliminary statistical analyses random samples of birds were selected from the treatments so that orthogonal comparisons could be carried out with equal subclass numbers. This preliminary procedure was adopted for analyses over 28 d periods for individual birds and also for overall analyses. These analyses were supportive of non-orthogonal analyses using all data with unequal subclass numbers. Due to possible serial correlation within the parameters over time on the same birds separate nalayses were carried out as well as the overall analyses. However for brevity only the overall analyses are included in the Appendices. The usual fixed effects linear additive model was used (Steel and Torrie 1960) for overall treatment comparisons. Logarithmic transformations were applied to liveweights prior to overall analyses in order to stabilize the variance. Feather scores were transformed using Fishers normal scores for ranked data (Fisher and Yates 1948) prior to analyses of variance. Statistical techniques are given in Section 2.9, Chapter 2.

3.3 RESULTS

3.3.1 Production parameters

3.3.1.1 Experiment 1

Two birds were removed temporarily from the experiment during the egg production period. One of these birds (Bird 74, limited-time restriction treatment) exhibited symptoms of leucosis; the other (Bird 11, *ad libitum* treatment) developed a foot-sore which caused temporary cessation of egg production and loss of appetite. Both birds recovered in approximately 14 d and were thereafter included for all production measurements. One bird in the limited-time restriction treatment weighed only 960 g at 129 d of age compared with the mean (N = 49) liveweight of 1453 g, and since this difference was greater than three standard deviations from the mean this bird was removed permanently from the experiment. The occurrence and causes of mortality during the experiment are given in Table 3.1. Apart from one bird which apparently died from suffocation, the sole cause of mortality was Marek's disease. The occurrence of mortality was insufficient to permit treatment comparisons.

TABLE 3.1 The occurrence of mortality and the diagnosed causes during the rearing and egg production periods (Experiment 1).

Treatment	Rearing feeding regimen	Period	Age (d) at which mortality occurred	Cause of death
1	*Ad libitum* (A)	Rearing	176 (1)+	Marek's disease
		Egg production	276 (1)	Marek's disease
2	Limited-time restriction (TR)	Rearing	-	-
		Egg production	288 (1)	Suffocation
3	Quantitative restriction (QR)	Rearing	149 (1)	Marek's disease
			151 (1)	Marek's disease
		Egg production	299 (1)	Marek's disease

+ number of birds which died is given in parentheses.

Liveweight (W, g) for the remainder of the rearing period after birds were transferred to the individual wire-mesh cages (see Section 3.2.2) are given in Table 3.2, and for 28 d periods during egg production in Table 3.3. Mean feed intake (g/bird d^{-1}) and liveweights for each of the three treatments for the rearing (114-162 d of age) and egg production (162-442 d of age) periods are given in Figure 3.2 for 7 d periods in conjunction with average maximum, minimum and mean shed temperatures. Egg production (number/100 hen d) and egg mass output (g/bird d^{-1}) are shown in Figure 3.3, and egg weights (g/bird) and gross energetic efficiency (kJ egg energy/kJ ME, %) in Figure 3.4 for each treatment. A detailed presentation and statistical analysis of the various production parameters measured chronologically after egg production commenced in the *ad libitum* treatment is given in Tables 3.4, 3.5 and Appendix Table A3.1. The production parameters calculated over nine 28 d periods after each treatment attained an approximate maximal rate of egg production (peak) are given in Table 3.6, and analyses for the treatments after each had attained other physiologic stages are given in Table 3.7.

3.3.1.1.1 Feed intake and feed conversion ratio

The apparently large fluctuations in feed intake (g/bird d^{-1}) which occurred for birds on the limited-time restriction treatment during rearing (see Figure 3.2) were due to the method of presentation of the results. Birds on this treatment were allowed *ad libitum* access to feed over a specified time period every 3 d (see Section 3.2.2 for details); therefore as feed intake was averaged over 7 d periods to permit presentation and analysis, on occasions two rather than one period of feed allocations were included. Mean feed intake for the rearing period (114-162 d of age) was 89, 64 and 54 g/bird d^{-1} for the *ad libitum*, limited-time and quantitative treatments respectively. Because of logistic problems during the initial period of measurement where individual feed intake was monitored daily (see Section 3.2.3.1.1) liveweight measurements could not be carried out over regular 7 d periods. Cumulative feed intake and feed conversion ratio (g feed/g liveweight gain) are given for each treatment during the rearing period in Table 3.2. Between the age period from 114 d to 162 d feed intake for birds on the limited-time and quantitative restriction treatments relative to the *ad libitum* treatment was reduced by 29% and 40% respectively. During this period (114-162 d) the mean feed conversion ratio for each treatment was 13.1, 20.7 and 14.7

TABLE 3.2 The effect of feeding regimen on average liveweight (W, g), cumulative feed intake (I, g/bird) and feed conversion ratio (FCR, g feed/g liveweight gain) of layer-type pullets during the rearing period (Experiment 1).

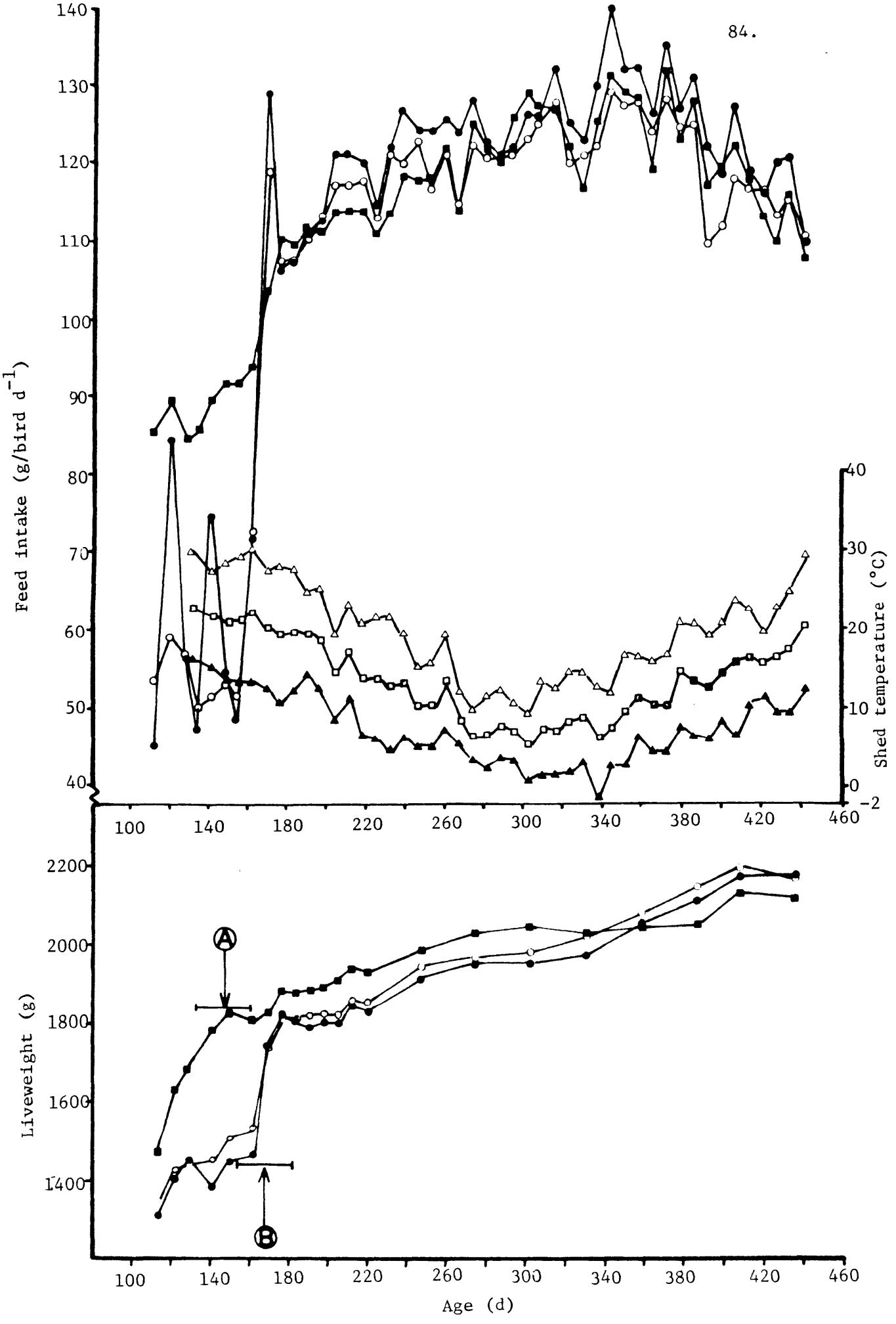
Treatment	Rearing feed regimen	Parameter	Age (d)					
			114	123	129	142	151	162
1	*Ad libitum* (A)	W	1476[a2]	1629[a]	1683[a]	1785[a]	1830[a]	1810[a]
		(±SD)[1]	128	140	148	182	183	210
		I	-	810	1321	2455	3264	4364
		FCR	-	5.3	9.5	11.1	18.0	-55.0
		N[3]	50	50	50	50	50	44
2	Limited-time restriction (TR)	W	1311[b]	1408[b]	1453[b]	1383[b]	1452[b]	1462[b]
		(±SD)	123	136	144	132	140	174
		I	-	567	963	1847	2432	3116
		FCR	-	5.8	8.8	-12.6	8.5	68.4
		N	50	50	50	49	49	43
3	Quantitative restriction (QR)	W	1354[b]	1430[b]	1441[b]	1457[c]	1511[c]	1539[c]
		(±SD)	88	88	100	102	99	97
		I	-	524	869	1541	2005	2648
		FCR	-	6.9	31.4	42.0	8.6	23.0
		N	50	50	50	50	48	42
Significance of differences between liveweights[4]			***	***	***	***	***	***

1. Standard deviation.
2. Means with superscripts not containing the same letter are significantly different.
3. N = number of birds.
4. See Table 2.6, Chapter 2, for significance levels.

for the *ad libitum*, limited-time and quantitative treatments respectively. However this calculation does not take account of the level of egg production on the *ad libitum* treatment. The feed conversion ratio was reduced to 8.0 for the *ad libitum* treatment during the period between 114 d of age to the mean age (140 d) for this treatment at sexual maturity (initial oviposition). Corresponding values for the limited-time and quantitative restriction treatments for the approximate period from 114 d to sexual maturity were 9.3 and 9.4 respectively. During the 7 d period immediately after cessation of the feed restriction programmes the feed conversion ratio was 3.6 and 4.6 for the limited-time and quantitative treatments respectively.

The limited-time and quantitative feed restriction treatments had a large increase in feed intake after ceassation of restriction (see Figure 3.2). The mean (±SD) feed intake in the 7 d period after cessation of feed restriction for the limited-time and quantitative feed restriction treatments (N = 42/treatment) was 128.8 (±25.5) and 118.9 (±18.8) respectively. Measured chronologically there were significant ($P < 0.001$) differences between treatments, ages and a significant ($P < 0.001$) interaction between treatments and age in feed intake during the egg production period (see Appendix Table A3.1). Over much of the egg production period the limited-time treatment had a greater feed intake than the *ad libitum* treatment ($P < 0.05$ for periods 2, 3, 8, 9 and 11; $P < 0.001$ for periods 4 and 5 in Table 3.5). Occasionally the limited-time treatment had a greater feed intake than the quantitative treatment during the egg production period ($P < 0.05$ for periods 9, 10 and 11; $P < 0.0$; for period 8; $P < 0.001$ for period 5 in Table 3.5). For the 28 d production period from 393 to 414 d of age (period 10 in Table 3.5), feed intake was lower ($P < 0.05$) in the quantitative treatment than either of the other treatments. During this particular period (period 10) there was a substantial decrease in egg production and egg mass output (g/bird d^{-1}) for all treatments (see Figure 3.3). There was also a decline in average egg weight (see Figure 3.4). The probable cause of these aberrations in the production of all treatments during this period was unable to be determined. However it coincided exactly with the placement of birds with Infectious Bronchitis in the shed without the author's knowledge.

FIGURE 3.2: Feed intake (g/bird d^{-1}) averaged over 7 d periods and liveweight (g) in relation to age (d) for birds either allowed *ad libitum* feed intake (■) or restricted (162 d of age) by limited-time (●) or quantitative (○) methods. Mean maximum (△), minimum (▲) and average (□) shed temperatures (°C) measured during the experiment are also given. The arrows originating from the letters A and B point to the mean age of sexual maturity (first oviposition) for birds on the *ad libitum* or restriction treatments respectively; the bar line either side of the point is the standard deviation (±SD) (Experiment 1).


Feed intake (g/bird d^{-1})
Shed temperature (°C)
Liveweight (g)
Age (d)
A
B

Peak of egg production was attained at the mean ages of 162 d and 183 d for the *ad libitum*, limited-time and quantitative treatments respectively; approximate mean egg production was 76.3, 79.6 and 76.9 eggs/100 hen d for each treatment respectively (see also Table 3.6). Feed intake for nine 28 d periods, inclusive of the 7 d period given above of approximate attainment of peak of egg production, is given in Table 3.6. Overall analyses for these nine 28 d periods, in conjunction with feed intake for ten 28 d periods after attainment of egg production equal to or greater than 10, and for nine 28 d periods after attainment of egg production equal to or greater than 50 for each of the treatments, are given in Table 3.7. Both the treatments which were previously subjected to feed restriction (TR and QR) had consistently greater feed intakes calculated for equal periods after, and inclusive of, the above physiological stages (see Table 3.7). Feed intake was greater ($P < 0.001$) for the limited-time than either of the other two treatments (A or QR) when calculated on these physiological stages.

3.3.1.1.2 Liveweight and sexual maturity

During the measured rearing period (114-163 d) the mean liveweight of birds on the *ad libitum* treatment was greater ($P < 0.001$) than for the two restriction treatments (TR and QR). At the ages of 114, 123 and 129 d there were no significant differences between the limited-time or quantitative restriction treatments (see Table 3.2). However from 142 to 162 d, inclusive, liveweights were lower for the limited-time restriction treatment than for the quantitative restriction treatment, although significance ($P < 0.05$) was only just attained at 151 d (difference between means of TR and QR was 59 g) and 163 d (difference between means of TR and QR was 77 g); the least significant differences (lsd) (see Section 2.9, Chapter 2) were 58 g and 71 g at 151 d and 162 d of age respectively. Liveweights for the limited-time and quantitative restriction treatments at the end of the restriction period (162 d), expressed as a proportion of the liveweight of the *ad libitum* treatment, were 0.81 and 0.85 respectively.

