FUNDAMENTAL ASPECTS OF RESTRICTED FEEDING OF GROWING PULLETS ON PERFORMANCE IN LAY

R.J. Johnson.* R.B. Cumming* and D.J. Farrell*

Summary

The paucity of information on reasons for the increased efficiency of egg production by pullets which have been restricted-fed during rearing is discussed. Preliminary results are presented which form part of a detailed research programme aimed at elucidating the mechanisms responsible. Production responses of hens which had been restricted fed during rearing were similar to those expected. Egg production of individual pullets in the restricted-fed groups showed increased stability initially after first oviposition and maximum production was achieved more rapidly than in the *ad libitum*-reared pullets. Adiposity was reduced by restriction of feed intake during rearing. Starvation heat production appeared to be altered to some degree by rearing-period feed restriction. General conclusions from a single experiment such as reported in this paper must be tentative.

I. INTRODUCTION

Food restriction during the rearing of egg- or broiler- type pullets has often been shown to result in an improvement in egg production (see reviews by Lee, Gulliver and Morris 1971 and Balnave 1973). Research into this field is largely concerned with the actual method of restriction, the age at commencement and duration of restriction, or the interaction of restriction and lighting regime. Although there is a serious lack of information on biological alterations caused by undernutrition in the rearing period, the reasons for an enhanced reproductive performance, physiological measurements which could have provided relevant information to aid in the elucidation of the mechanisms responsible remain very few. Studies which have attempted to explain the improved laying performance attributed to restricted feeding, are those of Fuller and Dunahoo (1962) on basal' metabolic rate; Fuller, Potter and Kirkland (1969) on body composition; Hollands, Gowe and Morse (1965) on organ weights; Watson (1975) on reproductive organs; Gous (1977) on intestinal absorption; Balnave *et al*. (1978) on hepatic enzyme activities and fasting metabolic rate. Fundamental data on an individual basis can make a large contribution to nutritional research (Bornstein 1977) but no data are available on this aspect in relation to the performance of poultry after restriction of feed intake during the rearing period.

Restricted feeding results in marked alterations in carcass composition, due mainly to a decreased adiposity in the developing pullet and in the young laying hen. For many years it has been stated, particularly with regard to broiler-type layer pullets, that the amount of body fat must be reduced at sexual maturity or subsequent reproductive performance will be depressed (e.g. ARC 1975). Although there appears little doubt that this is so for broiler breeders, there have been few experiments to determine the correlation between body fat and reproductive performance, in general, for laying stock. Neil, Reichmann and Connor (1977) studied the significance of adiposity in egg-type pullets

*Department of Biochemistry & Nutrition, University of New England, Armidale, N.S.W. 2351

and found that obese hens utilized food less efficiently for egg production and produced fewer saleable eggs. Greenberg (1976) measured external fat by skin pinch and internal fat by a score method, then related these indices to egg production in White Leghorn hens. Hens with high rates of production had less internal and external fat than hens with low rates of production. Annison (1971) has stressed the overall importance of adipose tissue in energy metabolism, and research into adiposity and its controlling factors will assume increasing importance as food restriction during the laying cycle is advocated. Although there is much controversy concerning the effect of homeostasis in adipose tissue on food intake regulation in birds (Lepkovsky & Furuta 1971) its influence on reproductive efficiency remains largely unsolved. The major disadvantage of body composition studies is that experimental animals are by necessity killed. Farrell (1974) realized the importance of monitoring body composition in the live fowl, and showed that radioactive water (tritiated water) could be successfully used to estimate other body components in broilers, depending largely on the inverse relationship between body water and body fat. This technique has now been validated for the laying hen (Farrell and Balnave 1977), and could thus allow repeated body composition measurements to be made on pullets and laying hens.

Utilization of food for bodyweight gain is more efficient in rats when feed intake is restricted than given ad libitum. This may be due to a lowered basal metabolic rate and/or reduced activity. Leveille and O'Hea (1967) showed that meal-feeding (allowed only l-2 h feeding daily) in rats lowers activity level but not fasting heat production. However, in contrast to rats, chickens which are restricted-fed during rearing utilize feed less efficiently for body weight gain compared to full-fed controls. This is probably due to increased activity of restricted-fed pullets, with a consequent increase in the absolute amount of metabolisable energy used to support locomotory activity (Wenk and van Es, 1976). Fuller and Dunahoo (1962) and Balnave et al. (1978) measured the influence of rearing period restricted feeding on the starvation heat production (SHP) of pullets and laying hens, and although the former workers found a lowered SHP (kJ/kg/d) in most restricted-fed groups, the results, at least on a between- group comparative basis, must be treated with caution due to the extremely short SHP measurement period (10 to 15 minutes) and imprecise respirometer equipment. Balnave et al. (1978); using the more commonly accepted 22 h measurement period and more sophisticated equipment, found no differences in SHP ($kJ/kg^{0.75}/d$) that could be related to restricted feeding in the rearing period. Both studies were undertaken on a chronological-age basis, and thus ignore differences in the physiological age of birds caused by restricted feeding. These physiological-age differences could obscure true'differences between birds (Leeson and Porter-Smith 1970) in their response to restricted feeding.

