LIFE-CYCLE FEEDING PROGRAMS FOR EGG PRODUCTION

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SUMMARY

Feeding management of egg laying strains involves both feed formulation. and feeding strategy. Life-cycle programs should be developed at day-of-age and be geared to desired production goals in the layer barn. Manipulation of juvenile growth can be accomplished in relation to these goals, the main parameters being mature body weight and age at sexual maturity. Growth of the immature pullet, especially approaching age at first egg, is very responsive to energy intake. Maximising energy intake at this time is not always easy, and choice of diet energy concentration may be dependent upon other management decisions, and especially environmental temperature. The feeding strategy during growth is usually aimed at maximising weight for age, although this may be less important where egg mass output rather than egg size per se is of economic significance. During the prelay period, there may be need to consider specialized diets, although this relates only to calcium level, and especially in situations of high environmental temperature. Feed programs for adult layers must be geared towards expected feed intake. During early production this can be problematic, due to reduced appetite. Egg production seems most responsive to energy intake while protein and amino acid intake seem more critical for maintaining egg size.

INTRODUCTION

The life-cycle of the modern laying hen is traditionally divided into an 18-19 week growing cycle and a subsequent 60-70 week period of egg production. Unfortunately these two phases are often considered in isolation, especially when birds are physically relocated prior to maturity. It is now obvious that body weight and body composition at maturity have such an overwhelming effect on subsequent layer performance, that true life-cycle feeding and management programs are most appropriate. With very rapid onset of egg production, it is now very difficult to manipulate pullet development after light stimulation, and this is especially true when factors such as high environmental temperature have negative impact on feed intake. Attaining desired mature body status of the pullet is, therefore, most easily achieved from manipulation of nutrition and management throughout the entire juvenile period. While most producers will strive to attain production goals suggested by the primary breeder, there is potential for manipulation of mature body size and composition so as to influence economically important criteria such as egg size. The following discussion outlines nutritional management of the laying hen from day of age, with a view to influencing various characteristics of economic importance during the egg production cycle.

Immature growth

General nutritional considerations Nutritional management of the immature pullet must ultimately be geared to optimizing adult performance. However criteria must be established during this juvenile development such that progress can be monitored and

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manipulated. For this reason **body weight becomes the major criterion in assessing** pullet growth.

In developing life cycle nutritional programs for birds, it is generally accepted that the major potential problem will occur around peak production, where energy insufficiency may result from limited physical appetite. In most instances, therefore, the goal of the growing program is to maximise growth of Leghorn birds, and/or to achieve idealised breeder goals for heavier-weight brown-egg strains. One of the most common situations seen today with egg laying stock, is reduction in egg production immediately following peak output (Fig. 1). Such losses in production are commonly due to negative energy balance predisposed by a combination of small appetite and reduced body mass/fat reserves. This scenario is now complicated by the fact that most strains of pullets are maturing at earlier ages.

In manipulating growth of pullets, consideration of energy, protein and amino acid intakes is of prime importance.

Nutrient intake Since pullets eat to energy requirement with fair precision when offered diets of varying energy content, there is some debate as to the appropriate energy levels of various diets, especially in relation to prevailing environmental conditions. Cunningham and Morrison (1976) and Leeson and Summers (1984a) concluded that pullet growth was quite acceptable when low-energy diets . were used. However with high barn temperatures there may be need to increase energy density (Leeson 1986 a,b; Leeson and Summers 1989). McNaughton et al. (1977) reported the difficulty commercial producers experienced in realizing required 20 week weights in summer months, relating this to inadequate levels of metabolizable energy in the diet. They reported higher energy intakes with higher levels of metabolizable energy in the diet, although high energy intakes were not always accompanied by more growth. With pullets identified as being small at 12 wk of age, these same authors show little differential bird response to diets of 3,100 kcal ME/kg and 20% CP vs diets of 2,700 kcal/kg and 14% CP. The above results are similar to those reported by Leeson and Summers (1984b), where genetically small pullets in a population failed to respond to comparable dietary manipulation. Another factor that may confound experiments involved with the use of high energy diets is inadequacy of protein or amino acid intake. For example, Leeson and Summers (1982, 1985) indicate poor growth rate of pullets fed high energy-low protein diets, relating this effect to a deficiency of protein As the bird's appetite control is governed mainly by energy intake, high energy diets usually reduce feed intake. Leeson and Summers (1982) report a cumulative protein intake of less than 1 kg for the small-weight pullet, which is much lower than that required to maximize body weight gain (Leeson and Summers, 1989).