After cessation of the feed restriction treatments (162 d) when birds were offered *ad libitum* feed intake, there was a period of rapid liveweight gain (see Figure 3.2). Consequently there were no significant differences between treatments in liveweight at 171 d of age ($0.05 < P < 0.10$) or 185 d of age ($P > 0.10$). However in the period

TABLE 3.3 The effect of feeding regimen during rearing on average liveweight (W, g) of layer-type pullets during the egg production period (Experiment 1).

Treatment	Rearing feeding regimen	Period	Age (d) 171	199	221	248	276	304	332	360	388	409	437
1	*Ad libitum* (A)	W	1830	1899[a][2]	1935	1984	2028	2042	2023	2043	2085	2123	2116
		(±SD)[1]	228	229	243	239	252	242	249	241	250	249	257
		N[3]	42	43	37	37	36	36	36	30	30	30	30
2	Limited-time restriction (TR)	W	1746	1805[b]	1838	1918	1957	1957	1973	2045	2103	2167	2176
		(±SD)	236	205	226	244	264	250	290	315	343	369	376
		N	43	42	37	37	37	36	36	30	30	30	30
3	Quantitative restriction (QR)	W	1744	1823[b]	1857	1945	1965	1980	2024	2079	2142	2188	2166
		(±SD)	131	134	145	157	180	172	178	188	221	239	242
		N	42	42	36	36	36	35	35	29	29	29	29
Significance of differences between groups[4]			-	-	NS	NS	NS	NS	NS	NS	NS	NS	NS

Notes 1, 2, 3 and 4, see Table 3.2.

from 185 d to 221 d of age birds on the *ad libitum* treatment were heavier ($P < 0.05$) than either the limited-time or quantitative restriction treatments (see Table 3.3). After this time there were no differences between treatments. This therefore caused the interaction effect between treatment and age to be non-significant (see Appendix Table A3.2).

Age at first oviposition, irrespective of the type of the egg produced (*viz.*, shell-less, double yolked, etc.) was determined for individual birds in each treatment. The mean (±SD) age for the *ad libitum* (N = 50), the limited-time (N = 44) and the quantitative (N = 47) treatments was 148.1 (±15.7), 170.3 (±15.1) and 167.6 (±15.2) respectively. To aid interpretation of the results these ages and the standard deviations have been included in one of the figures (see Figure 3.2). The ages when the average treatment egg production reached 50/100 hen d were 152 d, 173 d and 173 d for the *ad libitum*, limited-time and quantitative respectively. It should be noted that these ages are not directly comparable with the average age at initial oviposition because they are treatment means, not the means of the individual birds as for age at initial oviposition.

3.3.1.1.3 Egg production parameters

Production parameters averaged over the duration of the experiment from commencement of egg production in the *ad libitum* treatment are given in Table 3.4. Egg production (number/100 hen d) and egg mass output (g/bird d^{-1}) were significantly ($P < 0.001$) different between treatments when compared over eleven 28 d periods chronologically (Table 3.5). Analyses between each of the treatments for each of the individual periods (Table 3.5) showed that there were initial differences between the *ad libitum* and restricted (TR and QR) treatments ($P < 0.001$), but that these differences were due to the greater age at sexual maturity of the latter treatments (see Figure 3.3). However, after egg production commenced in the restricted (TR and QR) treatments both egg production and egg mass output were greater than on the *ad libitum* treatment (see periods 3, 4, 5, 6 and 7 in Table 3.5). After period 8 (Table 3.5) there were no differences ($P > 0.10$) between the *ad libitum* and quantitative treatments, although the limited-time treatment had a continued increased egg production and egg mass output than either the *ad libitum* or quantitative treatments.

TABLE 3.4 The effect of feeding regimen during rearing on feed intake (g/bird d^{-1}), egg production (no./100 hen d), egg mass output (g/bird d^{-1}) and average egg weight (g) on a chronological age basis from commencement of egg production of the *ad libitum* (A) treatment to the end of Experiment 1.

Production parameter[1]	Rearing treatment[2] 1	2	3	Significance[4]
Feed intake (g/bird d^{-1})	114.0[a][3] (20.7)	113.2[a] (27.4)	109.1[b] (27.1)	***
Egg production (number/100 hen d)	65.4[a] (30.5)	65.5[a] (32.3)	60.5[b] (33.2)	***
Egg mass output (g/bird d^{-1})	37.2[a] (17.6)	39.1[b] (19.4)	35.6[c] (19.7)	***
Average egg weight (g)	57.0[a] (7.7)	59.8[b] (7.6)	58.6[c] (7.4)	***

1 Standard deviations are given in parentheses below each mean.

2 Treatment 1: *Ad libitum* (A); Treatment 2: Limited-time restriction (TR); Treatment 3: Quantitative restriction (QR). See text (Section 3.2.2) for details.

3 Means of each production parameter with superscripts not containing the same letter are significantly different.

4 See Table 2.6, Chapter 2 for significance levels.

TABLE 3.5 The effect of feeding regimen during rearing on subsequent feed intake (g/bird d^{-1}), egg production (no./100 hen d), egg mass output (g/bird d^{-1}) and average egg weight (g/bird) in eleven 28 d periods from commencement of egg production on a chronological age basis. Standard deviations are given in parenthesis below each mean. (Experiment 1).

Production parameter	Rearing treatment[2]	Periods (28 d)[1] 1	2	3	4	5	6	7	8	9	10	11
Feed intake (g/bird d^{-1})	1	91.6[a3]	108.7[a]	112.9[a]	114.9[a]	119.4[a]	123.6	122.8	128.0[a]	124.7[a]	118.6[a]	111.1[a]
		(14.3)	(16.5)	(16.4)	(15.6)	(18.3)	(18.9)	(22.1)	(18.0)	(17.7)	(17.6)	(18.0)
	2	62.5[b]	113.3[b]	117.8[b]	121.5[b]	125.0[b]	122.5[b]	125.8	132.9[b]	129.2[b]	121.1[a]	116.2[b]
		(15.8)	(20.7)	(14.2)	(13.0)	(14.0)	(17.2)	(15.9)	(13.9)	(12.9)	(13.6)	(15.2)
	3	56.8[c]	111.1[ab]	115.9[ab]	118.7[b]	118.4[ab]	120.8	122.7	125.9[a]	124.7[a]	113.5[b]	113.4[ab]
		(9.4)	(15.5)	(15.2)	(11.8)	(15.5)	(15.6)	(15.4)	(17.0)	(14.7)	(21.3)	(14.2)
	Significance[4]	***	-	*	***	***	NS	NS	**	*	**	*
Egg production (number/100 hen d)	1	49.8[a]	77.6[a]	77.7[a]	75.5[a]	73.6[a]	71.5[a]	64.5[a]	65.5[a]	66.3[a]	54.5[a]	61.7[a]
		(38.9)	(26.1)	(26.2)	(23.2)	(23.1)	(21.1)	(27.1)	(29.0)	(23.7)	(28.6)	(26.6)
	2	5.4[b]	58.9[b]	84.9[b]	86.9[b]	85.8[b]	78.5[b]	77.6[b]	76.9[b]	73.9[b]	63.1[b]	68.0[b]
		(14.5)	(39.6)	(15.2)	(10.4)	(9.4)	(15.8)	(12.7)	(13.5)	(16.1)	(20.9)	(17.9)
	3	9.0[b]	57.7[b]	82.6[b]	82.4[c]	76.3[a]	73.0[a]	69.8[c]	69.9[a]	66.0[a]	50.1[a]	61.5[a]
		(21.2)	(38.7)	(18.1)	(15.6)	(21.4)	(21.1)	(22.3)	(19.2)	(22.4)	(25.3)	(21.2)
	Significance	***	***	**	***	***	**	***	***	**	***	*
Egg mass output (g/bird d^{-1})	1	22.0[a]	39.3[a]	41.6[a]	42.7[a]	43.1[a]	43.6[a]	39.6[a]	39.9[a]	41.0[a]	33.6[a]	39.3[a]
		(17.5)	(13.6)	(14.3)	(13.2)	(13.5)	(12.8)	(17.0)	(17.9)	(14.9)	(17.8)	(17.0)
	2	2.1[b]	29.6[b]	45.8[b]	50.2[b]	51.6[b]	48.2[b]	48.4[b]	49.2[b]	47.6[b]	40.0[b]	44.7[b]
		(5.6)	(20.5)	(8.6)	(6.2)	(6.3)	(9.9)	(8.0)	(8.1)	(9.8)	(13.0)	(11.3)
	3	3.6[b]	29.2[b]	44.6[b]	47.0[b]	45.3[a]	45.5[a]	43.3[c]	43.9[c]	42.2[a]	32.0[a]	40.3[a]
		(8.5)	(20.2)	(10.0)	(9.0)	(12.9)	(13.0)	(14.3)	(12.7)	(14.3)	(16.6)	(14.0)
	Significance	***	***	**	***	***	**	***	***	***	***	**
Average egg weight (g/bird)	1	43.3[a]	50.5	53.6	56.7[a]	58.7[a]	61.0	61.4	61.1[a]	62.1[a]	61.6[a]	64.0[a]
		(5.1)	(4.2)	(3.8)	(3.4)	(3.5)	(3.8)	(5.3)	(6.0)	(5.7)	(5.5)	(5.9)
	2	38.9[b]	49.7	54.2	57.9[b]	60.2[b]	61.6	62.6	64.5[b]	64.9[b]	63.9[b]	66.2[b]
		(2.9)	(4.6)	(4.3)	(4.2)	(4.4)	(4.6)	(4.8)	(5.7)	(5.8)	(6.1)	(5.8)
	3	39.4[b]	48.8	54.0	57.2[ab]	59.4[ab]	61.2	61.8	62.7[c]	64.1[b]	63.5[b]	65.5[b]
		(4.0)	(5.1)	(3.8)	(4.3)	(4.1)	(4.0)	(4.7)	(5.6)	(4.4)	(5.8)	(5.8)
	Significance	***	NS	NS	-	**	NS	NS	***	***	**	**

Notes 1 Period 1 began when the birds were 140 d of age.

Notes 2, 3 and 4, see Table 3.4.

FIGURE 3.3 Egg production (number/100 hen d) and egg output (g/bird d^{-1}) in relation to age (d) for birds which were either allowed *ad libitum* feed intake (■) or which were restricted by limited-time (●) or quantitative (○) methods during rearing (Experiment 1).

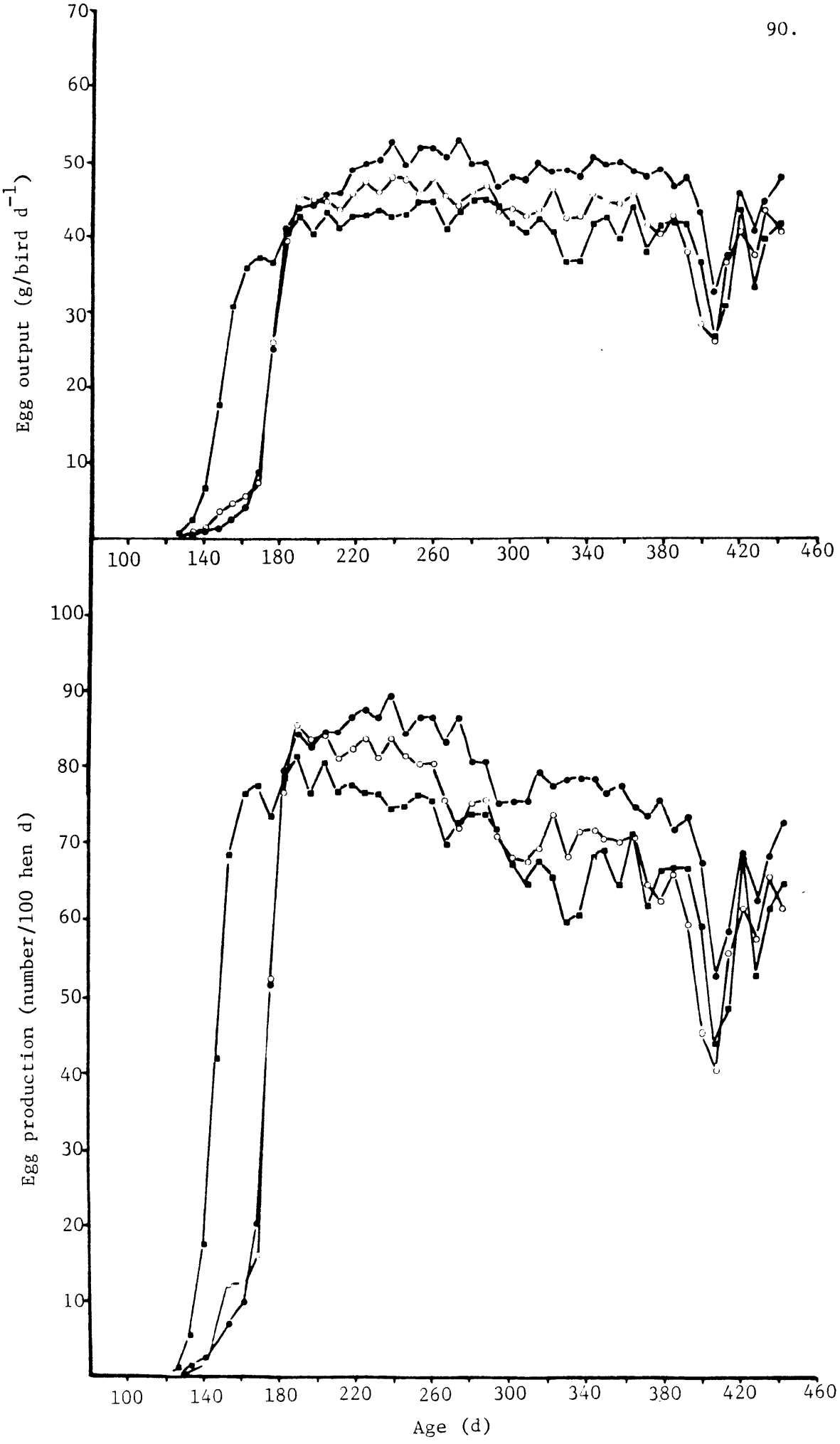

Egg output (g/bird d^{-1})
70
60
50
40
30
20
10
100
140
180
220
260
300
340
380
420
460
Egg production (number/100 hen d)
100
90
80
70
60
50
40
30
20
10
100
140
180
220
260
300
340
380
420
460
Age (d)

TABLE 3.6 The effect of feeding regimen during rearing on subsequent feed intake (g/bird d^{-1}), egg production (no./100 hen d), egg mass output (g bird d^{-1}) and average egg weight (g/bird) in nine 28 d periods after peak of egg production for individual treatments. Standard deviations are given in parenthesis below each mean (Experiment 1).