Accurate prediction of food intake is essential for feed formulation and in order to allocate accurately food allowance when restriction is imposed during the laying period. Food intake is primarily a function of body weight, or metabolic weight, growth and egg output. McDonald (1977) has outlined a number of factors that can influence the accuracy of prediction equations (e.g. temperature, housing systems). He concluded that hens restricted during lay compensated for restriction by reducing maintenance requirement, but that energy metabolism of the adult bird was not affected when restriction occurred in the rearing period. Leeson, Lewis and Shrimpton (1973) indicated that prediction equations obtained for one strain of bird may not necessarily be applicable to another strain even though of similar bodyweight. There is an obvious requirement therefore not only for specific prediction equations, but also for these equations to account for factors other than bodyweight, growth and egg output which are known to affect the accuracy of predicting food intake.

A research programme currently in progress at the University of New England is aimed at investigating many of 'the features outlined above, and this paper presents the initial results of some of these studies. Fundamental data are given that describe the effect of restricted feed intake on pullets on an individual, physiological age basis. Results are presented which illustrate the principal of body composition prediction simply by obtaining an estimate of total body water. Since tritiated water is radioactive, for economic reasons, it cannot be used in a large-scale practical situation. We have therefore carried out experiments to determine the ability of a stable isotope of water, deuterium oxide, to estimate total body water in the fowl. Prediction equations, once established, will be used to study body composition changes during the rearing and laying periods to determine the influence of body composition and the importance of restricted feeding on this parameter. An experiment is also in progress which is monitoring, at intervals, changes in starvation heat production on a physiological-age basis due to restricted feeding during rearing. The opportunity was taken to derive food intake prediction equations which could aid in elucidation of the factors involved in the increased reproductive efficiency of hens restricted during the rearing period.

II. EXPERIMENTAL

Nine hundred and sixty-five egg-type pullets (White Leghorn x Australorp) hatched in September 1977 and reared to 6 weeks of age under commercial conditions were housed in deep-litter pens and fed either ad libitum or on a limited-time basis (30 h feed in 72 h) up to 14 weeks of age. At 14 weeks 50 pullets from the ad libitum group and 100 pullets from the restricted-fed group were randomly selected and placed in single cages which were fitted with individual feeders and side baffles to prevent cross-feeding. Three groups were formed and housed in a galvanised iron shed fitted with ventilating flaps on the sides : Group 1 - ad libitum fed; Group 2 - limited-time feeding continued; Group 3 - received a weighed daily allowance of 60-70% of Group l's daily feed consumption (Table 1). Lighting was normal day length during rearing and artifically increased up to 17 h/d from 167 to 282 d of age. A growers mash of 12.6 MJ Metabolizable energy (ME)/kg and 160 g protein/kg (Fielders, Tamworth) was fed from 6 to 22 weeks of age, and a layers mash of 12.4 MJ ME/kg and 160 g protein/kg, thereafter. Feed intake was measured on an individual bird basis each day from 109 to 221 d of age and was then measured on a 7-d basis. Eggs were collected and weighed daily, with special attention being given to recording any abnormal eggs. Birds were weighed at regular intervals. Maximum and minimum temperatures were recorded daily.

Representative birds were taken at different stages of growth to study body composition changes with age and the influence of nutritional treatment. Concurrently these birds, in addition to others, were used

TABLE I Feeding treatments imposed during the rearing and laying periods

Group	Feeding treatment		
	Age: 6 to 15 weeks	15 to 23 weeks	23 weeks onwards
1. Ad libitum	Ad libitum	Ad libitum	Ad libitum
2. Limited-time restriction	Limited-time	Limited-time	Ad libitum
3. Quantitative restriction	Limited-time	Quantitative	Ad libitum

to establish prediction equations for body composition based on isotope dilution techniques. Following a 2 h fast, birds were injected with a known amount of tritiated water and/or deuterium oxide and a blood sample taken after equilibration (3h). Water space, estimated as either tritiated water space (TOH) or deuterium oxide space (D20) was determined by the relationship : Equilibrium concentration of isotope = amount of isotope injected ÷ amount body water. Birds were killed by cervical dislocation, frozen, coarsely chopped in the frozen state and ground to produce a mince. The liver was removed at time of slaughter and analysed separately. Dry matter, fat, protein and ash were determined for each bird using standard analytical procedures.

Starvation heat production (SHP) was determined in respiration chambers (Farrell 1972) prior to first oviposition (pre-lay, period 1), at the time of first oviposition, (sexual maturity, period 2), at 28 d after first oviposition (peak production, period 3), at 98 d after first oviposition (post-peak production, period 4). Birds were placed in darkened respiration chambers 24 h after removal of food, and after a 2 h adjustment period SHP was measured over 22 h. All measurements were carried out at 22^{o}C and at a relative humiditv of less than 80%.

Computerized multiple linear regression techniques were used to establish feed intake prediction equations on a 28-d basis for each period beginning when the birds were approximately 31 weeks of age.

III. RESULTS AND DISCUSSION

(a) Egg production, feed intake and bodyweight

Overall results are presented in Table 2 and the pattern of egg

TABLE 2 Effect of rearing period restriction (42 to 163 d) on food intake, body weight and sexual maturity. Values in parenthesis are relative (%) to the ad libitum-group.