It is likely that the pullets requirement for protein (amino acids) is increased (as a percentage of the diet) in hot weather conditions. Lodhi et al. (1975) suggest the protein requirement of pullets at 32 and 20 C mean environmental temperatures to be 18.5 and 15% CP, respectively. Leeson and Summers (1981) indicate that early growth rate of pullets reared in warm environments can be improved by providing higher concentrations of protein in the diet. Under more moderate temperatures, Leeson and Summers (1981) show a 4% increase in 8-wk body weight as a result of a 61% increase in protein intake. - However, in a warm environment, a 30% increase in protein intake resulted in a 10% increase in body weight. Stockland and Blaylock (1974) likewise concluded that the pullet's protein requirement in terms of dietary specifications was greater at higher ambient temperatures. March and Biely (1972) suggest that high environmental temperatures accentuate amino acid deficiencies. These workers indicated

Fig. 1 Reduction in egg production after peak, associated with small appetite and body weight
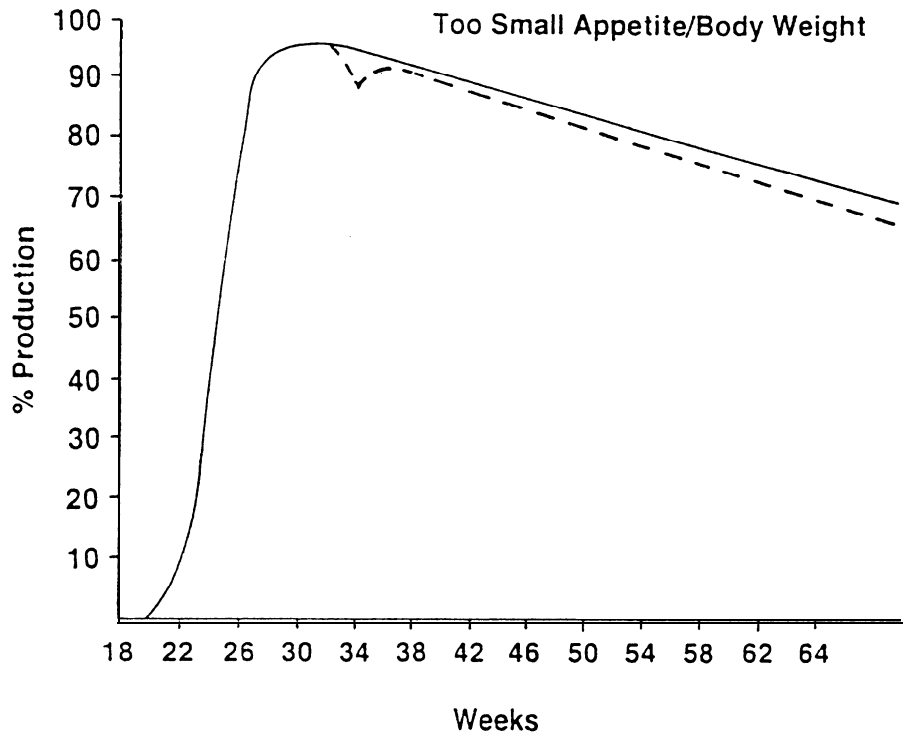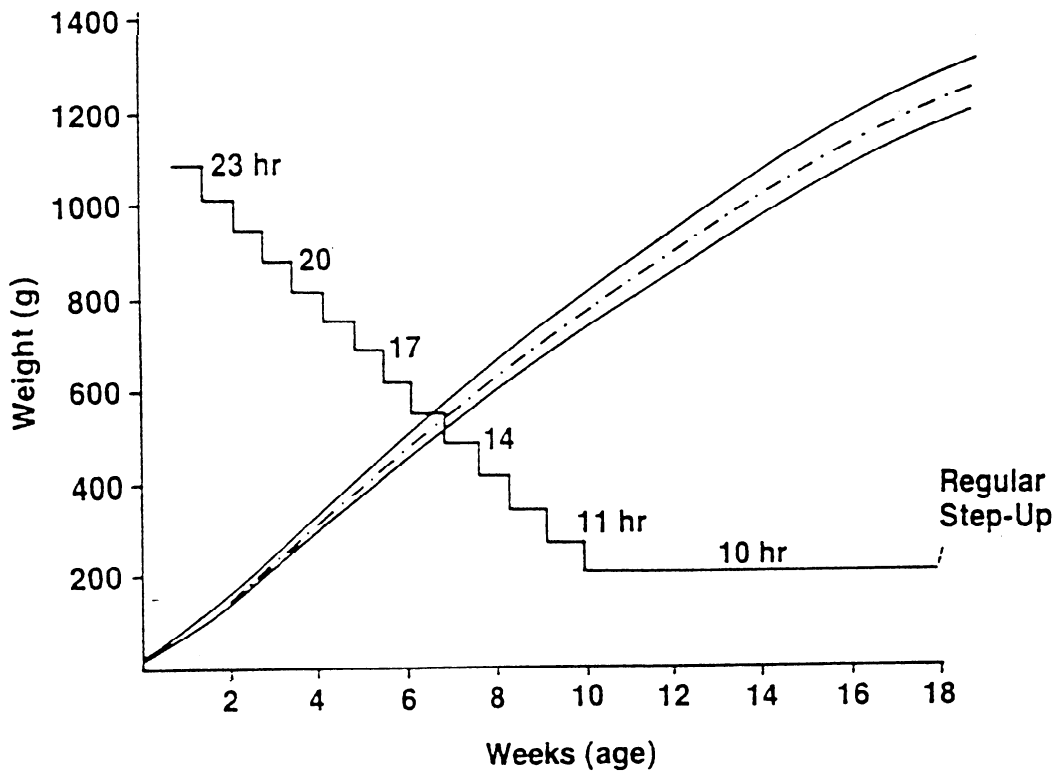

Fig. 2 Step-down lighting

that at suboptimal levels of dietary lysine, growth rates were depressed when energy supply was increased either by increasing the energy concentration of the diet or by increasing the environmental temperature.