Production parameter	Rearing treatment[2]	Periods (28 d)[1] 1	2	3	4	5	6	7	8	9
Feed intake (g/bird d^{-1})	1	104.2^{a}[3]	112.3^{a}	113.9^{a}	117.6^{a}	122.8	125.7	124.9^{a}	124.9^{a}	121.0^{a}
		(17.1)	(16.2)	(15.9)	(17.5)	(18.9)	(20.2)	(20.6)	(18.0)	(17.8)
	2	112.2^{b}	119.2^{b}	124.7^{b}	123.5^{b}	126.0	128.3	130.8^{b}	124.0^{a}	120.0^{a}
		(14.9)	(13.2)	(13.0)	(16.7)	(15.6)	(16.2)	(13.4)	(13.2)	(15.6)
	3	111.8^{b}	116.8^{b}	119.8^{c}	119.1^{a}	123.6	122.0	126.3^{a}	117.2^{b}	115.5^{b}
		(13.6)	(14.8)	(11.4)	(16.9)	(16.8)	(16.4)	(14.3)	(19.4)	(17.7)
	Significance[4]	***	***	***	**	NS	*	*	***	*
Egg production (number/100 hen d)	1	76.3^{a}	78.6^{a}	76.1^{a}	74.1^{a}	72.8^{ab}	66.4^{a}	64.2^{a}	65.7^{a}	59.0^{ab}
		(26.3)	(26.2)	(24.0)	(22.2)	(22.6)	(25.5)	(28.7)	(24.5)	(28.0)
	2	82.8^{b}	86.3^{b}	86.9^{b}	82.7^{b}	76.9^{a}	77.3^{b}	75.6^{b}	72.1^{b}	60.6^{a}
		(22.6)	(9.9)	(10.7)	(11.9)	(14.3)	(13.9)	(14.7)	(17.4)	(21.3)
	3	82.5^{b}	81.9^{ab}	80.6^{c}	74.6^{a}	69.6^{b}	70.4^{a}	68.9^{a}	58.2^{c}	53.6^{b}
		(21.2)	(18.1)	(17.6)	(21.9)	(21.5)	(22.4)	(18.4)	(26.1)	(23.0)
	Significance	*	**	***	***	**	***	***	***	-
Egg mass output (g/bird d^{-1})	1	37.5^{a}	41.7^{a}	42.6^{a}	43.0^{a}	44.0^{a}	40.9^{a}	39.0^{a}	40.5^{a}	36.4
		(13.3)	(14.1)	(13.5)	(12.8)	(13.6)	(16.0)	(17.8)	(15.2)	(17.5)
	2	43.5^{b}	48.3^{b}	51.2^{b}	50.5^{b}	47.6^{b}	48.7^{b}	48.6^{b}	46.3^{b}	39.0
		(12.2)	(6.3)	(6.6)	(7.6)	(9.2)	(8.3)	(9.0)	(10.5)	(13.5)
	3	43.4^{b}	45.4^{c}	47.0^{c}	45.1^{a}	43.0^{a}	43.9^{a}	43.7^{c}	37.2^{a}	34.7
		(11.5)	(10.2)	(10.4)	(13.5)	(13.5)	(14.4)	(11.9)	(16.7)	(15.6)
	Significance	***	***	***	***	**	***	***	***	NS
Average egg weight (g/bird)	1	49.1^{a}	53.1^{a}	56.0^{a}	58.2^{a}	60.5^{a}	61.6^{ac}	60.9^{a}	61.9^{a}	61.6^{a}
		(4.1)	(3.7)	(3.5)	(3.4)	(3.7)	(4.6)	(6.1)	(5.9)	(5.5)
	2	52.6^{b}	56.0^{b}	59.0^{b}	61.2^{b}	62.1^{b}	63.4^{b}	64.8^{b}	64.8^{b}	64.7^{b}
		(4.1)	(4.6)	(4.2)	(4.5)	(4.8)	(5.4)	(5.7)	(6.0)	(6.1)
	3	52.5^{b}	55.5^{b}	58.4^{b}	60.4^{b}	61.8^{b}	62.1^{c}	63.5^{b}	64.0^{b}	64.0^{b}
		(4.1)	(4.3)	(4.2)	(4.0)	(4.1)	(5.2)	(5.2)	(5.0)	(6.1)
	Significance	***	***	***	***	**	**	***	***	***

1 See Section 3.2.4 for details.

2, 3 and 4, see Table 3.4.

TABLE 3.7 The effect of feeding regimen during rearing on subsequent feed intake (g/bird d^{-1}), egg production (no./100 hen d), egg mass output (g/bird d^{-1}) and average egg weight (g) during equal periods of egg production after the attainment of various physiological stages by individual treatments. Standard deviations are given in parentheses below each mean (Experiment 1).

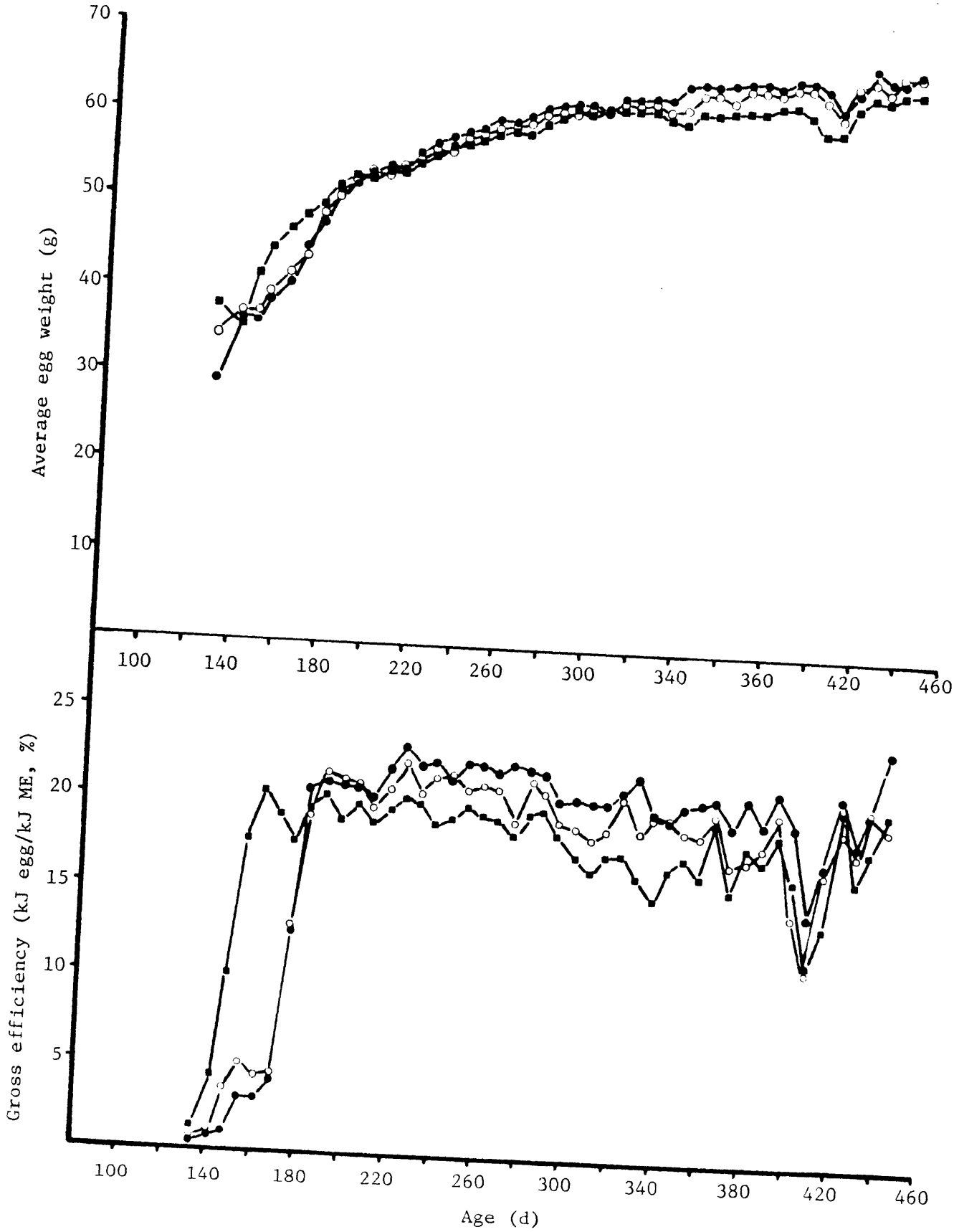
Physiological stage[1]	Rearing treatment[2]	Production parameter			
		Feed intake (g/bird d^{-1})	Egg production (no./100 hen d)	Egg mass output (g/bird d^{-1})	Egg weight (g/bird)
(1) EP≠>10	1	115.2[a3]	67.7[a]	38.2[a]	56.6[a]
		(20.4)	(29.0)	(16.7)	(7.5)
	2	120.9[b]	73.7[b]	44.0[b]	60.0[b]
		(18.4)	(24.4)	(14.6)	(7.2)
	3	115.1[a]	66.3[a]	39.0[a]	58.9[c]
		(21.0)	(29.1)	(17.3)	(6.9
	Significance[4]	***	***	***	***
(2) EP>50	1	116.8[a]	70.1[a]	40.1[a]	57.5[a]
		(19.7)	(26.6)	(15.3)	(6.8)
	2	122.3[b]	78.0[b]	46.5[b]	60.1[b]
		(15.9)	(18.8)	(11.0)	(6.8)
	3	118.6[c]	71.9[a]	42.4[c]	59.3[c]
		(16.3)	(23.8)	(14.0)	(6.3)
	Significance	***	***	***	***
(3) EP>Peak	1	117.9[a]	71.1[a]	40.7[a]	57.6[a]
		(19.3)	(26.1)	(15.0)	(6.3)
	2	122.8[b]	78.6[b]	47.2[b]	60.5[b]
		(15.6)	(17.4)	(10.0)	(6.5)
	3	118.8[c]	72.1[c]	42.9[c]	59.9[c]
		(16.2)	(23.0)	(13.5)	(6.2)
	Significance	***	***	***	***

1 Details of physiological stages are given in the text (Section 3.2.4).

2, 3 and 4. See Table 3.4.

≠ Abbreviation for egg production (number/100 hen d).

FIGURE 3.4 Average egg weight (g) and gross efficiency of egg production (kJ egg/kJ ME, %) in relation to age (d) for birds which were either allowed *ad libitum* feed intake (■) or which were restricted by limited-time (●) or quantitative (○) methods during rearing (Experiment 1).


Average egg weight (g)
70
60
50
40
30
20
10
100
140
180
220
260
300
340
360
420
460
Gross efficiency (kJ egg/kJ ME, %)
25
20
15
10
5
100
140
180
220
260
300
340
380
420
460
Age (d)

Some of these period differences between treatments were reduced when compared for equal periods after each attained peak of egg production (Table 3.6) or other physiological stages (Table 3.7). Both the limited-time and quantitative restriction treatments produced a greater ($P < 0.05$) number of eggs (per 100 hen d) and had a greater ($P < 0.001$) egg mass output at peak of egg production than the *ad libitum* treatment. However the limited-time treatment consistently produced a greater number of eggs and egg mass than either the *ad libitum* or quantitative treatments over the nine 28 d periods after attainment of peak of egg production in individual treatments.

Although there was no statistical difference between the *ad libitum* and quantitative treatments in egg production measured over ten 28 d periods after egg production was equal to or greater than 50 for each treatment, the quantitative treatment had a greater ($P < 0.001$) egg mass output due to greater ($P < 0.001$) egg weights (Table 3.7). Average egg weights (g/bird) are shown in Figure 3.4, and are given for chronological periods in Table 3.5 and for physiological periods in Table 3.6 and 3.7. Chronologically the *ad libitum* treatment initially had heavier egg weights than either the limited-time or quantitative treatments (see periods 1 and 2 in Table 3.5), but this was only significant ($P < 0.001$) for the first 28 d period. However for nine 28 d periods after each treatment attained peak of egg production (Table 3.6) the limited-time and quantitative treatments had greater ($P < 0.001$) average egg weights over the majority of the egg production period (see also Table 3.7).

3.3.1.1.4 Egg classification

The quantities of eggs produced during Experiment 1 which were classified as abnormal (see Section 3.2.3.3) and expressed as a percentage (%) of the total number of eggs produced during ten 28 d periods after attainment of 10 egg/100 hen d in each treatment are given in Table 3.8. The incidence of abnormal egg production in egg producing birds (layers) was approximately 32% in the *ad libitum* treatment compared to 5% for the two restriction treatments (TR and QR) during the initial two 28 d egg production periods (Table 3.8). The average percentage (%) of all eggs produced which were abnormal during the ten 28 d periods was 3.8, 1.6 and 2.6 for the *ad libitum*, limited-time and quantitative treatments respectively. However, more importantly, during the first two 28 d

TABLE 3.8 The percentage of birds in egg production, the percentage of egg producing birds which laid an egg classified as abnormal and the production of abnormal eggs as a percentage of the total number of eggs produced during ten 28 d periods after attainment of 10 eggs/100 hen d in each treatment (Experiment 1).

Parameter+	Rearing treatment[2]	Period (28 d)[1]									
		1	2	3	4	5	6	7	8	9	10
Percentage (%) in egg production	1	73	94	92	94	95	94	91	88	92	89
	2	59	98	100	100	99	100	100	100	99	99
	3	41	98	98	99	97	99	97	99	92	95
Percentage (%) of egg producing birds which laid abnormal eggs	1	39	24	6	7	8	10	14	16	10	7
	2	5	4	5	3	6	6	8	10	10	13
	3	7	5	2	9	6	10	8	13	11	13
Percentage (%) of total eggs produced which were abnormal	1	10.3	5.5	0.9	1.7	1.5	2.8	4.8	5.1	3.0	2.7
	2	1.3	0.7	0.9	0.5	1.1	1.0	1.7	2.0	2.7	3.6
	3	1.9	1.0	0.3	2.0	1.9	3.2	3.7	4.1	3.2	5.0
Percentage (%) of total eggs produced with shell formation defects	1	7.3	3.3	0.9	0.7	0.8	1.3	2.4	2.8	2.1	1.6
	2	0.9	0.4	0.3	0.3	0.5	0.6	0.3	0.5	0.2	1.5
	3	1.2	0.3	0.2	0.5	1.4	2.1	3.2	1.8	1.1	2.7
Percentage (%) of total eggs produced with double yolks	1	2.7	2.2	0.0	0.3	0.0	0.0	0.2	0.0	0.0	0.3
	2	0.3	0.3	0.2	0.2	0.6	0.0	0.0	0.0	0.2	0.0
	3	0.7	0.7	0.1	0.1	0.0	0.0	0.0	0.2	0.0	0.0
Percentage (%) of total eggs produced classified as 'other'	1	0.3	0.0	0.0	0.8	0.7	1.6	2.3	2.4	0.9	0.9
	2	0.0	0.0	0.3	0.0	0.1	0.4	1.4	1.6	2.0	2.8
	3	0.0	0.0	0.0	1.4	0.5	1.2	0.5	2.1	2.1	2.3

1 See Section 3.2.4 for details.
2 See Table 3.4.

+ See Section 2.8, Chapter 2 for details of the scheme used for egg classification.

periods abnormal egg production averaged 8% of all eggs produced in the *ad libitum* treatment. The majority, about 70%, of the abnormal eggs produced during these two periods were eggs with a shell formation defect, particularly shell-less eggs.