Group	Food intake (kg/bird)	Bodyweight (kg/bird)		Age at Sexual Maturity (d)
Age (d):	109-163	114	163	
1. Ad libitum	4.87	1.48	1.81	146
2. Limited-time	3.27 (67)	1.31 (89)	1.46 (81)	168
3. Quantitative restriction	2.97 (61)	1.35 (92)	1.51 (84)	165

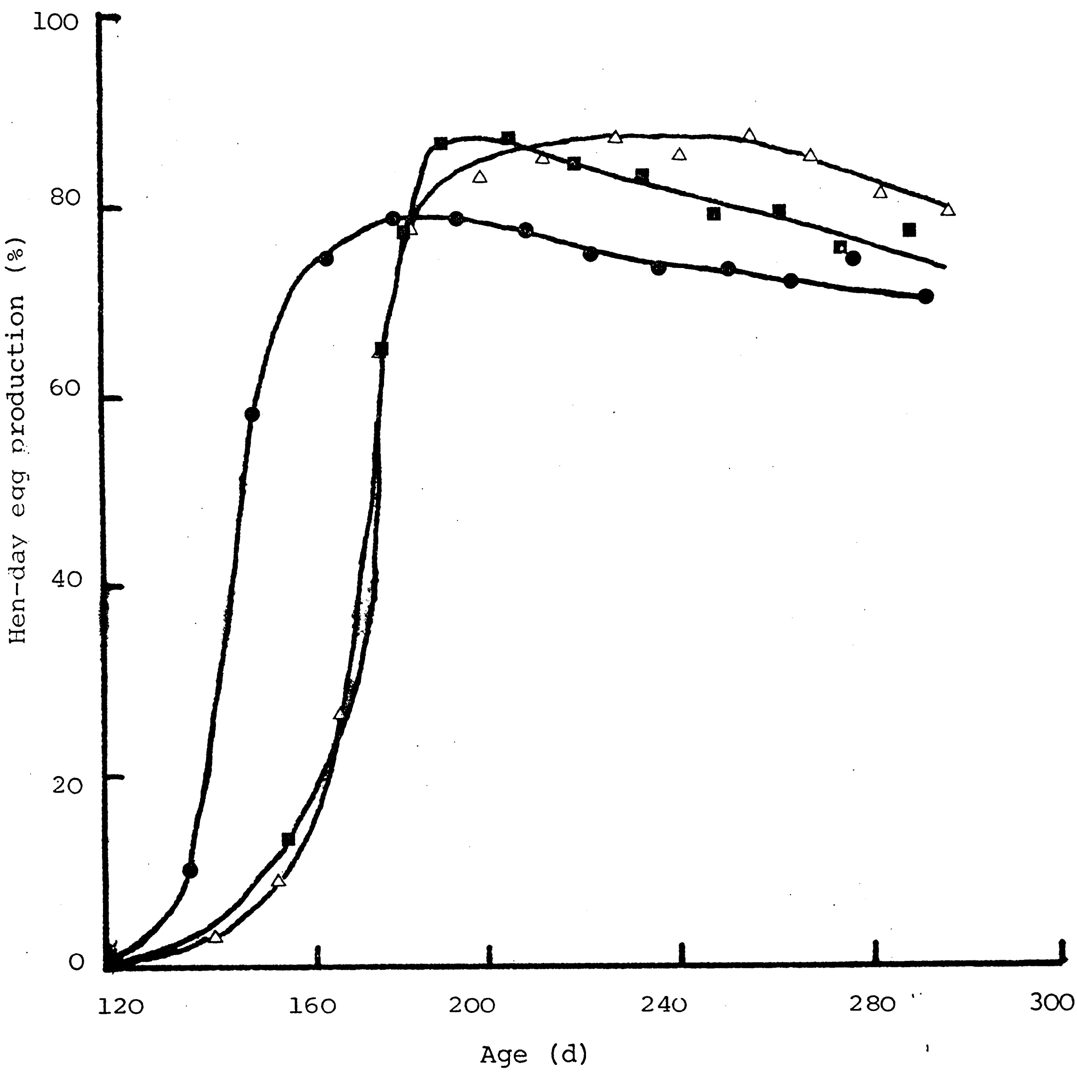

Fig. I Percentage egg production (H-D basis) of birds fed either ad libitum (●), on a limited-time basis (△) or quantitatively restricted (■) during rearing.

production is shown in Figure 1. Unfortunately group feedintakes are not available for the 6-15 week period when the pullets were reared at the University Poultry Farm. The main effects of the treatments imposed in this experiment on feed intake, liveweight and egg production can besummarised as follows :

(i), Feed intake (109-163 d) was reduced-by 33 and 39% for the limited-time and quantitative restriction groups respectively compared to the ad libitum group consumption. The sudden increase in feed intake which occurred when restriction was lifted is similar to the responses normally observed in pullets of this type after rearing restriction (Connor, 1976).