Energy seems to be the major nutrient influencing growth rate. Leeson and Summers (1989) indicate a good correlation between energy intake and growth of pullets regardless of environmental temperature, whereas there was little association with protein/amino acid consumption. This is not to say that protein per se is unimportant, rather that up to 20 weeks of age there seems little benefit in terms of either growth or carcass composition from intake of > 1 kg balanced protein Contrary to this, there is increased growth with energy intake > 20 Mcal over this same period.

In open-sided poultry houses, pullets are often subjected to changes in environmental conditions, and this can obviously affect nutrient intake. Leeson and Caston (1991) recently subjected pullets to abrupt changes in environment (18 ⇆ 300C) and/or diet energy (2500 ⇆ 3000 kcal ME/kg) at 56d of age. Surprisingly abrupt changes in diet and/or environment had little effect on pullet development. Final mature weight and condition were most influenced by diet and/or environment conditions prevailing during late growth (Leeson and Caston 1991).

Regardless of nutrient specifications of diets fed to growing pullets, perhaps the most important consideration today is use of such diets in a feeding program. In this context it is imperative that diets be fed according to weight-for-age, and not to either specific ages in isolation of weight or weight in isolation of bird age. In reality this means that each flock is considered on an individual basis, and managers be given flexibility in dictating day-to-day feeding management.

Skeletal development With Leghorn pullets there is interest in early rapid development in order to accommodate early maturity. Lerner (1946) suggests skeletal size to be the limiting factor in increasing body size, hence, the recent interest in trying to increase early skeleton size. The two most common measures of frame size are shank length (tarsometatarsus) and keel length. Shank length has been suggested as a criterion for body size (Lerner, 1937) while Jaap (1938) suggests shank length to be a reliable measure of skeletal size. It is realized that although two pullets may be of similar weight, their skeletal dimensions may differ, leading to the suggestion that birds of equal weight may not be similar or uniform. There is little information dealing with skeletal dimension or how it is influenced by nutritional modification.

Although it is known that deficiencies (Garlich et al. 1992) or imbalance (Lee et al. 1980) of certain minerals can influence skeletal development, such dietary situations invariably lead to abnormal bone growth. Of the major nutrients, protein is most likely to influence frame size, because birds fed diets low in protein or amino acid content will be smaller than contemporaries fed adequate levels of these nutrients (Leeson and Summers 1979). However, just what changes in bone length, if any, are precipitated by given changes in protein intake are not documented. Leeson and Summers (1984) suggest that it is very difficult to influence frame size independent of body weight. In recent studies (S. Leeson, unpublished observation) we have shown that Leghorn pullets subjected to 300C vs 18°C, regardless of diet treatment, exhibit 10% increase in shank length per unit body mass. This effect may relate to increased blood flow to the legs during heat stress (Steen and Steen 1965) and so greater vascularization at the growth plate. If these results are confirmed in other studies, then guidelines used to establish pullet development may need to be reviewed in relation to prevailing environmental conditions.

Lighting programs Due to the significance of photoperiod on layer performance,, lighting programs must be considered as a factor in the selection of growing programs. Leeson and Summers (1985) showed increased growth rate of pullets grown under 14 vs 8 h light per day up to 19 weeks of age. This effect was directly related to increased feed intake throughout the growing period. Longer photoperiods can therefore be used in an attempt to stimulate nutrient intake, and this may be important under hot-weather conditions when feed intake is normally reduced. In order to resolve potential problems related to subsequent light stimulation for pullets grown on long daylengths, a step-down photoperiod can be considered (Fig. 2).

This type of photoperiod does not delay maturity, since the reduction in daylength is stopped at 10-11 weeks of age. This program is especially useful in hot-weather conditions since not only are birds able to eat feed for longer periods of time, but perhaps more importantly they are able to consume feed at cooler times of the day.