From the third 28 d egg production period there was a gradual increase in abnormal egg production irrespective of rearing treatment. This was due to an increased incidence of eggs with cracked shells and eggs which were deformed (i.e. flat-sided). The production of double yolk eggs was negligible in all treatments after the first two 28 d periods.

3.3.1.1.5 Feather cover

Mean feather cover scores (±SD) for the *ad libitum*, limited-time and quantitative treatments determined at each age specified (see Section 3.2.3.6) were as follows: (a) *280 d*, 2.23 (±1.17), 1.50 (±0.68) and 1.67 (±0.63); (b) *350 d*, 2.47 (±1.15), 1.69 (±0.88) and 1.74 (±0.77); (c) *434 d*, 2.67 (±1.21), 2.25 (±1.16) and 1.96 (±1.10). There were significant treatment ($P < 0.001$) and age ($P < 0.01$) effects but the interaction between treatment and age was not significant ($P > 0.60$). At 280 d and 350 d of age birds on the *ad libitum* treatment had higher feather scores, and therefore poorer feather cover, than either the limited-time ($P < 0.01$) or quantitative ($P < 0.05$) restriction treatments. At 434 d of age there were no significant differences ($P > 0.13$) between treatments. Feather cover deteriorated with age for all treatments.

3.3.1.2 Experiment 2

Three birds were removed from the limited-time restriction treatment at 90 d of age due to severe pecking damage. Cannibalism during the rearing period (56-168 d of age) was the only cause of mortality for birds on the limited-time restriction treatment. The amount of mortality during the rearing and egg production periods, and the causes diagnosed, are given in Table 3.9. During the egg production period (168-476 d) three birds died in each of the *ad libitum* and quantitative treatments. The major cause of death in the *ad libitum* treatment was Marek's disease, but cause of death could not be ascertained for the majority of birds which died on the quantitative restriction treatment. To facilitate analysis of the data the production parameters for the

TABLE 3.9 The occurrence of mortality and the diagnosed causes during the rearing and egg production periods (Experiment 2).

Treatment	Rearing feeding regimen	Period	Age (d) at which mortality occurred	Cause of death
1	*Ad libitum* (A)	Rearing	70 (1)+	Marek's disease
		Egg production	318 (1)	Unknown
			347 (1)	Marek's disease
			373 (1)	Marek's disease
2	Limited-time restriction (TR)	Rearing	70 (1)	Cannabilism
			84 (5)	Cannabilism
			91 (6)	Cannabilism
		Egg production	-	-
3	Quantitative restriction (QR)	Rearing	134 (1)	Unknown
		Egg production	319 (1)	Unknown
			370 (1)	Lymphoid leucosis
			429 (1)	Unknown

+ Number of birds which died is given in parentheses.

birds which died during the egg production period were omitted. Also omitted were the data on the four birds from each treatment which were slaughtered at 280 d of age for body composition determination (see Section 3.2.3.7). Therefore the number of birds for which analyses were carried out during the egg production period were 46, 49 and 44 for the *ad libitum*, limited-time and quantitative treatments respectively.

Liveweights, cumulative feed intake and feed conversion ratios are given for the rearing period (56-168 d of age) in Table 3.10. Liveweights for the egg production period are given in Table 3.11. Mean feed intake and liveweights are shown for each of the treatments in Figure 3.5 for 7 d periods in conjunction with average shed temperatures during both the rearing and egg production periods. Egg production and egg mass output are shown in Figure 3.6, and average egg weights and gross efficiency in Figure 3.7. Detailed analyses on both a chronological and a physiological age basis are given in Tables 3.12, 3.13, 3.14, 3.15 and in Appendix Table A3.3.

3.3.1.2.1 Feed intake and feed conversion ratio

A similar reason is proposed as that given in Section 3.3.1.1.1 to explain the apparent large fluctuations in feed intake during the rearing period of the limited-time treatment (see Figure 3.5). The approximate 20% drop in feed intake which occurred in the *ad libitum* treatment at 98 d of age (mean age 102 d in Figure 3.5) was probably associated with the movement of the sampled birds from the flat-deck cages to the individual wire-mesh cages. Shed temperatures (°C) were also very high at this time (see Figure 3.5). The depression in feed intake at 119 d of age (mean age 124 d in Figure 3.5) in the *ad libitum* treatment was probably due to a change in diet from the grower diet to the layer diet.

Cumulative feed intake during the rearing period (56-168 d) is given in Table 3.10. Mean feed intakes (g/bird d^{-1}) during the rearing period were 86, 54 and 55 for the *ad libitum*, limited-time and quantitative treatments respectively. Feed conversion ratios for the period 56-168 d of age were 8.57, 8.25 and 7.63 for the *ad libitum*, limited-time and quantitative treatments respectively. However egg production commenced in the *ad libitum* treatment at approximately 150 d of age; this caused a large increase in the feed conversion ratio calculated in this manner.

TABLE 3.10 The effect of feeding regimen on average liveweights (W, g), cumulative feed intake (I, g/bird), and feed conversion ratio (FCR, g feed/g liveweight gain) of layer-type pullets during the rearing period (Experiment 2).

Treatment	Rearing feed regimen	Parameter	Age (d)								
			56	70	84	98	112	126	140	154	168
1	*Ad libitum* (A)	W[5]	701	920	1127	1321[a][2]	1381[a]	1475[a]	1632[a]	1702[a]	1709[a]
		(±SD)[1]	-	-	-	103	125	150	164	170	170
		I	-	961	2199	3410	4447	5576	6867	8219	9678
		FCR	-	4.39	5.98	6.24	14.61	11.88	8.33	19.59	208.4
		N[3]	77	77	76	75	46	46	46	46	46
2	Limited-time restriction (TR)	W	698	715	1012	1110[b]	1179[b]	1221[b]	1169[b]	1306[b]	1364[b]
		(±SD)	-	-	-	107	108	121	118	128	136
		I	-	530	1526	2290	2907	3640	4334	5254	5994
		FCR	-	31.2	3.36	7.80	9.64	17.45	-13.35	6.72	12.54
		N	78	77	75	65	49	49	49	49	49
3	Quantitative restriction (QR)	W	700	805	1005	1157[b]	1137[b]	1137[c]	1267[c]	1353[b]	1438[c]
		(±SD)	-	-	-	122	85	75	69	87	87
		I	-	547	1350	2136	2760	3518	4372	5282	6191
		FCR	-	5.21	4.02	5.17	-31.20		6.62	10.46	10.45
		N	78	78	78	76	44	44	44	44	44
Significance of differences between liveweights[4]			≠	NA[+]	NA	***	***	***	***	***	***

Notes 1, 2, 3 and 4. See Table 3.2.

≠ Not applicable.

\+ NA. Statistical analysis not available due to method of liveweight measurement.

5 Liveweights presented from 112 d of age are only for those birds included in the overall analyses (see Section 3.3.1.2) whereas feed intake and feed conversion ratio were calculated with all birds included.

A better estimation of the differences in feed conversion between the treatments can be obtained by comparison during the period of 56-126 d of age, feed conversion ratios for this period were 5.87, 6.00 and 6.80 for the *ad libitum*, limited-time and quantitative treatments respectively.

Feed intake increased markedly on the two restriction treatments (TR and QR) after cessation of restriction (see Figure 3.5). The mean (±SD) feed intakes during the 7 d period after cessation of restriction for the limited-time and quantitative feed restriction treatments were 140.6 (±17.2) and 135.7 (±19.1) respectively. Overall analysis of feed intake on a chronological age basis from commencement of egg production for birds on the *ad libitum* treatment (131-474 d of age) is given in Table 3.12. Differences in feed intake between treatments within each of twelve 28 d periods from commencement of egg production in the *ad libitum* treatment on a chronological age basis are given in Table 3.13. Measured on this basis, feed intake was greater ($P < 0.001$) for the *ad libitum* treatment than for the two restriction treatments (TR and QR) during the first two 28 d periods. During the initial 28 d period the restricted feeding schedules were still in progress. Also, during the two 28 d periods after cessation of restriction and when egg production commenced in the restriction treatments (TR and QR) (see periods 2 and 3 in Table 3.13) the quantitative treatment had a greater ($P < 0.05$ and $P < 0.001$ for periods 2 and 3 respectively) feed intake than the limited-time treatment.

Peak of egg production was attained at the mean ages of 166 d, 201 d and 194 d for the *ad libitum*, limited-time and quantitative treatments respectively; approximate mean peak egg production was 82.6, 88.9 and 88.6 eggs/100 hen d for each treatment respectively (see also Table 3.14). Feed intake for ten 28 d periods, inclusive of the 7 d period given above is given in Table 3.14. Overall analyses of feed intake for this and other physiological periods during egg production are given in Table 3.15. Both the treatments which were previously subjected to feed restriction (TR and QR) had a greater ($P < 0.001$) feed intake during egg production than the *ad libitum* treatment. This effect was evident irrespective of the physiological period employed for anlaysis (Table 3.15). The quantitative treatment also had a greater feed intake over each of these physiological periods than the

FIGURE 3.5: Feed intake (g/bird d^{-1}) averaged over 7 d periods and liveweight (g) in relation to age (d) for birds either allowed *ad libitum* feed intake (■) or restricted (to 168 d of age) by limited-time (●) or quantitative (○) methods. Mean maximum (△), minimum (▲) and average (□) shed temperatures (°C) measured during the experiment are also given. The arrows originating from the letters A and B point to the mean age of sexual maturity (first oviposition) for birds on the *ad libitum* or restriction treatments respectively; the bar line either side of the point is the the standard deviation (± SD) (Experiment 2).

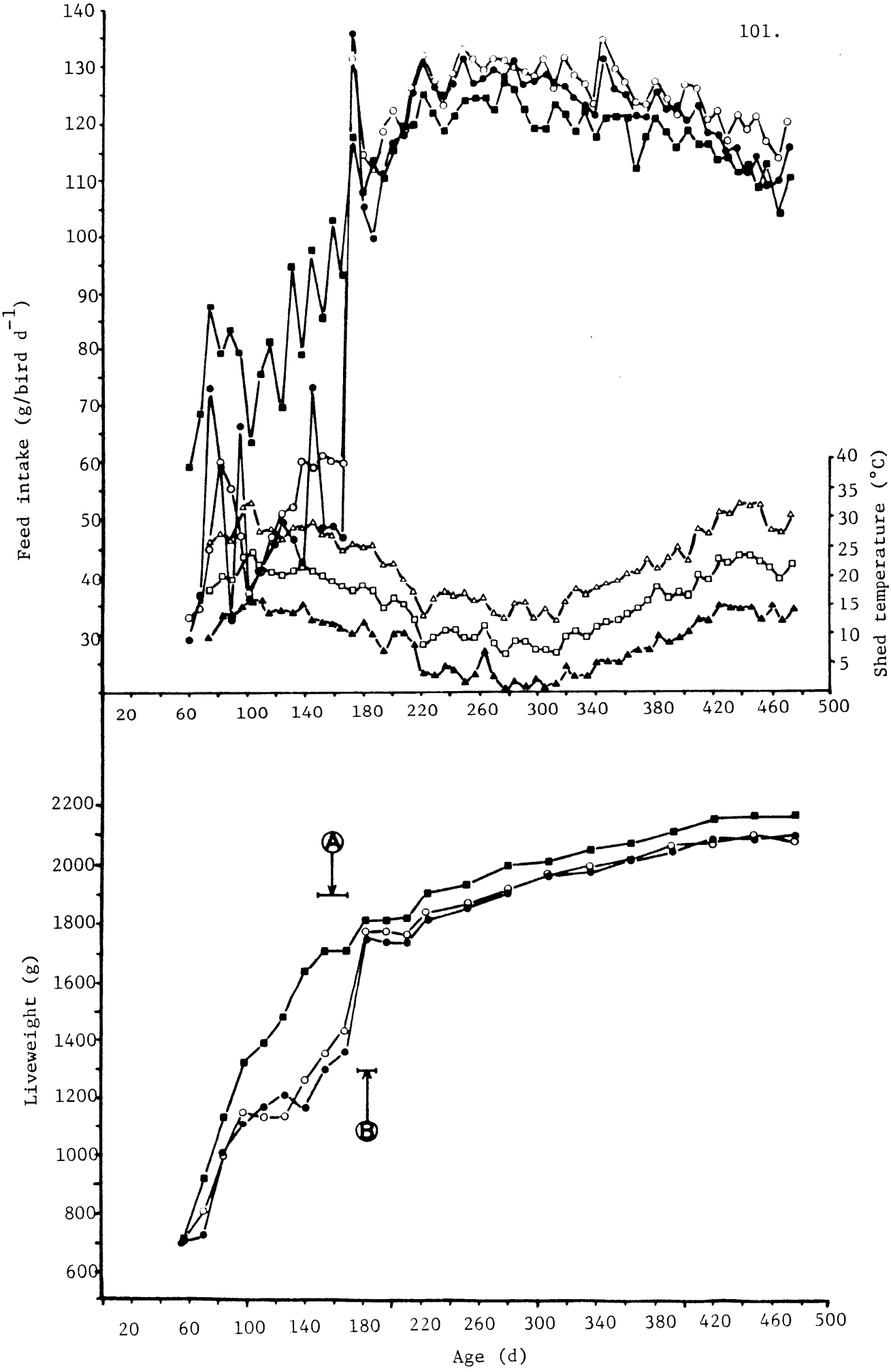

Feed intake (g/bird d^{-1})
Shed temperature (°C)
Liveweight (g)
Age (d)
A
B

TABLE 3.11 The effect of feeding regimen during rearing on average liveweights (W, g) of layer-type pullets during the egg production period (Experiment 2).