(ii). Bodyweights at the end of the restriction period (163d) were reduced by 19 and 16% respectively. The majority of the restricted-fed birds reached sexual maturity within 7 d of lifting restriction. During this time bodyweight gain was approximately 30-40 g/d compared to 3 g/d for the *ad libitum*-fed group over this period (163-170 d) or 5 g/d at a similar physiological age (142-151 d). However, bodyweights of the restricted-fed groups are still 3-5% lower than *ad libitum* reared hens (276 d).

(iii), Both groups which had been restricted during rearing had a peak of egg production which was 7-8 percentage units greater than the *ad libitum*-reared group, and a superior rate of production is being maintained up to the present time. Shelless and weak-shelled eggs accounted for the larger percentage of abnormal eggs which were laid by the *ad libitum* reared group in the initial and peak stages of lay. The amount of double-yolked eggs, weak-shelled eggs and shelless eggs is directly related to age at sexual maturity (Lacassagne & Jacquet 1965), and represent a serious economic loss to the industry.

When results are expressed on a physiological-age basis rather than on a chronological-age basis, as in Figures 2 and 3, a clearer indication of the effect of restricted feeding during rearing on the ensuing performance of young pullets emerges :

(iv). All pullets showed the now well-known depression in food intake (Foster 1968, Meyer, Babcock and Sunde 1970; Hurwitz, Bornstein & Lev 1971) as they approached sexual maturity, although this varied depending on the nutritional treatment by which pullets were reared. Feed intake increased up to 10 d prior to sexual maturity for the *ad libitum*-reared pullets, then began to decrease slowly to 3 d before, then declined sharply to reach minima at first oviposition and 2 d after first oviposition. This was followed by a slow increase over the following 18 d. Pullets restricted during rearing showed a similar pattern as sexual maturity approached, except the magnitude of the decreased food intake was greater due to the marked hyperphagia which occurred when restriction was lifted. The pullets reared-under limited-time feeding showed minima in food intake at first oviposition and 2 d after, similar to *ad libitum*-reared pullets. Actual consumption was 17-21% greater at first oviposition in the restricted reared groups than in the *ad libitum*-reared groups.

(v). Egg production of the *ad libitum*-reared hens showed a variable and fluctuating pattern during the initial 7 d of production which was remarkably similar to that observed by Hurwitz *et al.* (1971). In contrast, pullets which had been restricted during rearing showed a decrease in production on the day after first oviposition, but attained maximum production within 2-4 d after first oviposition. Average egg weight was greater for restricted-fed pullets and increased to reach a plateau within 7 d whereas required 10 d for the pullets which were reared *ad libitum*. Gross efficiencies of egg production (g egg/g feed) showed that restricted-reared pullets attained maximum efficiency of production within 3-4 d after initial oviposition. This was due to these pullets (i) reaching maximum egg production very rapidly after first oviposition, and (ii) laying heavier eggs at sexual maturity and thereafter.

Coefficients obtained for the multiple linear energy intake prediction equations are given in Table 3 for the first two 28 d periods of measurement. Indications are that maintenance energy requirement was