TABLE 1   Effect of l&week body weight on layer performance to 72 weeks of age

18 wk body weight	Final body weight (g)	Egg weight	Eggshell deformation (µm)	Egg production (% hen-day per bird)	Feed intake (g/day per bird)
1,060 ± 42	1,598 ± 227	58.1 ± 5.6	23.4 ± 2.4	75.2 ± 17.3	94.3 ± 9.6
1,151 ± 12	1,674 ± 197	59.7 ± 5.6	23.1 ± 2.1	76.7 ± 17.6	95.7 ± 9.4
1,252 ± 17	1,797 ± 205	61.1 ± 5.8	23.8 ± 2.0	76.7 ± 17.1	101.7± 8.9
1,349 ± 16	1,917 ± 218	62.1 ± 5.5	23.6 ± 1.8	77.2 ± 15.9	103.8± 9.6
1,448 ± 15	2,014 ± 269	64.3 ± 5.5	24.1 ± 3.8	76.7 ± 14.8	108.4± 9.6
1,543 ± 38	2,117 ± 296	65.9 ± 5.6	23.9 ± 2.2	77.8 ± 14.0	112.5± 9.2
Regression analysis	NS	**	NS	NS	**

Dependent variable (y)	Relationship with 18 wk body weight[2]	R^2	CV
Average egg weight g	$Y=.02\,(\pm.001)\,X + 41.2\,(\pm1.6)$	.75	2.5
Egg mass, kg	$Y=6 \times 10^{-3}(\pm8 \times 10^{-4})X + 9.97(\pm1.25)$	.43	5.9
Egg size classification[3], %			
Extra large	$Y=.09\,(\pm7.74 \times 10^{-3})X - 72.0(\pm10.5)$	.64	24.7
Large	$Y=-.03(\pm.006)X + 72.1\,(\pm 8.2)$	.27	23.6
Medium	$Y=-.05(\pm.004)X + 82.7\,(\pm 5.5)$	.70	26.5
Small	$Y=-.02(\pm.002)X + 25.6\,(\pm 2.7)$	.57	43.6
Feed intake, g/day per bird	$Y= 3.9 \times 10^{-2}(\pm3.2 \times 10^{-3})X + 52.8\,(\pm 4.2)$	.72	3.9

[1]All equations were highly significant ($P < .01$).
[2]Values in parentheses are standard errors.
[3]Extra large; ≥ 64; large, 57 to 63 g; medium, 49 to 56 g; small, 42 to 48 g.

Mature body size In most situations there is an advantage to maximizing mature body weight, especially for the smaller Leghorn strains. In large part this is due to larger birds eating more feed and so producing a larger egg (Table 1, Leeson et al. 1991). At first

glance, data in Table 1 suggests that feeding programs for growing pullets should be directed to attaining, within reason, the greatest mature body weight, assuming the bird is not overly fat. However the answer to this question relates to system of egg pricing. If eggs are sold by mass, without a weight grading, then maximum mature weight may be advantageous. If eggs are weight graded, as occurs in many countries, then return for extra large vs large must be considered. This latter situation is of concern in Ontario, where there is no premium for extra large vs large eggs. In this situation there is need to either grow a slightly smaller pullet, or to attain maximum early pullet growth, but to light stimulate at an earlier age.

There is current interest in egg-breakout for further processing, and this scenario requires us to totally rethink pullet growing systems. For the shell-egg market where eggs are graded by weight, the foregoing discussions are pertinent and very critical. On the other hand when egg mass (and ultimately solids yield) becomes the major criterion, then early maturing, light-bodied pullets with small appetites may play an important role. Leeson et al. (1991) recently detailed the classical effect of light-stimulating pullets at an early age without attention to body weight (Table 2).

TABLE 2   Effect of pullet weight and age at light stimulation on egg grading and egg mass production

Pullet characteristics		Egg size classification[2]				Total eggs produced to 329 days of age	Egg mass to 329 days of age
Body weight (g)	Age[1] (wk)	Extra large	Large	Medium (%)	Small	(no.)	(kg)
1,243	15	9.6c	35.8	41.9a	13.7a	239.8	12.3
1,288	16	12.2c	39.8	35.5ab	13.9a	232.9	11.7
1,377	17	25.1b	38.8	27.0bc	8.9ab	239.3	12.9
1,425	18	14.1c	43.1	32.0b	10.6ab	231.1	11.7
1,462	19	28.3ab	39.8	27.7bc	7.6bc	227.3	11.6
1,605	20	36.5ab	34.7	22.5c	6.1bc	231.4	12.5
1,722	21	41.7a	33.9	20.8c	4.6c	229.3	12.7
±SD		12.0	8.8	8.9	4.9	22.4	1.6

a-cMeans within columns with no common superscripts are significantly different (P < .01)

[1]Treatment refers to age at light stimulation of 15 to 21 wk.
[2]Extra large, ≥ 64 g; large, 57 to 63 g; medium, 49 to 56 g; small, 42 to 48 g.

As anticipated, light stimulation of small pullets at 15 weeks of age results in dramatic loss in egg size, and this scenario will be uneconomical when income is based on egg size. However if egg mass is the criterion, as occurs with in-line egg breakout units, then there is no treatment difference to 329 d of age (Table 2). Obviously earlier maturing birds produce more eggs, since in the extremes shown in Table 2, there is potential for 6 weeks (21-15) extra production (albeit of a smaller egg). Assuming comparable egg solids yield for all treatments (not measured) then the smaller early maturing bird is attractive, since there is greatly reduced rearing cost.

In reality,, body size at maturity is still of importance, since the larger the bird at any age, the greater the resultant egg size. In the future, therefore, we may have to be even more cognizant of selecting nutrition programs for pullets, dependent upon criteria established for the laying cycle.