Treatment	Rearing feeding regimen		Age (d) 196	224	252	280	308	336	364	392	420	448	476
1	*Ad libitum* (A)	W	1818[a2]	1905[a]	1940[a]	1988[a]	2014	2053	2077	2116	2156	2169	2162
		(±SD)[1]	175	187	198	209	209	216	260	276	281	319	304
		N[3]	46	46	46	46	46	46	46	46	46	46	46
2	Limited-time restriction (TR)	W	1742[b]	1818[b]	1853[b]	1905[b]	1959	1973	2011	2050	2085	2089	2101
		(±SD)	175	182	177	181	200	223	221	240	254	285	297
		N	49	49	49	49	49	49	49	49	49	49	49
3	Quantitative restriction (QR)	W	1776[ab]	1843[ab]	1869[ab]	1913[ab]	1960	1994	2016	2057	2079	2094	2077
		(±SD)	144	148	162	163	176	188	204	216	235	248	261
		N	44	44	44	44	44	44	44	44	44	44	44
Significance of differences between treatments[4]			-	*	*	-	NS	NS	NS	NS	NS	NS	NS

Notes 1, 2, 3 and 4. See Table 3.2.

limited-time treatment. This was partially due to a non-significant difference in feed intake between the *ad libitum* and limited-time treatments during the latter part of the egg production period (see for example periods 7, 8, 9 and 10 in Table 3.14).

3.3.1.2.2 Liveweight and sexual maturity

From 98 d of age the mean liveweight of the *ad libitum* treatment was greater ($P < 0.001$) than for the two restriction treatments (TR and QR). At the termination of restriction (168 d) the mean liveweights of the limited-time and quantitative restriction treatments expressed as a proportion of the mean liveweight of the *ad libitum* treatment were 0.79 and 0.84 respectively. The difference between the liveweights of the limited-time and quantitative treatments at 168 d of age was significant ($P < 0.01$). Similar to Experiment 1 (section 3.3.1.1.2) there was a period of rapid liveweight gain in the restriction treatments (TR and QR) after cessation of restriction (see Figure 3.5). At 182 d of age there were no liveweight differences between treatments ($P > 0.10$). Between 196 d to 280 d of age the limited-time restriction treatment was lower in liveweight than the *ad libitum* treatment ($P < 0.05$). Overall analysis of variance for liveweights for 28 d periods from 196 d of age showed a non-significant interaction term (treatment x age) (see Appendix Table A3.2). Although liveweight of the birds on the two restriction treatments (TR and QR) remained marginally below that for birds on the *ad libitum* treatment, the differences did not attain significance ($P > 0.10$).

The mean (±SD) ages (d) at first oviposition were 149.3 (±10.3), 185.0 (±5.5) and 180.3 (±6.8) for the *ad libitum*, limited-time and quantitative treatments respectively. One of the birds on the limited-time restriction treatment failed to produce an egg and was omitted from this analysis. As in Experiment 1 (section 3.3.1.1) the mean age at sexual maturity for each of the treatments was included in Figure 3.5 to aid interpretation. The mean age when the average treatment egg productions reached 50/100 hen d were 152, 187 and 187 d respectively for the three treatments.

3.3.1.2.3 Egg production parameters

Egg production parameters for each treatment averaged over the period from commencement of egg production in the *ad libitum* treatment to the termination of the experiment (131-474 d of age) are given in Table 3.12.

TABLE 3.12 The effect of feeding regimen during rearing on feed intake (g/bird d^{-1}), egg production (no./100 hen d), egg mass output (g/bird d^{-1}) and average egg weight (g/bird) on a chronological age basis from commencement of egg production of the *ad libitum* (A) treatment to the end of Experiment 2 (131 - 474 d of age).

Production parameter[1]	Rearing treatment[2]			Significance[4]
	1	2	3	
Feed intake (g/bird d^{-1})	119.3[a3] (17.8)	117.9[a] (28.6)	121.5[b] (27.0)	***
Egg production (number/100 hen d)	74.4[a] (26.9)	68.6[b] (35.3)	71.7[c] (32.6)	***
Egg mass output (g/bird d^{-1})	44.9[ab] (16.7)	43.8[a] (22.7)	45.2[b] (20.9)	*
Average egg weight (g/bird)	60.5[a] (6.8)	63.9[b] (5.8)	62.4[c] (6.2)	***

1 Standard deviations are given in parentheses below each mean.

Notes 2, 3 and 4. See Table 3.4.

TABLE 3.13 The effect of feeding regimen during rearing on subsequent feed intake (g/bird d^{-1}), egg production (number/100 hen d), egg mass output (g/bird d^{-1}) and average egg weight (g/bird) in twelve 28 d periods from commencement of egg production on a chronological age basis. Standard deviations are given in parentheses below each mean (Experiment 2).

Production parameter	Rearing treatment[2]	Period (28 d)[1] 1	2	3	4	5	6	7	8	9	10	11	12
Feed intake (g/bird d^{-1})	1	93.9[a3] (16.2)	110.2[a] (16.2)	119.2[a] (14.7)	125.8[a] (14.2)	127.8[a] (14.3)	128.7[a] (14.4)	125.0[a] (16.1)	124.2[a] (14.7)	122.5[a] (14.7)	122.8[a] (13.8)	119.7[a] (15.1)	115.9[a] (18.1)
	2	57.7[b] (13.5)	89.1[b] (40.0)	116.1[b] (16.3)	131.3[b] (14.7)	132.5[b] (18.1)	133.2[b] (16.3)	131.7[b] (14.9)	129.4[b] (16.8)	127.8[b] (16.0)	126.9[b] (16.3)	122.7[ab] (15.1)	116.8[a] (19.8)
	3	63.0[c] (3.5)	96.1[c] (34.3)	122.7[c] (15.4)	131.4[b] (15.1)	134.8[b] (16.2)	134.5[b] (15.8)	133.5[b] (14.7)	132.6[b] (20.9)	130.1[b] (17.7)	129.1[b] (16.9)	125.8[b] (17.6)	123.9[b] (19.6)
	Significance[4]	***	***	***	***	***	**	***	***	***	***	**	***
Egg production (number/100 hen d)	1	23.4[a] (35.8)	78.2[a] (25.9)	88.6[a] (18.2)	86.2[a] (16.9)	82.1[a] (20.8)	82.6[a] (16.5)	78.2[a] (20.2)	77.2 (19.3)	75.4[a] (20.4)	73.4[a] (21.0)	75.6 (18.9)	74.6[a] (21.9)
	2	0.0[b] (0.0)	4.1[b] (14.5)	81.3[b] (28.7)	89.4[b] (16.3)	86.3[b] (18.1)	86.4[b] (15.9)	82.3[b] (22.6)	80.5 (22.0)	81.0[b] (20.3)	78.2[b] (19.5)	78.2 (19.4)	76.7[ab] (21.2)
	3	0.0[b] (0.0)	13.4[c] (26.5)	89.4[a] (21.6)	91.8[b] (9.5)	89.2[b] (9.7)	86.4[b] (12.4)	84.7[b] (13.7)	81.3 (15.8)	82.9[b] (13.0)	80.1[b] (13.7)	79.4 (13.7)	80.3[b] (16.6)
	Significance	***	***	***	**	***	*	**	NS	***	**	NS	*
Egg mass output (g/bird d^{-1})	1	10.6[a] (16.6)	39.5[a] (13.7)	49.0[a] (10.4)	50.2[a] (10.1)	49.1[a] (12.5)	50.7[a] (10.4)	49.1[a] (12.7)	49.0[a] (12.5)	48.2[a] (13.4)	47.3[a] (13.9)	48.8[a] (12.6)	48.0[a] (14.4)
	2	0.0[b] (0.0)	1.9[b] (7.0)	45.1[b] (16.8)	53.6[b] (9.9)	53.6[b] (11.4)	55.2[b] (10.6)	53.4[b] (14.7)	53.1[b] (14.9)	54.0[b] (13.8)	52.4[b] (13.3)	52.3[b] (13.2)	51.1[b] (14.1)
	3	0.0[b] (0.0)	6.6[c] (13.2)	50.4[a] (13.0)	54.9[b] (6.8)	54.8[b] (7.1)	54.6[b] (8.6)	54.8[b] (9.9)	53.2[b] (11.3)	54.9[b] (9.8)	53.0[b] (9.8)	52.4[b] (10.0)	52.5[b] (11.2)
	Significance	***	***	***	***	***	***	***	***	**	***	*	**
Average egg weight (g/bird)	1	43.8 (4.9)	50.2[a] (4.3)	55.4 (3.3)	58.3[a] (3.5)	59.9[a] (3.6)	61.4[a] (3.8)	62.8[a] (4.2)	63.4[a] (5.0)	63.9[a] (5.5)	64.6 (4.8)	64.6 (5.2)	64.5 (4.7)
	2	-	46.8[b] (2.6)	55.3 (4.4)	60.1[b] (3.6)	62.2[b] (4.0)	63.9[b] (3.9)	65.0[b] (3.9)	66.0[b] (4.2)	66.3[b] (4.2)	67.1 (4.3)	66.7 (5.8)	66.7 (4.4)
	3	-	48.2[b] (4.6)	56.1 (4.4)	59.7[b] (3.8)	61.4[c] (4.0)	63.2[b] (4.2)	64.6[b] (4.6)	65.4[b] (4.9)	66.2[b] (5.3)	66.1 (5.0)	65.8 (5.5)	65.5 (5.6)
	Significance	-	**	NS	***	***	***	***	***	***			

1 See Section 3.2.4.2 for details.

Notes 2, 3 and 4. See Table 3.4.

FIGURE 3.6: Egg production (number/100 hen d) and egg output (g/bird d^{-1}) in relation to age (d) for birds which were either allowed *ad libitum* feed intake (■) or which were restricted by limited-time (●) or quantitative (○) methods during rearing (Experiment 2).

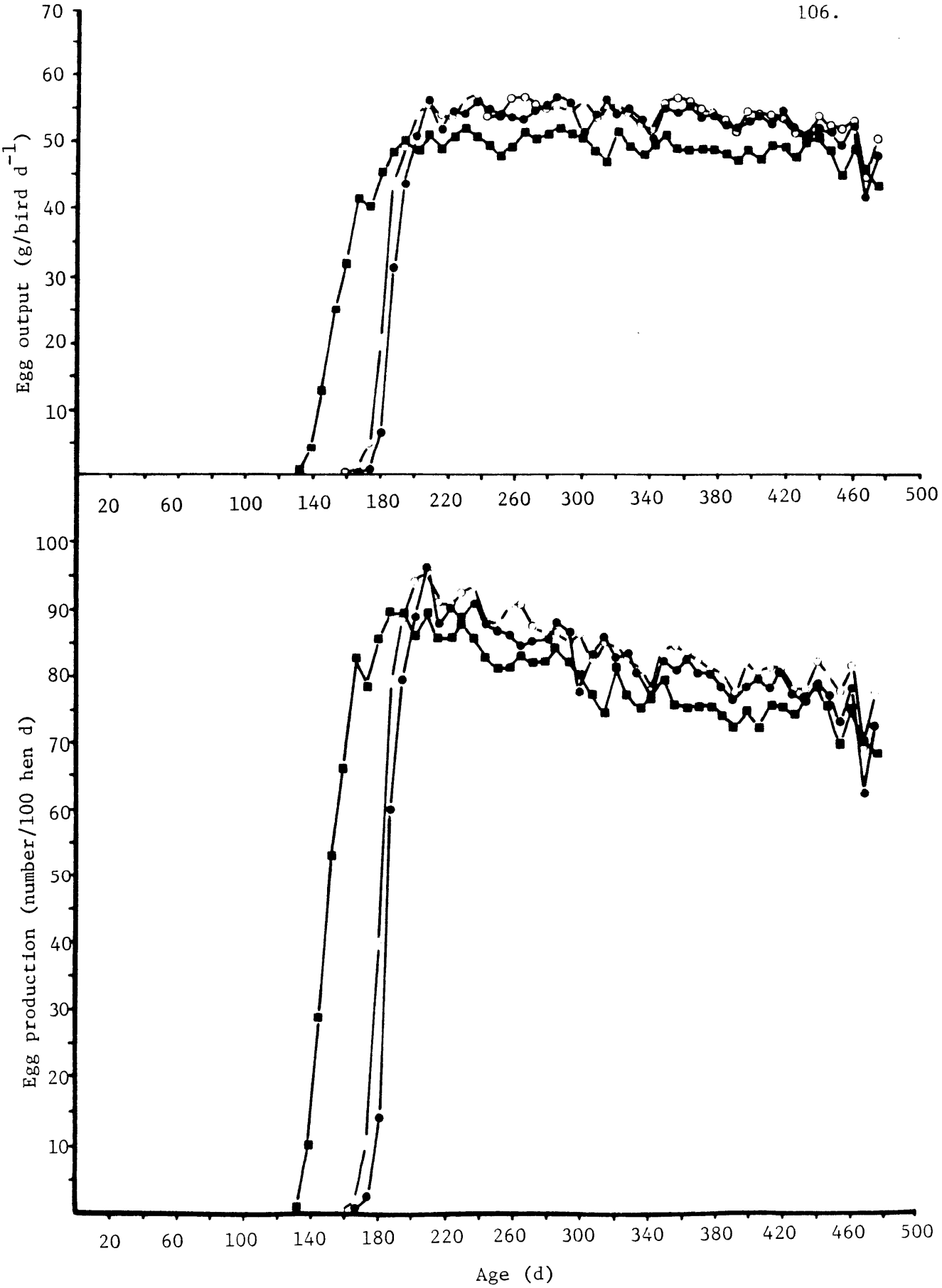

Egg output (g/bird d^{-1})
70
60
50
40
30
20
10
20 60 100 140 180 220 260 300 340 380 420 460 500
Egg production (number/100 hen d)
100
90
80
70
60
50
40
30
20
10
20 60 100 140 180 220 260 300 340 380 420 460 500
Age (d)

TABLE 3.14 The effect of feeding regimen during rearing on subsequent feed intake (g/bird d^{-1}), egg production (number/100 hen d), egg mass output (g/bird d^{-1}) and average egg weight (g/bird) in ten 28 d periods after peak of egg production for individual treatment groups. Standard deviations are given in parentheses below each mean (Experiment 2).