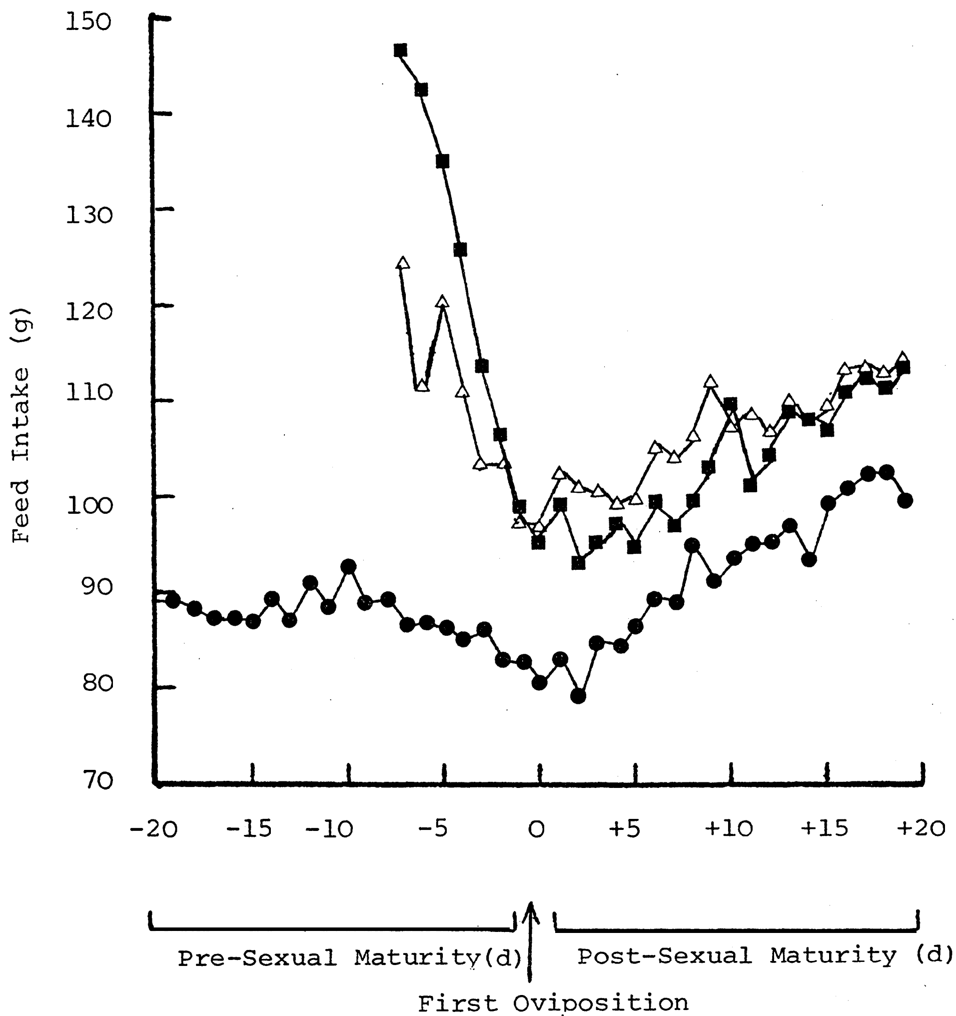

Fig. 2. Changes in feed intake associated with sexual maturity in birds fed either ad libitum (●), limited-time (■), or quantitatively restricted (△) during rearing.

increased in hens which had been restricted-fed during rearing, but that these hens convert metabolisable energy in the feed into egg energy more efficiently. Maintenance energy requirements increased in all groups in period 2 undoubtedly because of the decrease in environmental temperature at this time. Temperature has been linearly regressed only for illustrative purposes since the relationship between energy intake and temperature is not linear (Emmans 1974).

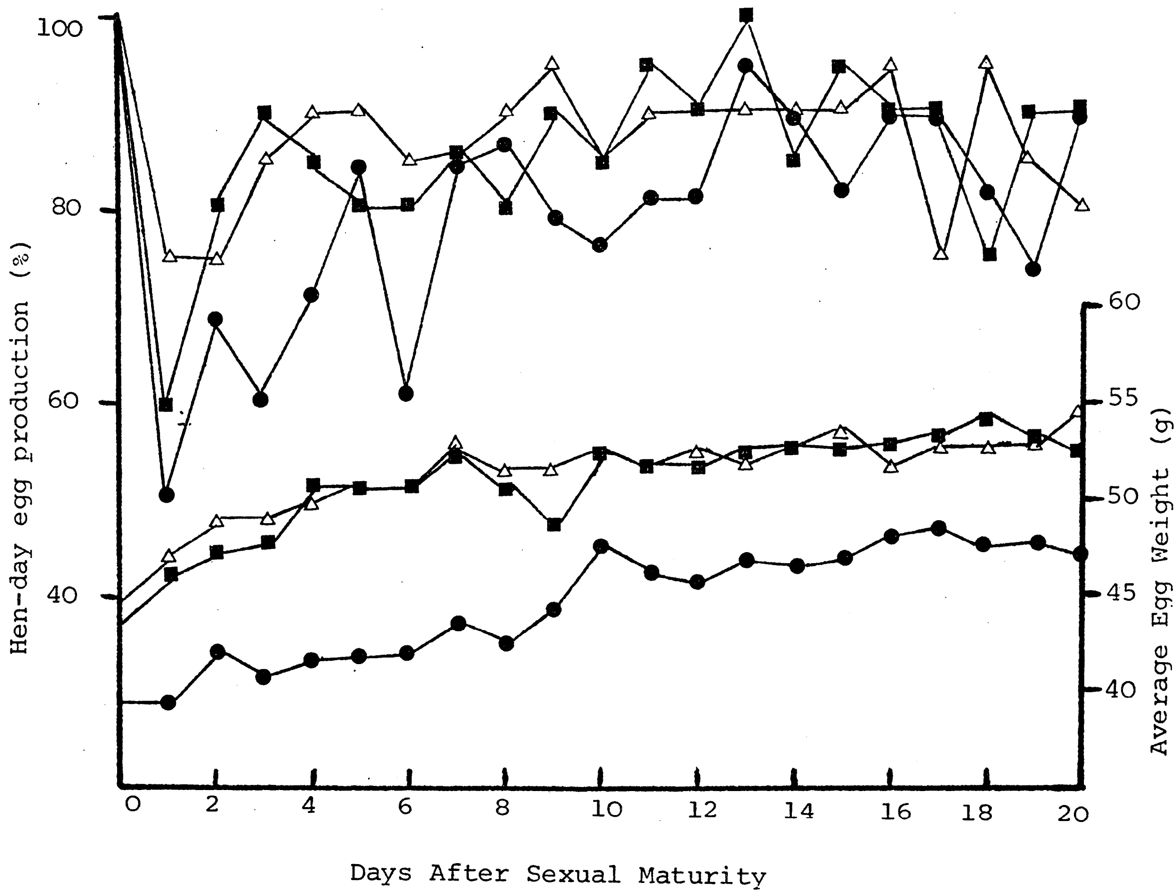

Fig. 3. Egg production and average egg weight after sexual maturity. Ad libitum (●), Limited-time (■), Quantitative-restriction (△).

(b) Carcass and liver compositions

The effects of rearing period nutrition on carcass and liver composition at varying times during the rearing and laying periods are shown in Table 4 and Table 5. Results indicate that restricted-feeding of birds caused changes in both carcass and liver composition, as was expected.