Prelay nutrition

The need for specific **prelay** diets assumes that the birds' nutrient requirements are different to those occurring during rearing and/or the early laying cycle. This seems highly unlikely (Bowmaker and **Gous,** 1989) with the possible exception related to calcium metabolism. As cited by Bell and Siller **(1962),** calcium equilibrium involves some seven separate mechanisms and some 37 factors and hence it is not surprising that this sudden change in the birds' calcium status is dealt with by an array of feeding practices. In general these can be classified into one of three major systems, namely (a) continuance of the grower diet ($\approx$0.9% Ca) up to some arbitrary point denoted by 1st egg, 5% production,, etc.; **(b)** a **prelay** diet involving some 2% Ca, or **(c)** introduction of a layer diet (3.5-4% Ca) as early as 17 wk of age.

Prolonged feeding of a grower diet is claimed to improve an animal's efficiency of calcium utilization (Henry et al. 1960) such that when a diet of higher-calcium content is eventually introduced, a greater proportion of calcium is absorbed and temporarily retained. However, proponents of other theories suggest that prolonged feeding of a **low**-calcium diet is detrimental to bone mineralization (Miller and Sunde 1975; Scott et al. 1977) and that low-calcium diets are inadequate for ovary and oviduct development (Nevalainen 1969) and egg production (Gilbert et al. 1981).

Use of **prelay** diets containing around 2% Ca is a compromise in supposedly allowing for medullary bone development while providing more calcium to the earlier maturing pullet that may start production at this time. Studies on diet self-selection of calcium during this **prelay** stage confirm the bird's requirement for this intermediate level of calcium **(Classen** and Scott 1982).

Introduction of the laying diet before maturity is the other main alternative with proponents of the system suggesting that it allows for adequate medullary reserves to develop **(Halnan** 1925) while at the same time meeting the requirement of early maturing birds in a flock. Although not well documented, it is often claimed that prolonged feeding of a 3.5-4% Ca diet prior to maturity is detrimental to kidney structure and that calcium deposits can occur (Niznik et al. **1985).**

Leeson et al. **(1987)** observed no detrimental effects of feeding high calcium diets (3.5%) from 18 weeks of age. However, since there was only marginal increase in calcium retention, relative to birds fed 0.9% Ca, then fecal calcium level was greatly increased (7.7 vs 1.4% **D.M.).** This situation led **Leeson** and Summers (1987) to more closely study water balance of these birds. High calcium pre-lay diets did result in increased water intake and excreta moisture, leading to the suggestion that lower calcium levels (actual 2% Ca **prelay** diets) be considered in hot climates where manure moisture content can be problematic.

Apart from this specific problem, feeding programs around the pre-lay period should involve early introduction of layer diets designed for the expected level of feed intake during early lay.

Laying period

It is now general practice to describe feeding programs for layers according to level of feed intake. The following daily intakes are suggested for the most important nutrients (Table 3).

TABLE 3   Daily nutrient recommendations

Crude protein	17 g
ME	280 kcal
Calcium	3.5 g
Av phosphorus	0.4 g
Methionine	360 mg
Lysine	720 mg

These values will obviously depend on egg mass output, and energy requirement is greatly influenced by environmental temperature.   As feed intake changes so diet proportions of all nutrients must be adjusted. Major problems occur today with some strains of Leghorn, again under hot weather conditions, when feed intake can be close to 90 g at peak production. It is very difficult to formulate diets for such low intakes, and so this reinforces the concept of growing larger pullets with inherently larger appetites. Through peak production, and almost up to time of attaining peak egg mass, the layer can be in a very precarious situation with respect to energy balance. In some flocks, there will in fact be an apparent negative energy balance for a few weeks. This scenario obviously means that the bird is obtaining energy other than from the feed, the most likely candidate being body fat stores.

It is well known that protein (amino acid) and energy intake (Auckland and Wilson 1975 b; Morris and Blackburn 1982) influence egg mass output, although there is little documentation on the interaction between these nutrients. Voreck and Kirchgessner (1980 b) suggest that when energy intake is limiting, only marginal responses to protein intake in terms of egg output are noted. However, Voreck and Kirchgessner (1980 a) indicate an energy sparing effect of protein at low energy intakes in terms of improved energy balance. Since layers adjust their intake according to energy concentration of the diet, it is difficult to study an energy-intake response without using some form of restricted feeding. On this basis, we recently conducted a series of studies in which birds were offered one of three diets (2,400, 2,800 or 3,000 kcal ME/kg) all at 17% CP, fed either ad libitum, or restricted to 100, 90 or 75 g/bird/d. (Leeson, unpublished observation). This scenario imposed average daily intakes of from 185-322 kcal ME/bird from 18 to 66 weeks of age. Protein intake varied from 13-21 g/bird/d. Egg production and egg weight data are shown in Figures 3 and 4 respectively.