Production parameter	Rearing treatment[2]	Periods (28 d)[1] 1	2	3	4	5	6	7	8	9	10
Feed intake (g/bird d^{-1})	1	112.8^{a}[3]	120.8^{a}	126.2^{a}	128.0^{a}	127.9^{a}	124.9^{a}	124.9^{a}	122.3^{a}	121.7^{ab}	118.4^{a}
		(16.7)	(14.8)	(14.8)	(13.9)	(14.5)	(17.1)	(13.2)	(14.5)	(14.8)	(14.5)
	2	127.2^{b}	131.7^{b}	132.4^{b}	132.8^{b}	129.5^{a}	130.3^{b}	126.7^{ab}	125.3^{a}	119.1^{a}	116.7^{a}
		(14.4)	(15.4)	(19.1)	(15.6)	(15.6)	(15.6)	(17.2)	(15.2)	(16.2)	(19.8)
	3	125.9^{b}	132.1^{b}	135.4^{b}	133.6^{b}	133.7^{b}	132.9^{b}	129.5^{b}	128.9^{b}	124.6^{b}	122.2^{b}
		(14.6)	(16.2)	(15.3)	(15.3)	(18.2)	(18.3)	(18.1)	(17.0)	(18.1)	(18.7)
	Significance[4]	***	***	***	***	**	***	*	***	**	*
Egg production (number/100 hen d)	1	84.0^{a}	87.6^{a}	85.5^{a}	81.9^{a}	82.1	77.5	76.8^{a}	75.1^{a}	73.8^{a}	76.2^{a}
		(22.4)	(18.2)	(17.7)	(19.6)	(16.9)	(20.6)	(19.9)	(20.7)	(20.4)	(19.2)
	2	90.7^{b}	88.5^{b}	85.4^{a}	83.8^{ab}	83.1	80.3	78.8^{ab}	79.2^{b}	77.3^{ab}	71.7^{b}
		(17.0)	(16.2)	(17.8)	(21.6)	(20.3)	(21.6)	(20.0)	(19.1)	(19.6)	(23.9)
	3	92.3^{b}	91.0^{b}	89.1^{b}	86.3^{b}	83.8	81.7	81.8^{b}	80.3^{b}	79.7^{b}	77.1^{a}
		(13.8)	(9.8)	(9.7)	(13.2)	(13.4)	(16.1)	(13.3)	(13.3)	(13.7)	(18.6)
	Significance	***	***	*	-	NS	NS	*	*	**	*
Egg mass output (g/bird d^{-1})	1	43.7^{a}	49.2^{a}	50.3^{a}	49.3^{a}	50.7^{a}	48.8^{a}	48.9^{a}	48.2^{a}	47.6^{a}	49.1
		(12.0)	(10.4)	(10.6)	(12.0)	(10.6)	(13.0)	(13.1)	(13.4)	(13.6)	(12.8)
	2	52.8^{b}	54.3^{b}	53.9^{b}	53.9^{b}	54.4^{b}	53.4^{b}	52.6^{b}	53.1^{b}	51.4^{b}	47.6
		(10.1)	(9.9)	(11.7)	(14.0)	(13.5)	(14.6)	(13.6)	(13.1)	(13.1)	(16.0)
	3	52.9^{b}	54.8^{b}	55.2^{b}	54.8^{b}	54.3^{b}	53.8^{b}	54.1^{b}	53.1^{b}	52.4^{b}	50.1
		(9.0)	(7.1)	(7.0)	(9.1)	(9.8)	(11.5)	(9.9)	(9.6)	(10.0)	(12.4)
	Significance	***	***	***	***	**	**	**	***	***	NS
Average egg weight (g/bird)	1	51.9^{a}	56.2^{a}	58.9^{a}	60.3^{a}	61.8^{a}	63.1^{a}	63.2^{a}	64.3^{a}	64.6^{a}	64.6^{a}
		(4.0)	(3.4)	(3.4)	(3.8)	(3.9)	(4.1)	(6.1)	(4.3)	(4.8)	(5.3)
	2	58.3^{b}	61.4^{b}	63.1^{b}	64.4^{b}	65.5^{b}	66.6^{b}	66.8^{b}	67.0^{b}	66.6^{b}	66.5^{b}
		(3.6)	(4.0)	(4.0)	(3.8)	(4.1)	(4.3)	(4.2)	(5.7)	(4.4)	(4.5)
	3	57.2^{c}	60.2^{c}	61.9^{c}	63.6^{c}	64.7^{b}	65.7^{b}	66.1^{b}	66.2^{b}	65.6^{ab}	65.2
		(4.4)	(3.8)	(4.0)	(4.3)	(4.8)	(5.0)	(5.2)	(5.0)	(5.4)	(5.6)
	Significance	***	***	***	***	***	***	***	***	***	***

1 See Section 3.2.4.2 for details.

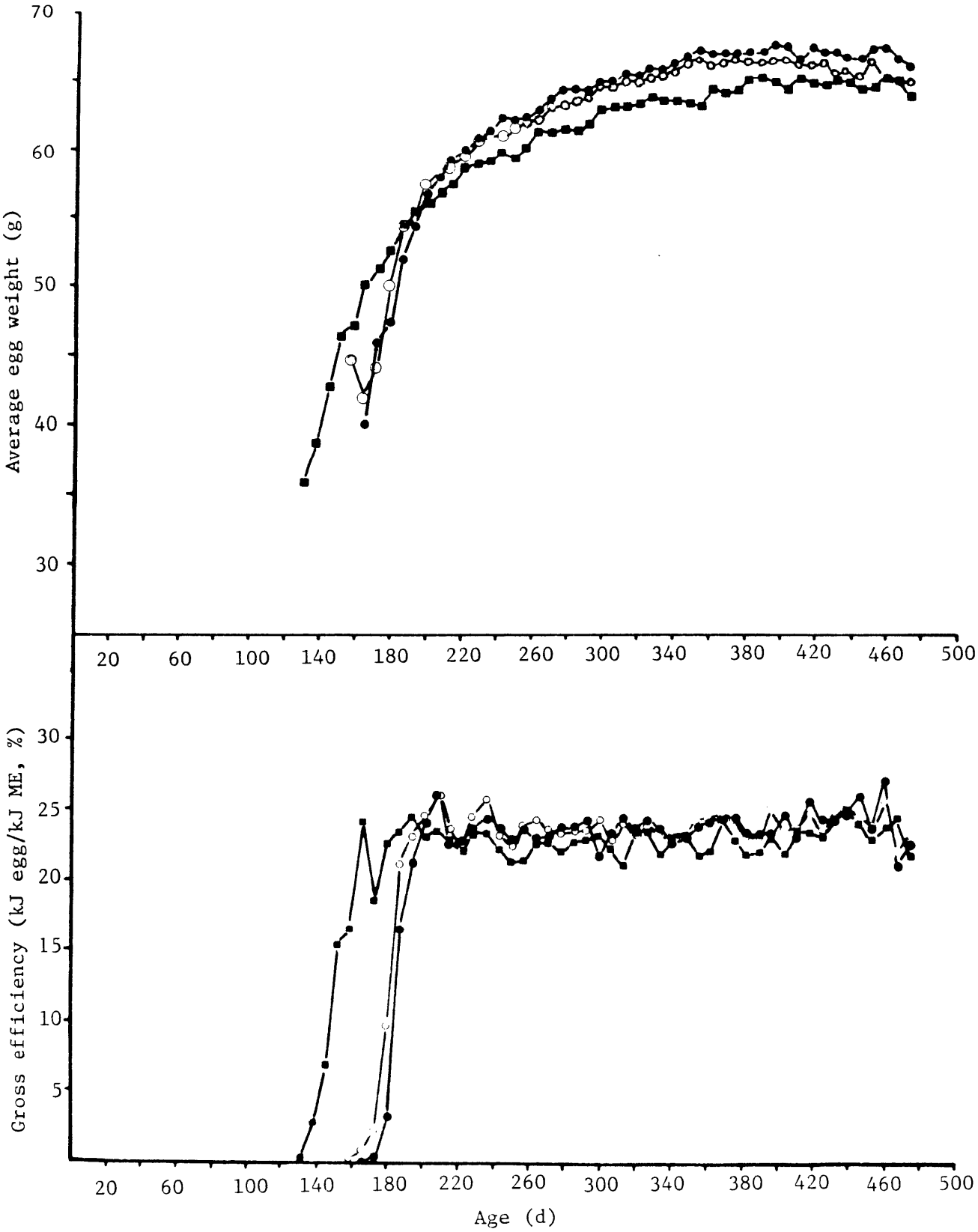
Notes 2, 3 and 4. See Table 3.4.

TABLE 3.15 The effect of feeding regimen during rearing on subsequent feed intake (g/bird d^{-1}), egg production (no./100 hen d), egg mass output (g/bird d^{-1}) and average egg weight (g/bird) during equal periods of egg production after the attainment of various physiological stages by individual treatments. Standard deviations are given in parentheses below each mean (Experiment 2).

Physiological stage[1]	Rearing treatment[2]	Production parameter			
		Feed intake (g/bird d^{-1})	Egg production (no./bird hen d)	Egg mass output (g/bird d^{-1})	Egg weight (g/bird)
(1) EP≠>10	1	120.6[a3]	76.4[a]	45.5[a]	59.5[a]
		(17.7)	(25.8)	(15.9)	(6.8)
	2	126.8[b]	80.4[b]	51.2[b]	63.7[b]
		(17.4)	(23.6)	(15.3)	(5.8)
	3	130.0[c]	81.9[b]	51.5[b]	62.9[c]
		(17.4)	(20.6)	(13.6)	(6.1)
	Significance[4]	***	***	***	***
(2) EP>50	1	121.9[a]	79.2[a]	47.5[a]	60.1[a]
		(16.5)	(21.7)	(13.4)	(6.4)
	2	126.8[b]	82.0[b]	52.4[b]	64.0[b]
		(17.5)	(21.0)	(13.6)	(5.6)
	3	129.8[c]	84.6[c]	53.5[c]	63.4[c]
		(17.5)	(14.9)	(10.0)	(5.7)
	Significance	***	***	***	***
(3) EP>Peak	1	122.8[a]	80.1[a]	48.6[a]	60.9[a]
		(15.5)	(20.1)	(12.3)	(5.9)
	2	127.2[b]	81.9[b]	52.7[b]	64.6[b]
		(17.3)	(20.5)	(13.2)	(5.1)
	3	129.9[c]	84.3[c]	53.6[c]	63.6[c]
		(17.5)	(14.5)	(9.8)	(5.6)
	Significance	***	***	***	**

Notes 1, 2, 3 and 4. See Table 3.13.

FIGURE 3.7: Average egg weight (g) and gross efficiency of egg production (kJ egg/kJ ME, %) in relation to age (d) for birds which were either allowed *ad libitum* feed intake (■) or which were restricted by limited-time (●) or quantitative (○) methods during rearing (Experiment 2).


Average egg weight (g)
70
60
50
40
30
20
60
100
140
180
220
260
300
340
380
420
460
500
Gross efficiency (kJ egg/kJ ME, %)
30
25
20
15
10
5
Age (d)

This represents a strict chronological analysis. The pattern of the results was similar to that obtained in Experiment 1 (section 3.3.1.1). Analyses between treatments over chronological age periods after commencement of egg production in the *ad libitum* treatment showed that egg production, egg mass output and average egg weight were initially greater for birds on the *ad libitum* treatment than on the restriction treatments (TR and QR) (see periods 1 and 2 in Table 3.13). Again, this was due to the greater age at sexual maturity for the restriction treatments (TR and QR) (see section 3.3.1.2.2).

Differences between treatments in rate of egg production were reduced when treatments were compared for equal periods after each attained peak of egg production (Table 3.14). However, peak of egg production was greater ($P < 0.001$) for the two restriction treatments (TR and QR) (see periods 1 and 2 in Table 3.14 and Figure 3.6). Because of the greater ($P < 0.001$) egg weights, the restriction treatments (TR and QR) had a greater ($P < 0.001$) egg mass output over most of the physiological egg production periods (Table 3.14). Overall analyses for the total physiological periods (see Section 3.2.3.4.2) showed that the restriction treatments (TR and QR) produced a greater ($P < 0.001$) number of eggs and a greater ($P < 0.001$) egg mass output. Also, for the physiological periods from 50 eggs/100 hen d and peak production the quantitative restriction treatment had a greater ($P < 0.001$) egg production and a greater ($P < 0.001$) egg mass output than the limited-time restriction treatment. Egg weight was greater ($P < 0.001$) for the two restriction treatments (TR and QR) than the *ad libitum* treatment, but the limited-time restriction treatment had a greater ($P < 0.001$) average egg weight than the quantitative restriction treatment for all of the physiological age periods tested (Table 3.15).

3.3.1.2.4 Egg classification

The quantities of eggs produced during Experiment 2 which were classified as abnormal (see Section 3.2.3.3) and expressed as a percentage (%) of the total number of eggs produced during ten 28 d periods after attainment of 10 eggs/100 hen d in each treatment are given in Table 3.16. The results obtained were very similar to Experiment 1. The incidence of abnormal egg production in egg producing birds (layers) was 34%, 8% and 15% for the first two 28 d periods in the *ad libitum*, limited-time

TABLE 3.16 The percentage of birds in egg production, the percentage of egg producing birds which laid an egg classified as abnormal and the production of abnormal eggs as a percentage of the total number of eggs produced during ten 28 d periods after attainment of 10 eggs/100 hen d in each treatment (Experiment 2).

Parameter[+]	Rearing treatment[2]	Period (28 d)[1]									
		1	2	3	4	5	6	7	8	9	10
Percentage (%) in egg production	1	59	97	98	98	97	98	97	99	97	98
	2	78	98	98	98	96	96	97	96	97	96
	3	75	100	100	100	100	100	100	100	100	100
Percentage (%) of egg producing birds which laid abnormal eggs	1	41	27	16	19	13	14	17	16	14	14
	2	8	8	9	11	11	13	21	18	19	22
	3	12	17	11	18	15	10	14	16	27	25
Percentage (%) of total eggs produced which were abnormal	1	18.1	9.2	3.6	3.8	2.9	3.1	3.8	4.6	3.8	4.5
	2	2.0	1.3	1.5	2.2	2.1	2.5	4.5	4.5	5.7	6.2
	3	2.3	3.1	2.1	3.7	3.0	2.1	3.3	3.2	5.8	6.8
Percentage (%) of total eggs produced with shell formation defects	1	13.0	4.6	1.2	0.6	0.5	0.6	0.6	0.5	0.5	0.9
	2	0.2	0.2	0.2	0.3	0.4	0.2	0.6	1.0	1.0	1.2
	3	0.1	0.9	0.6	1.6	1.0	0.9	0.8	0.6	1.2	1.5
Percentage (%) of total eggs produced with double yolks	1	4.4	3.6	1.1	0.3	0.1	0.0	0.0	0.1	0.0	0.0
	2	1.5	0.5	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0
	3	1.0	1.0	0.3	0.2	0.2	0.0	0.0	0.0	0.0	0.1
Percentage (%) of total eggs produced classified as 'other'	1	0.7	1.1	1.2	2.9	2.3	2.5	3.2	4.1	3.2	3.7
	2	0.3	0.6	1.2	1.7	1.8	2.4	3.8	3.6	4.7	5.0
	3	0.4	1.2	1.2	2.0	1.8	1.2	2.6	2.6	4.6	5.1

1 See Section 3.2.4 for details.

2 See Table 3.4.

\+ See Table 3.8.

and quantitative treatments respectively (Table 3.16). The average percentage (%) of all eggs produced which were abnormal during the ten 28 d periods was 5.7, 3.3 and 3.5 for the *ad libitum*, limited-time and quantitative treatments respectively. During the first two 28 d periods abnormal egg production averaged 13.7% of all eggs produced for birds on the *ad libitum* treatment. These were mainly shell-less eggs (Table 3.16). After the two initial 28 d periods the quantity of abnormal eggs gradually increased, particularly in the two restriction treatments (TR and QR). This was associated with an increased incidence of eggs with cracked shells or which were deformed (i.e. flat-sided). Similar to Experiment 1 the production of double yolk eggs was negligible in all treatments after the first two 28 d periods.