Pullets which had been restricted during rearing had a markedly lower carcass fat content at the age when restriction (163 d) was lifted than when ad libitum food intake was allowed, the magnitude

TABLE 3 Energy intake prediction coefficients, where $W^{0.75}$ = metabolic body weight (kg), ΔW = weight change (g/d), E = egg output (g/d), T = average of maximum and minimum temperature

(a) With Constant/With Temperature

Period	Age (d)	Group	Intercept	$W^{0.75}$	ΔW	E	T
1	221-249	Ad libitum	162.7	630.6	1.7	10.7	-19.4
		Limited	425.9	520.4	22.6	7.3	-15.9
		Quantitative	45.3	782.8	-0.4	6.0	-10.9
2	249-277	Ad libitum	-316.4	780.6	23.7	10.2	1.4
		Limited	- 26.5	774.0	-7.4	6.2	- 0.1
		Quantitative	- 7.1	683.6	24.2	7.6	- 2.3

(b) Without Constant/Without Temperature

Period	Age (d)	Group	$W^{0.75}$	ΔW	E
1	221-249	Ad libitum	588.8	2.0	10.5
		Limited	630.7	18.6	8.6
		Quantitative	736.5	-0.3	5.6
2	249-277	Ad libitum	624.0	26.8	9.3
		Limited	763.0	-7.2	6.0
		Quantitative	668.4	24.5	7.5

TABLE 4 Bodyweight and total carcass composition of representative (N = G/group/time) pullets and hens as influenced by rearing period treatments expressed on a dry-matter (DM) and wet-matter basis)

Age	Treatment	Bodyweight(g)	Protein (mg/g DM)	(mg/g carcass)	Ether Extract (mg/g DM)	(mg/g carcass)
39	Ad libitum	422.6	705.1	215.3	133.1	40.6
70	Ad libitum	832.8	608.7	217.3	268.2	95.7
	Limited-time	780.8	611.1	211.3	250.0	86.4
98	Ad libitum	1169.8	659.6	228.9	220.0	76.3
	Limited-time	1075.5	625.0	215.0	235.4	81.0
163	Ad libitum	1817.0	462.1	203.5	353.6	155.7
	Limited-time	1540.1	518.0	212.9	314.5	129.3
	Quantitative	1404.2	508.7	212.5	313.4	130.9
218*	Ad libitum	1842.3	451.4	203.4	460.8	207.6
	Limited-time	1743.2	464.1	213.1	438.3	201.2
	Quantitative	1757.0	478.5	210.2	424.0	186.2

* Values uncorrected for liver composition

of reduction being similar irrespective of the type of restriction programme. Enlargement of the abdominal fat pad appeared to be decreased in the restricted-fed birds (personal observation). Carcass fat content continued to be reduced in the restricted-fed birds at 31 weeks of age, particularly in the group which was quantitatively restricted in food intake from 15-23 weeks of age.

TABLE 5 Effect of age and rearing treatment on liver weight and liver composition in growing and laying pullets

Age	Treatment	Liver weight (g)	(g/kg body weight)	Protein (mg/g DM)	(mg/g liver)	Fat (mg/g DM)	(mg/g liver)
39	Ad libitum	11.3	26.7	744.0	196.0	127.2	33.5
70	Ad libitum	16.8	20.2	661.3	178.7	135.6	36.6
	Limited-time	18.0	23.1	692.2	185.9	114.1	30.6
98	Ad libitum	21.0	18.0	690.6	187.0	171.8	46.5
	Limited-time	21.6	20.1	669.4	172.8	177.8	45.9
163	Ad libitum	34.1	18.8	593.0	190.4	262.4	84.3
	Limited-time	39.1	25.4	396.6	147.1	282.8	104.9
	Quantitative	25.4	18.1	622.0	184.7	183.0	54.4

Pullets which were restricted in their time of access to food had both an increased liver weight relative to bodyweight and liver lipid content when compared to the other two groups. Intermittent starvation in rats (e.g. Fabry et al. 1962) and chicks (Simon and Brisson 1972) has been shown to cause an enhanced hepatic lipogenesis, and the results reported here substantiate these findings and in addition indicate that the increased liver fat content may be specifically related to the type of restricted feeding rather than restricted feeding per se.

Determined total body water (TBW,g) was related to tritiated water space (TOH, g) by the equation :

(1) TBW = 0.36 + 0.91 TOH (r = 0.99) (N = 76)

A simple linear regression equation of tritiated water space (independent variable) on total body fat content (dependent variable) determined on 94 pullets and laying hens indicates the excellent inverse relationship which exists over a wide range of bodyweights and nutritional treatments :

(2) Body Fat (% of carcass) = 74.78 - 0.92 TOH (% of carcass) (r=- 0.92)

Although it is possible to estimate body fat content in the live fowl using tritiated water, the non-radioactive deuterium oxide has the major advantage that it can be used in large-scale practical experiments. The results from an experiment in which both tritiated water and deuterium oxide were injected simultaneously into laying hens (N = 16) (figure 4) indicate that deuterium oxide can be used with a high degree of accuracy to determine TBW in the fowl. Both isotopes over-estimated TBW, but by different extents. Tritiated