As energy intake increases, there is a dramatic increase in egg production, particularly when protein intake is very low. Figure 3 shows egg production increasing from 45% to 85% when energy intake increases from 184 to 312 kcal/d for birds consuming 13.1 g CP/d. At low energy intakes, there is some improvement in egg production when protein intake is increased* However, increasing protein intake from 13.1 to 20.7 g/d when energy intake is high (312 kcal) has little effect on egg production.

These data suggest that energy intake is the most critical nutrient for egg production, and that the response to protein intake is only significant when energy intake is limiting. As with the growing pullet, it is not intended to suggest that protein can be neglected,

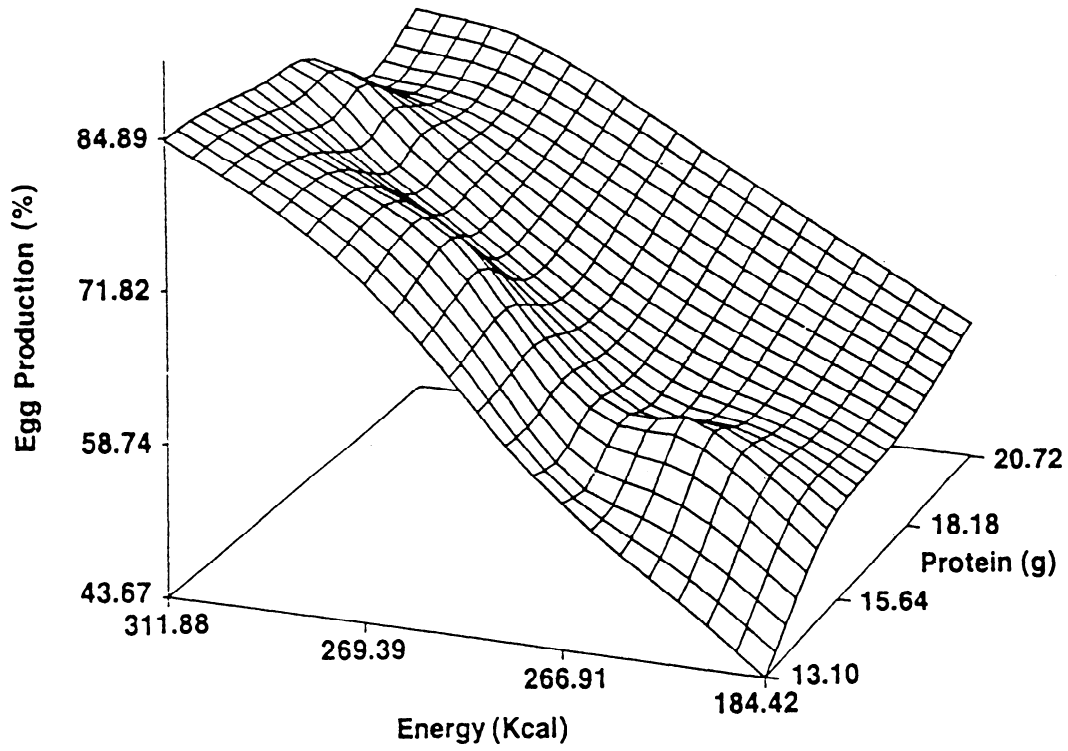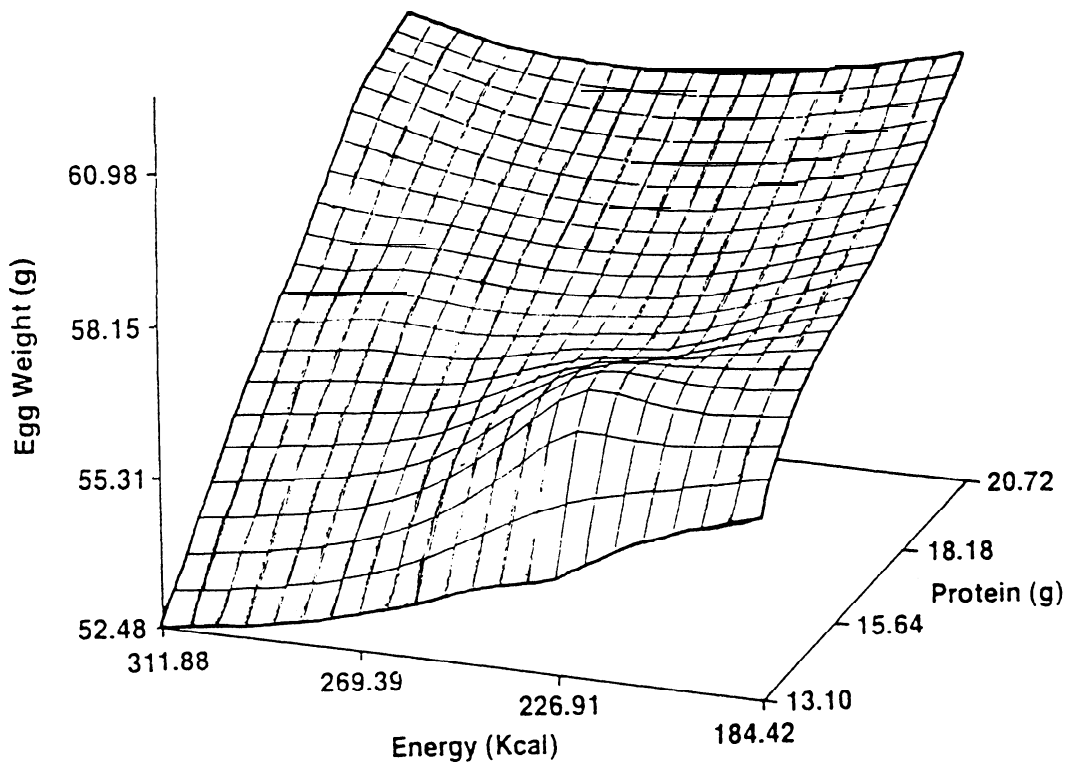Fig. 3 **Egg** production **(18-66 weeks) in response to intakes of** energy and protein