3.3.1.2.5 Feather score

Mean feather scores (±SD) for the *ad libitum*, limited-time and quantitative treatments determined at each age specified (see section 3.2.3.6) were as follows: (a) *276 d*, 2.33 (±0.86), 2.48 (±0.85), 2.36 (±0.89); (b) *289 d*, 2.54 (±0.80), 2.59 (±0.84), 2.65 (±.066); (c) *303 d*, 2.70 (±0.80), 2.79 (±0.78), 2.76 (±0.72); (d) *331 d*, 2.92 (±0.80), 3.09 (±0.80), 3.02 (±0.66); (e) *359 d*, 3.17 (±0.79), 3.30 (±0.68), 3.31 (±0.63); (f) *387 d*, 3.32 (±0.87), 3.40 (±0.60), 3.47 (±0.58); (g) *415 d*, 3.34 (±0.77), 3.45 (±0.60), 3.48 (±0.66); (h) *443 d*, 3.49 (±0.88), 3.67 (±0.77), 3.68 (±0.67). There were significant effects of treatments ($P < 0.05$) and age ($P < 0.001$) but no interaction between treatments and ages ($P > 0.99$). There were no differences ($P > 0.10$) between treatments at any specific age, but averaged over all ages the feather score was lower ($P < 0.05$) for the *ad libitum* treatment than either of the restriction treatments (TR and QR).

3.3.2 Gross energetic efficiency of egg production

Gross efficiency of egg production with respect to metabolisable energy (kJ egg output/kJ ME, %) can be calculated from the relevant data already presented. Because of this, and also because of the direct relevance of gross energetic efficiency to calculations in Chapter 6, this data is given in Appendix Table A3.4 for Experiment 1, and in Appendix Table A3.5 for Experiment 2 for nine and ten 28 d periods respectively from peak of egg production for individual treatments. Variation is shown over 7 d periods in Figure 3.4 for Experiment 1 and

in Figure 3.7 for Experiment 2. For nine 28 d periods from peak egg production in Experiment 1, both the restriction treatments (TR and QR) had a greater ($P < 0.001$) gross efficiency of egg production than the birds which were allowed *ad libitum* feed intake during rearing, and the limited-time treatment had a greater ($P < 0.001$) gross efficiency than the quantitative restriction treatment. In Experiment 2 similar differences were apparent between the *ad libitum* and restriction treatments (TR and QR) ($P < 0.001$) but there was no significant difference between the two restriction treatments (TR and QR).

3.3.3 Physiologic parameters (Experiment 1)

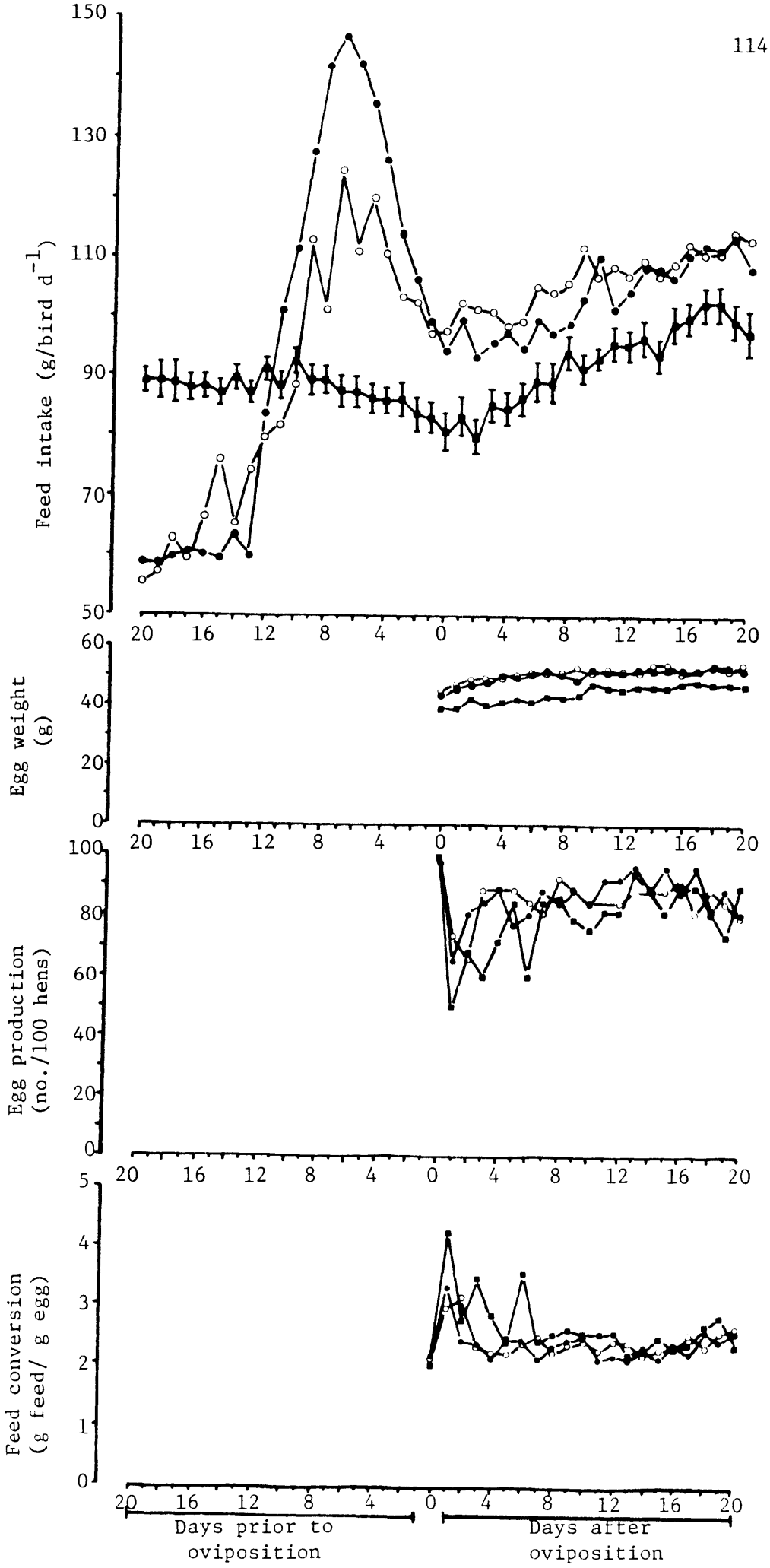
Feed intake (g/bird), egg weight (g/bird), egg production (number/100 hens) and feed conversion for egg production (g feed/g egg output) prior to and after sexual maturity (first oviposition) for individual birds are given in Figure 3.8. The number of birds which could be included in these analyses for each treatment were: *ad libitum*, N = 38; limited-time, N = 20; quantitative, N = 20. Only those birds which commenced egg production within the specified interval and which were on the layer diet were included. Birds which were previously selected for serial determination of starvation heat production (see Chapter 6), and those selected for slaughter at 162 d of age (see Chapter 5) were omitted. Also, a number of birds on the two restriction treatments (TR and QR) commenced egg production prior to cessation of restriction.

The main findings of this investigation are summarised below.

3.3.3.1 Feed intake

Feed intake began to decline 9 d prior to first oviposition in the birds on the *ad libitum* treatment, with a marked depression 2 d prior to-5 d after first oviposition. During this latter period (2 d prior to-5 d after) feed intake averaged 83.3 whereas during the period 9 d prior to-2 d prior to first oviposition feed intake averaged 87.3. Birds on the limited-time treatment had a maximum feed intake which was 18% greater than that of birds on the quantitative restriction treatment (146.7 versus 124.5 g/bird d^{-1}). At first oviposition, feed intake of the two restriction treatments (TR and QR) was on average 19% greater than that of the birds on the *ad libitum* treatment. After this, feed intake remained substantially higher for the two restriction treatments (TR and QR).

FIGURE 3.8: Feed intake (g/bird d^{-1}), egg weight (g) egg production (number/100 hens) and feed conversion (g feed/g egg) in relation to first oviposition (day zero) for birds which were either allowed *ad libitum* feed intake (■) or restricted by limited-time (●) or quantitative (○) methods during rearing. Vertical bars on the mean feed intake values for birds on the *ad libitum* treatment are standard errors of the mean (±SEM).


Feed intake (g/bird d^{-1})
150
130
110
90
70
50
Egg weight (g)
60
40
20
0
Egg production (no./100 hens)
100
80
60
40
20
0
Feed conversion (g feed/ g egg)
5
4
3
2
1
0
20 16 12 8 4 0 4 8 12 16 20
Days prior to oviposition
Days after oviposition

3.3.3.2 Egg production parameters

Birds on the restriction treatments (TR and QR) commenced egg production with a greater egg weight than those on the *ad libitum* treatment, and this difference (approxiately 5 g) was maintained during the period of measurement. The birds on the *ad libitum* treatment had an erratic egg production during the initial 7 d period after initial oviposition; this was associated especially with the finding that 50% of all birds measured on this treatment failed to produce an egg on the day immediately after initial oviposition. This effect was partially evident for birds on the two restriction treatments (TR and QR) but production for these birds stabilised within the first three days after initial oviposition.

3.3.3.3 Feed conversion

Feed conversion (g feed/g egg) was greater in the initial 6 d period after first oviposition for birds on the *ad libitum* treatment rather than the two restriction treatments (TR and QR). This was a direct reflection of the erratic egg production and lower egg weights for birds on the *ad libitum* treatment.

3.4 DISCUSSION

The techniques used to achieve nutritional deprivation during the rearing of egg production strains of poultry in these studies *viz.*, limited-time and quantitative feed restriction, resulted in major alterations in biological performance. Lee *et al.* (1971a) concluded that time limitation methods did not give adequate feed reduction. Although this was a valid conclusion with the available evidence, particularly with the techniques employed, the present study, and many other Australian studies (Cumming 1972; Moffatt and Unicomb 1974; McMahon *et al.* 1974; Connor *et al.* 1977b), have validated the use of time limitation as a method of nutrient restriction. In the experiments reported in this chapter the aim was to reduce the mean liveweight of birds on the restriction treatments at the stage immediately prior to commencement of egg production by approximately 20% relative to the liveweight of the birds allowed *ad libitum* feed intake during rearing. This aim was achieved in both experiments, but at the cessation of the restriction programmes the birds on the limited-time restriction treat-

ment had a lower liveweight than birds on the quantitative feed restriction treatment. In Experiment 1, this apparently occurred despite an 18% higher feed intake during the measured rearing period (114-163 d).

Feed conversion ratio is defined as the amount of feed required per unit of liveweight gain; in energetic terms the inverse is the gross efficiency of feed utilization. The factors which determine the feed conversion ratio are therefore the feeding level, the energy content of the liveweight gain and the efficiency of utilization of energy for growth. The feeding level is itself clearly dependent on the energy content of the diet and the metabolisable energy required for maintenance. Therefore, it was not surprising that a review of the published reports showed variable results for feed conversion ratios during the rearing period as influenced by nutritional treatment (see Chapter 1, section 1.5.3.2). Feed conversion ratio during rearing was either increased (Isaacks *et al.* 1960; Denton and Quisenberry 1963; Harms *et al.* 1968; Lee *et al.* 1971b; Watson 1976) or decreased (Berg *et al.* 1963; Bullock *et al.* 1963; Sherwood *et al.* 1969; Schumaier and McGinnis 1969; Powell and Gehle 1977) by controlled feeding restriction programmes during specified chronological age periods. Results derived from the literature (see Chapter 1, section 1.5.3.2), often with certain assumptions, showed that feed conversion ratio during rearing was dependent on the severity of the restriction imposed (see Figure 1.6). The results of Connor *et al.* (1977b) provide a good example of this effect. Similar results were obtained in the present study.

However the present studies also showed that on a chronological age basis the earlier sexual maturity of birds allowed *ad libitum* feed intake during rearing can have a confounding effect on the feed conversion ratio estimated over chronological intervals. A more appropriate indication of basic biological differences between treatments was gained by the comparison of feed conversion ratio up to sexual maturity. Feed conversion ratio during rearing up to age at sexual maturity was increased for birds on the restriction treatments, but the effect was only marginal. The reasons for the disparity between the chronological and physiological comparisons was the marked reduction in the feed

conversion ratio that occurred during the period of compensatory growth immediately after cessation of the restriction treatments. Two main factors are likely to account for this observation. The first is the level of feeding relative to the energy requirement for maintenance; the second is the large increase in body fat (g/kg W) which occurred in the period immediately after cessation of feed restriction (see Chapter 5). Deposition of body fat is an energetically efficient process (e.g. Pullar and Webster 1977).

The substantial increase in feed intake and the resultant compensatory growth that occurred after cessation of feed restriction is similar to that generally found in a range of animal species after prior nutritional deprivation (Osbourn and Wilson 1960; McManus *et al.* 1969; Thornton *et al.* 1979; Brody *et al.* 1980). The major factors which affect the degree of compensatory growth, regardless of species differences, are the severity, the duration, and the age of commencement of undernutrition (see Wilson and Osbourn 1960). The use of liveweight as the criteria for the assessment of the degree of feed restriction imposed (Cumming 1972) partially incorporates these factors. However in egg producing poultry the duration of feed restriction would probably directly affect the degree of compensatory growth by interacting with physiological stage. The interaction of duration of restriction and sexual maturity was identified as an important determinant of subsequent egg production (MacIntyre and Gardiner 1964; Connor *et al.* 1977b). This may be an area where the influence of lighting pattern could be particularly important.