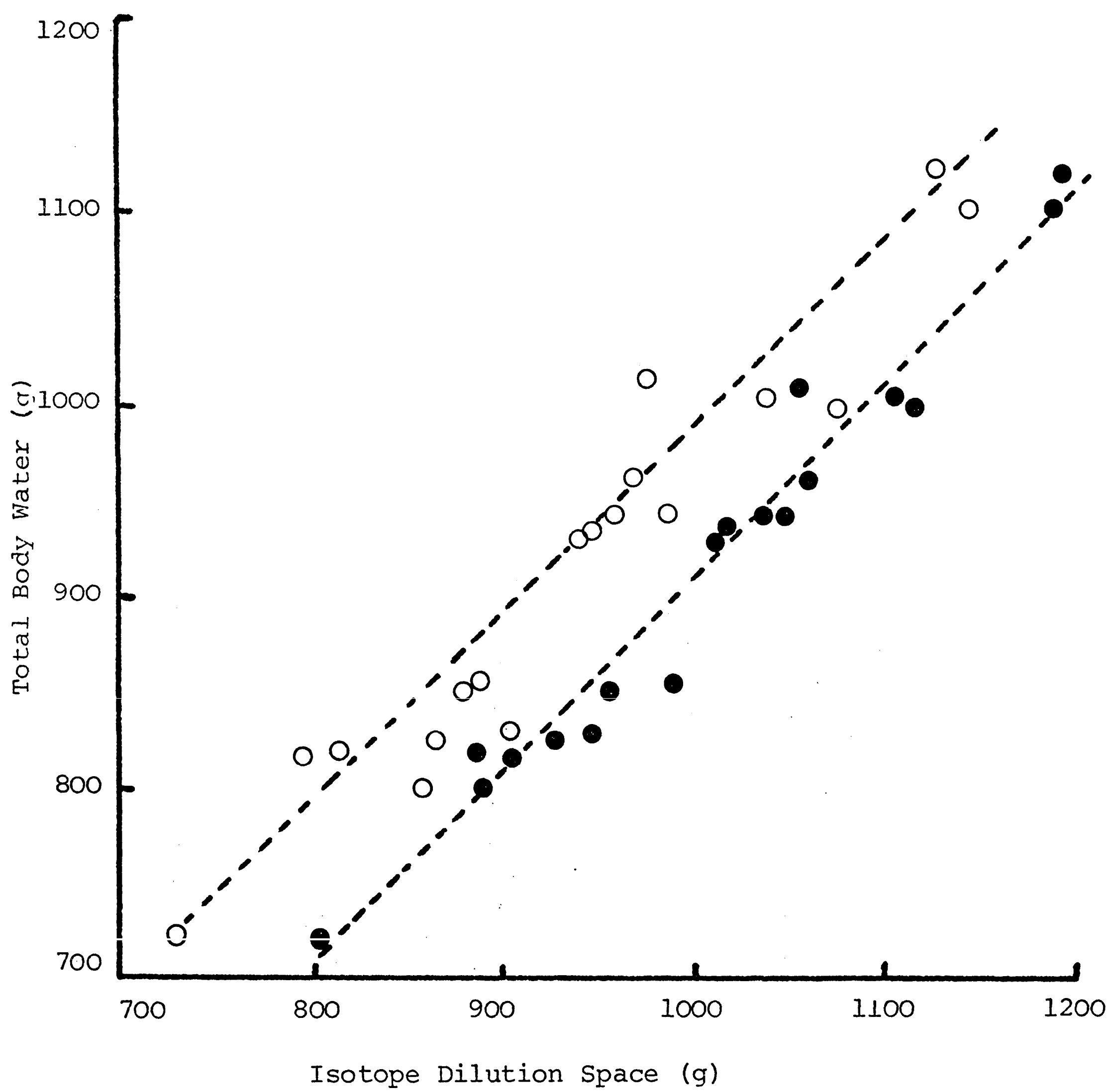

Fig. 4. Relationship between determined total body water and that predicted from tritiated water space (●) and deuterium oxide space (O).

water space was approximately 10% greater, and deuterium oxide water space 3% greater than determined TBW in this experiment.

(c) Starvation heat production

Results given in Table 6 show that SHP significantly increased from pre-lay to post-peak production independent of rearing treatment.

TABLE 6 Starvation heat production (SHP) of representative pullets (6 birds/group) and laying hens either-fed *ad libitum* or restricted-fed during rearing, on a physiological-age basis

	Bodyweight			SHP kJ/kg/d			SHP kJ/kg$^{0.75}$/d		
	Ad lib.	Ltd.	Qr.	Ad lib.	Ltd.	Qr.	Ad lib.	Ltd.	Qr
Period*									
1	1627	1337	1338	271	272	288	305	292	310
2	1733	1743	1638	270	288	276	309	331	312
3	1697	1722	1638	305	304	291	348	347	329
4	1797	1894	1820	308	326	296	356	382	344

* 1. Pre-lay, 2. Sexual maturity, 3. Peak production, 4. Post-peak production

SHP substantially increased after attainment of sexual maturity. Birds which were limited-time reared showed a further increase in SHP after peak-production. These birds had a much higher rate of lay than did the other two groups at post-peak production, which could cause a higher SHP since Balnave *et al.* (1978) showed that laying hens have an increased SHP due to egg synthesis alone and not to any direct effect of oestrogen on metabolic rate. Energy expenditure due to synthetic processes and mechanical movements associated with egg production would be expected to depend on the rate of egg production (Balnave 1974).