Fig. 4 Egg weight (18-66 weeks) in response to intakes of energy and protein

since when one considers egg size, then protein (presumably methionine) intake is **critical.** Figure 4 suggests dramatic increases in egg size, when diet protein intake is increased from 13.1 to 20.7 g/b/d, regardless of energy intake. Thus even for a bird that is deficient in energy at 184 **kcal** ME/d, there is still a classic response in egg size to protein, even though egg production is being little affected (Figure 3).

Data in Figure 4 indicate that energy intake has virtually no effect on egg size, and, at low intakes of protein, increasing energy intake may result in reduced egg size. If one considers daily egg mass output, then the effect of egg numbers seems to dominate, and the response surface is similar to that shown in Figure 3.

Results generally indicate that energy is the critical nutrient for egg **production,and** that the response to protein is somewhat dependent on the energy status of the bird. With younger birds (18-30 weeks), our other studies show egg numbers to be most responsive to energy intake, with a response to protein becoming more apparent at energy intakes in excess of 240 **kcal** ME/d. Auckland and Wilson 1975 (b) show an essentially linear trend between energy intake and egg mass output, and that even slight reductions in energy intake below that seen with ad-libitum intake resulted in reduced egg output.

Auckland and Wilson (1975 a) suggest a reduction in egg mass output of 0.15 **g/kcal** ME reduction in energy intake. Data from our study indicates a comparable value of 0.12 **g/kcal** ME. Similarly comparison of data of Auckland and Wilson (1975 a) and that in Figure 3 for change in egg production in response to energy intake, show values of .2% and .25% per **kcal** ME, respectively. Cerniglia et al. (1984) and Cunningham (1984) also give evidence for the positive relationship between energy intake and egg mass output. Extrapolation of data from Slagter and Waldroup (1984) suggest an energy requirement of laying hens housed at 20ºC of approximately 315 **kcal** ME/d which corresponds to the situation of maximum egg numbers and mass seen in the current study with birds consuming this amount of energy.

There are, however, reports of birds showing little response to increased energy intake, and that it may be economical to restrict feed intake. Snetsinger and Zimmerman (1974) indicated that a 5-10% reduction in energy intake did not influence egg production, although egg weight was reduced .5-1.5%. These results are at variance with Figures 3 and 4 where energy intake influences egg production, but not egg weight. However, if one considers a reduced intake up to 10% from that of ad libitum intake (Figure 3), as described by Snetsinger and Zimmerman (1974), no effect on egg production is observed. It should also be noted that bird type has changed over the period from 1974 to 1987 (Leeson 1987) particularly with respect to feed intake.

Gous et al. (1987) suggested that energy intake does not influence egg output directly,, but rather diet energy concentration may influence feed intake, and consumption of critical amino acids. However the relationship between energy intake and diet energy concentration as given by **Gous** et al. (1987) is quite tenuous, being based only on three points of measurement and specific to very short-term trials where effective energy intake varies at most by 5%.

However, this does raise an important question of practical manipulation of energy intake. Carew et al. (1980) show that energy intake cannot effectively be altered by varying diet energy concentration, since birds eat to their energy requirement. In relation to the current discussion, it obviously follows that maximizing diet energy concentration is unlikely to greatly influence energy intake. Optimum energy intake can perhaps best be achieved through feeding management practices that maximize feed intake.

There does not seem to be any significant energy sparing effect of protein, especially in terms of egg numbers. Morris and Blackburn (1982) suggest a curvilinear relationship between protein intake and egg mass output, with the response diminishing with higher

inputs over the range **8-22** g/d. Voreck and Kirchgessner (1980 b) indicate that when energy intake is limiting, there is only a slight response in egg energy output when protein intake is increased.

In terms of energy balance, Voreck and Kirchgessner (1980 a) indicate little energy sparing effect of protein when energy intake is limiting. In our study, increases in protein intake from **13-20** g/bird/d resulted in a 30% increase in egg mass output, suggesting some energy sparing effect of protein when energy intake was approximately 184 **kcal/d.** Voreck and Kirchgessner (1980 b) did, however, indicate that maximum egg output was realized with maximum nutrient intake and that at high energy intakes birds responded to increased protein intake.