It is therefore likely that the argument advanced by Cumming (1972) is valid but represents only a part of a complex series of inter-relationships which may ultimately determine subsequent egg production. The factors which determine the attainment of sexual maturity in animals, and the reasons why undernutrition causes a delay, are unclear (*rats:* Schenck *et al.* 1980; *poultry:* Brody *et al.* 1980). Although the severity of feed restriction predictably determines the feed intake and degree of compensatory growth that occurs after its cessation (Pym and Dillon 1974) there may be a relationship between the degree of compensatory growth which occurs, or which is allowed to occur, prior to or within a certain time interval relative to sexual maturity, and subsequent egg

production. In both the experiments reported in the present study, feed intake of the birds previously on the limited-time restriction treatment was greater immediately after the cessation of restriction than for birds previously on the quantitative restriction treatment (see Figures 3.2 and 3.6). This was probably, but not entirely, due to the greater liveweight reductions achieved by the former restriction treatment. Other factors to be considered in this regard would include differences between treatments in certain anatomical alterations (e.g. crop size). Comparison of the feed intake levels attained immediately after cessation of restriction between each of the experiments indicates a possible effect of ambient (shed) temperature on subsequent feed intake during this period, although a strain effect cannot be discounted. The importance of feed intake immediately after cessation of feed restriction and the relationship between it and sexual maturity needs to be investigated. For example, there may be an optimum duration of feed restriction in relation to commencement of egg production which allows sufficient liveweight gain prior to sexual maturity but which allows feed intake to be high at sexual maturity. Lighting pattern and ambient temperature would certainly interact in this regard.

Methods were used in the present studies to illustrate the major differences in interpretation of restricted feeding experiments on poultry which can occur by calculation of the production parameters on either a chronological or a physiological age basis. In both experiments, calculation of egg production on a chronological age basis from commencement of egg production in the birds allowed *ad libitum* feed intake during rearing, and which matured earlier, to the completion of the experiment (see Tables 3.4 and 3.11), gave a greater rate of egg production for these birds rather than birds on the two restriction treatments (with the exception of birds on the limited-time treatment in Experiment 1). Calculations on a physiological age basis reversed this effect, particularly for egg mass output. Many reports have acknowledged the influence of delayed sexual maturity on interpretation of results, but have presented only chronological details (e.g. Pym and Dillon 1974; Maclachlan *et al.* 1977b; Abu-Serewa 1978). The probable basis for which this practice is perpetuated is for commercial application of the results. However, in reality, it has long been recognised that the

practice of restricted feeding as applied to the commercial situation would involve certain managerial modifications, such as an extension of the time allowed in egg production facilities (e.g. Moffatt and Unicomb 1974). In the present studies, egg production and peak egg production were higher for birds on Experiment 2 than on Experiment 1 (see Tables 3.7 and 3.15). The fact that egg weights were also greater for birds on Experiment 2 resulted in a substantial increase in egg output for these birds compared with birds on Experiment 1. Such differences are probably genetically based because of the different genotypes used in the two experiments. However, importantly, restricted feeding during rearing significantly increased physiological egg output independent of the apparent genetic capabiltiy. The finding that limited-time feed restriction was superior in terms of production improvement in Experiment 1 but that quantitative feed restriction was optimal in Experiment 2 may be indicative of an interaction between genotype and type of restriction, but the present studies were not designed to consider this although there may certainly be a physiological basis for such an effect. The evidence for an effect of strain of bird was discussed previously (section 1.4.1, Chapter 1); the results recalculated from Proudfoot and Gowe (1967) clearly illustrated the effect of strain on response to feed restriction (see Figure 1.2, Chapter 1). Additionally there was a difference in treatment effects on feather cover between experiments (see sections 3.3.1.1.5 and 3.3.1.2.5).

One of the questions concerning the basis for an increased egg production due to prior nutritional deprivation which was unanswered by the literature on restricted feeding of poultry is whether the true rate of egg production in individual birds is increased, or whether the effect is due to a greater proportion of birds which commenced egg production or a reduced proportion of birds which ceased egg production with increased age. The present studies indicate that the latter effect may partially explain the increased rate of egg production which occurred in the previously restricted treatments (see Tables 3.8 and 3.16), particularly during the later stages of the egg production period. For example, in the ten 7 d periods from the age of 210 d in Experiment 1, the average egg production was 65.5, 76.2 and 68.7 eggs/100 hen d for the *ad libitum*, limited-time and quantitative treatments respectively;

inclusion of only those birds which were in egg production changed these figures to 72.6, 76.2 and 71.0 eggs/100 hen d for the three treatments respectively.

One of the major findings of the studies reported in this chapter was the increase in average egg weight due to feed restriction during rearing. Bullock *et al.* (1963), on the basis that egg weight was a function of chronological age, proposed a model which accounted for an increased average egg weight as found by some workers. The main proposal in this model was that heavier eggs are produced at peak of egg production, which therefore results in an overall greater average egg weight for birds which were previously on the restriction treatments. Lee *et al.* (1971a) discussed the necessity for egg weights determined on certain days only to be corrected for level of production. Such a procedure was not necessary in the present study because all eggs were weighed individually. Indeed the results obtained in the present study showed a change in the basic relationship between egg weight and age (Gilbert *et al.* 1978; Williams and Sharp 1978) due to prior nutritional treatment. Such an effect is likely to be due to a basic change in the follicular deposition of yolk (Williams and Sharp 1978), and is the main determinant of the increased egg mass output found in the present study for birds previously on restricted feeding treatments. Therefore, it was the main determinant of the observed increase in the gross energetic efficiency of egg production found for birds previously on the restricted feeding treatments. However this consideration ignores the possibility of a relationship between egg production and egg weight, such that the greater the rate of egg production the lower the egg weight. Clearly the most appropriate index of biological performance is not egg production or egg weight, but egg mass output. The reason for the observed increased egg weights for birds previously on rearing feed restriction in the present studies may be directly related to the greater feed intake of the birds. Australian diets typical of the diets used in the present studies (see Section 2.3, Chapter 2) were shown to be extremely low in linoleic acid (Balnave 1981). Assuming a linoleic acid content in the laying diet (Diet 2, Table 2.1, Chapter 2) used in the present studies, of 4.3g/kg (Srichai and Balnave 1981) the linoleic acid intake can be calculated from feed intakes (Tables 3.7 and 3.15 for Experiments 1 and 2 respectively) as: *Experiment 1*, 502, 526 and 510 mg/bird d^{-1}; *Experiment 2*, 524, 545

and 558 mg/bird d^{-1} for the *ad libitum*, limited-time and quantitative treatments respectively (calculated for equal periods after attainment of 50 eggs/100 hen d). These results suggest a direct relationship between feed intake and egg weight; for example, the lowest egg weight was at the lowest linoleic acid intake, and at approximately 525 mg linoleic acid/bird d^{-1} for the limited-time treatment on Experiment 1 and the *ad libitum* treatment on Experiment 2 the egg weights were identical at 60.1 g. Srichai and Balnave (1981) observed increases in egg weights of young pullets with linoleic acid intakes up to 2708 mg/bird d^{-1} over intakes at 655 mg/bird d^{-1}. There was also an interaction between linoleic acid content of the diet used during rearing and the response obtained to increased linoleic acid in the laying diet during egg production (see Balnave 1981). However the requirement during egg production for linoleic acid appears to be approximately 1000 mg/bird d^{-1} (Agricultual Research Council 1975). The low linoleic acid content of typical Australian rearing and laying diets was confirmed by independent analysis (R.B. Cumming, pers. comm.), and it is apparent that this represents a major area for future study on the effect of restricted feeding; certainly it would be interesting to determine the extent of the increase in egg weight which can be achieved in birds previously restricted during rearing. The variable results obtained on the influence of restriction on subsequent egg weight (see Lee *et al.* 1971a) may be due to variable linoleic acid intakes in the different experiments. The hypothesis put forward by Polin and Wolford (1973) that increased egg size following restriction may be due to an increased feed intake (see section 1.6.5, Chapter 1) may therefore be valid but only under certain dietary conditions.

The proportion of birds in egg production which laid abnormal eggs, and the proportion of total eggs produced which were abnormal, were substantially reduced by the feed restriction treatments imposed. Few studies have previously investigated this phenomenon adequately (e.g. Fuller *et al.* 1973). The production of abnormal eggs is directly related to age at sexual maturity (Lacassagne and Jacquet 1965; Lacassagne and Mongin 1965). The bias which can occur due to the omission of soft-shelled eggs or eggs without shells represented a hen-day rate of egg production of about 7% during the initial 7 d period of peak egg production for birds allowed *ad libitum* feed intake during rearing, in

both experiments. During the two initial 28 d periods after commencement of egg production in the *ad libitum* treatment the production of eggs with shell defects averaged 4.2 and 2.6 eggs/100 hen d for Experiment 1 and 3.8 and 3.7 eggs/100 hen d for Experiment 2 respectively. Production of such eggs by the birds which were on the restriction treatments, on a physiologic basis, was negligible. Abnormal egg production is therefore a very real consideration in the investigation of the biological effects of restricted feeding in poultry.

Gross energetic efficiency of egg production was improved by the feed restriction treatments used during the present study. Data derived from the literature showed no consistent effects of rearing feed restriction on subsequent feed conversion (g feed/g egg output) during the egg production period (see Chapter 1, Table 1.6), although some reports found a lower feed conversion ratio for previously restricted layer-type birds (e.g. Lillie and Denton 1966; Sherwood *et al.* 1969). However this parameter will also be confounded by a chronological analysis of results. The interesting aspect observed in both the experiments reported here was sudden drop in gross efficiency for birds on the *ad libitum* rearing treatment which occurred immediately after peak egg production. This represents a disparity between actual egg production or egg mass output and feed intake at this time for this treatment, and may indicate a disturbance in the regulation of feed intake *per se*. However the more probable explanation is a high incidence of internal laying, which occurs when ovulation is not followed by oviposition; up to 30% of the early ova may be missed by the oviduct due to some malfunction in synchronization (see review by Gilbert 1969).

The pattern of feed intake observed in individual birds which were allowed *ad libitum* feed intake (Experiment 1) was similar to that reported previously for birds approaching sexual maturity (Foster 1968a; Meyer *et al.* 1970; Hurwitz *et al.* 1971), although the 5% decline in the immediate period of first oviposition in the present study was not as great as in the studies cited above. Foster (1968a) found a 13% decrease in feed intake near sexual maturity, and Hurwitz *et al.* (1971) and Meyer *et al.* (1970) found a 20 to 30% decrease. The differences in the magnitude of the decrease in feed intake at sexual maturity between these studies and the present study may be due to factors such as strain of

bird, quality of diet and environment. Foster (1963a) showed significant effects of strain, but Meyer *et al.* (1970) found no consistent effects of calcium content of the diet in the period prior to sexual maturity on the magnitude of the observed decrease in feed intake at sexual maturity. The erratic egg production of birds on the *ad libitum* treatment in the present study immediately after sexual maturity agrees with the findings by Hurwitz *et al.* (1971). Feed intake and egg production of birds on the restriction treatments were in direct contrast to those of birds allowed *ad libitum* feed intake during rearing. In the 7 d period immediately after first oviposition the feed intakes were 84, 97 and 101 g/bird d^{-1} for birds on the *ad libitum*, limited-time and quantitative treatments respectively; corresponding egg outputs were 29, 39 and 41 g/bird d^{-1} respectively. With an assumed maintenance energy requirement of 450 kJ/kg $W^{0.75}$ d^{-1} (see Table 6.9) irrespective of treatment, the metabolisable energy available for production at approximate liveweights of 1830, 1746 and 1744 g respectively for the three treatments can be estimated as 335, 513 and 569 kJ/bird d^{-1}. Taking into account the observed levels of egg production, and on the assumption that egg energy was 6.7 kJ/g (see section 2.6, Chapter 2) produced with an efficiency of 70%, then the metabolisable energy available for growth can be estimated as 57, 136 and 177 kJ/bird d^{-1} for the *ad libitum*, limited-time and quantitative treatments respectively. If the maintenance energy requirement was 560 kJ/kg $W^{0.75}$ d^{-1} (see Table 6.8) then the metabolisable energy available for growth would change to -116, -31 and 10 kJ/bird d^{-1} for the three treatments respectively. These estimates may indicate the reason for the liveweight decline for birds on the *ad libitum* and limited-time treatments soon after commencement of egg production (see Figure 3.2), but must be treated cautiously due to the assumptions involved. With a maintenance requirement of 450 kJ/kg $W^{0.75}$ d^{-1} and with the above efficiencies and assumptions, the quantity of feed required, at a liveweight gain of 2 g/d for the *ad libitum* treatment and 6 g/d for the restriction treatments, would be approximately 83, 95 and 96 g/bird d^{-1} for the *ad libitum*, limited-time and quantitative treatments respectively. That these values are close to the observed feed intakes during the 7 d period immediately after first oviposition suggests that feed intake for birds on all treatments was regulated according to maintenance and production.

Summary

Two experiments were carried out to study the production responses of layer-type poultry to feed restriction during rearing. There were three feeding treatments during the rearing period in both experiments: (1) *ad libitum*; (2) limited-time restriction, and (3) quantitative restriction. Restriction was from 42-162 d of age and 56-168 d of age in Experiments 1 and 2 respectively. Genotype of the birds differed between experiments (Experiment 1: WL X A; Experiment 2: WL X NH) but environmental conditions were similar with increasing temperatures and lighting during rearing. Liveweight was reduced by 20% at cessation of feed restriction relative to birds allowed *ad libitum* feed intake during rearing. Mean age (d) of sexual maturity for birds on the *ad libitum*, limited-time and quantitative treatments was 148, 170 and 168 respectively in Experiment 1, and 149, 185 and 180 respectively in Experiment 2. Comparisons between treatments of subsequent egg production and egg output depended on method of analysis (chronological or physiological). Egg production calculated over equal physiological age periods was increased by feed restriction during rearing, but in Experiment 1 this was significant only for birds on the limited-time treatment. Due to the large increase in egg weight for birds on the restriction treatments, egg output was significantly increased for all restriction treatments on a physiological age basis. A hypothesis was advanced that the increased egg weight was due to a greater linoleic acid intake for birds on the restriction treatments. Rate of abnormal egg production was higher for birds allowed *ad libitum* feed intake during rearing. Feather cover deteriorated with age, and treatment effects were apparently reversed between experiments. Feed intake near first oviposition of birds on the *ad libitum* treatment decreased, and although it was substantially higher at this time for birds previously on the restriction treatments, it was concluded that this was directly related to the extra energy requirements for liveweight gain of these birds.