IV. CONCLUSIONS

This paper has given preliminary details of an experiment designed to investigate the effects of restricted feeding of egg-type pullets in terms of reproductive efficiency, body composition and metabolic rate. The results, encouraging as they are, relate only to a single experiment carried out under defined conditions, so caution must be exercised in drawing overall conclusions. The particularly interesting aspects of this study were: (i) The more consistent and rapid rise to peak of egg production after attainment of sexual maturity in the restricted-fed pullets, (ii) the significant reduction in adiposity at commencement of lay of the restricted-fed pullets, in conjunction with changes in liver-lipid levels, perhaps contributing to the enhanced reproductive efficiency obtained, (iii) an indication that starvation heat production is altered in hens restricted-fed for a limited time during rearing. Experiments principally concerned with body composition using prediction equations outlined in this paper, and energy metabolism using open-circuit indirect respirometers will form the basis of future work aimed at elucidating the mechanisms responsible for an enhanced reproductive efficiency in pullets subjected to undernutrition during rearing.

V. ACKNOWLEDGMENTS

We thank Mrs. A. Choice for technical assistance, and Mr. J. Wolfenden for some of the blood sampling.

VI. REFERENCES

ANNISON, E.F. (1971). "Physiology and Biochemistry of the Domestic Fowl" (London, Academic Press)
AGRICULTURAL RESEARCH COUNCIL (1975). "The Nutrient Requirements of Farm Livestock. Report No. 1 Poultry" 1st Ed. (London, Agricultural Research Council)
BALNAVE, D. (1973). Wld's Poult. Sci. J. 29 : 354
BALNAVE, D. (1974). "Energy Requirements of Poultry" (British Poultry Science Ltd., Edinburgh)
BALNAVE, D., FARRELL, D.J., CUMMING, R.B. and WOLFENDEN, J. (1978). Poult. Sci. (submitted for publication)
BORNSTEIN, S. (1977). "Recent Advances in Animal Nutrition". (University of New England Publishing Unit, Armidale)
CONNOR, J. (1976). "Birds Should Be Controlled Fed" (Department of Primary Industries, Queensland)
EMMANS, G.C. (1974). "Energy Requirements of Poultry" (British Poultry Science Ltd., Edinburgh)
FABRY, P., PETRASEK, R., BRAUN, T., BEDNAREK, M., HORAKOVA, E. and KONOPASEK, E. (1962). Experientia (Basel) 18 : 555
FARRELL, D.J. (1972). Poult. Sci. 51 : 683
FARRELL, D.J. (1974). "Energy Requirements of Poultry" (British Poultry Science Ltd., Edinburgh)
FARRELL, D.J. and BALNAVE, D. (1977). Br. Poult. Sci. 18 : 381
FOSTER, W.J. (1968). Br. Poult. Sci. 9 : 367
FULLER, H.L. and DUNAHOO, W.S. (1962). Poult. Sci. 41 : 1306
FULLER, H.L., POTTER, D.K. and KIRKLAND, W. (1969). Poult. Sci. 48 : 801
GOUS, R.M. (1977). Br. Poult. Sci. 18 : 511
GREENBERG, H. (1976). Ph. D. Thesis, Iowa State University
HOLLANDS, K.G., GOWE, R.S. and MORSE, P.M. (1965). Br. Poult. Sci. 6 297
HURWITZ, S., BORNSTEIN, S. and LEV, Y. (1971). Poult. Sci. 50 : 1889
LACASSAGNE, L. and JAÇQUET, J.P. (1965). Ann. Zootech. 14 : 169
LEE, P.J.W., GULLIVER, A.L. and MORRIS, T.R. (1971). Br. Poult. Sci. 12 : 413
LEESON, S. and PORTER-SMITH (1970). Br. Poult. Sci. 11 : 275
LEESON, S., LEWIS, D. and SHRIMPTON, D.H. (1973). Br. Poult. Sci. 14 : 595
LEPKOVSKY, S. and FURUTA, F. (1971). Poult. Sci-50: : 573
LEVEILLE, G.A. and O'HEA, E.K. (1967). J. Nutr. 93 : 541
McDONALD, M.W. (1977). "Technical Publication No. 1" (Queensland Agricultural College)
MEYER, G.B., BABCOCK, S.W. and SUNDE, M.L. (1970). Poult. Sci. 49 : 1164
NEILL, A.R., REICHMANN, K.G. and CONNOR, J.K. (1977). Br. Poult. Sci. 18 : 315
SIMON, J. and BRISSON, G.J. Can. J. Physiol. Pharmacol. 50 : 634
WATSON, N. (1975). Br. Poult. Sci. 16 : 259
WENK, C. and VAN ES, A.J.H. (1976). "7th Symposium on Energy Metabolism" (E.A.A.P. Publication No. 19).