The present data suggests that egg mass output over a production cycle is optimized when nutrient intake is maximized, and that birds are most responsive to energy intake.

REFERENCES

AUCKLAND, J.N. and WILSON, S.B. (1975 a). Br. Poult. Sci. 16: 23.
AUCKLAND, J.N. and WILSON, S.B. (1975 b). Br. Poult. Sci. 16: 453.
BELL, R.J. and SILLER, W.G. (1962). Res. Vet. Sci. 3: 219-230.
BOWMAKER, J.E. and GOUS, R.M. (1980). Br. Poult. Sci. 30: 663-676.
CAREWL.B., FOSS, DC. and BEE, D.E. (1980). Poult. Sci. 59:1090.
CERNIGLIA, G.J., GOODLING, A.C. and HEBERT, J.A. (1984). Poult. Sci. 63:1105.
CLASSEN, H.L. and SCOTT, T.A. (1982). Poult. Sci. 61: 2065-2074.
CUNNINGHAM, D.L. (1984). Poult. Sci. 63: 2352.
CUNNINGHAM, D.C. and MORRISON, W.D. (1976). Poult. Sci. 55: 85-97.
GARLICH, J., MORRIS, C. and BRAKE, J. (1982). Poult. Sci. 61: 1003-1006.
GILBERT, A.B., PEDDIE, J., MITCHELL, G.G. and TEAGUE, P.W. (1981). Br. Poult. Sci.
        22: 537548.
GOUS, R.M., GRIESSEL, M. and MORRIS, T.R. (1987). Br. Poult. Sci. 28: 427.
HALNAN, E.T. (1925). J. Nat. Poult. Institute 10: 410-416.
HENRY, K.M., KON, S.K., TODD, P.E., TOOTHILL, J. and TOMLIN, D.H. (1960). Acta.
        Biochemica. Polonica 7: 167-185.
JAAP, R.G. (1938). US Egg Poult. Mag. 44: 488-503.
JULL, M.A. and GLASENER, E.W. (1946). Poult. Sci. 25: 256-261.
LEE, S.R., BRITTON, W.M. and ROWLAND, G.N. (1980). Poult. Sci. 59: 2403-2411.
LEESON, S. (1986 a). in: Proc. Poult. Nutr. and Disease Control Technical Symposium.
        MSD-Ag Vet., Princeton, NJ.
LEESON, S. (1986 b). World's Poult. Sci. J. 42: 619-81.
LEESON, S. (1987). 14th Carolina Poultry Nutr. Conf. Charlotte, N.C. Dec. 24th.
LEESON, S. and CASTON, L.J. (1991). Poultry Sci. 70: 1732-1738.
LEESON, S., CASTON, L. and SUMMERS, J.D. (1991). Poult. Sci. 70: 37-43.
LEESON, S., JULIAN, R.J. and SUMMERS, J.D. (1987). Can. I. Anim. Sci. 66: 1087-1096.
LEESON, S., and SUMMERS, J.D. (1979). Poult. Sci. 58: 681-686.
LEESON, S. and SUMMERS, J.D. (1981). Can. I. Anim. Sci. 61: 743-749.
LEESON, S. and SUMMERS, J.D. (1982). Poult. Sci. 61: 1684-1691.
LEESON, S. and SUMMERS, J.D. (1984 a). Poult. Sci. 63: 875-882.
LEESON, S. and SUMMERS, J.D. (1984 b). Poult. Sci. 63: 17641772.
LEESON, S. and SUMMERS, J.D. (1984). Poult. Sci. 63: 1222-1228.
LEESON, S. and SUMMERS, J.D. (1985). Can. I. Anim. Sci. 65: 205-210.
LEESON, S. and SUMMERS, J.D. (1985). Poult. Sci. 64: 1617-1622.
LEESON, S. and SUMMERS, J.D. (1987). Poult. Sci. 66: 1918-1923.

LEESON, S. and SUMMERS, J.D. (1989). Poult. Sci. 68: 546-557.

LERNER, I.M. (1937). Poult. Sci. 16: 213-215.

LERNER, I.M. (1946). Poult. Sci. 25: 204209.

LODHI, G.N., CHAWLA, J.S., AHUJA, A.K. and ICHHPONANI, J.S. (1975). Indian J. Anim. Sci. 45: 664-668.

MARCH, B.E. and BIELY, J. (1972). Poult. Sci. 51: 665-668.

McNAUGHTON, J.L., KUBENA, L.F., DEATON, J.W. and REECE, F.N. (1977). Poult. Sci. 56: 1391-1398.

MILLER, P.C. and SUNDE, M.L. (1975). Poult. Sci. 54: 1856-1867.

MORRIS, T.R. and BLACKBURN, H. (1982). Br. Poult. Sci. 23: 405.

NEVALAINEN, T.J. (1969). Poult. Sci. 48: 653-659.

NIZNIK, R.A., WIDEMAN, R.F., COWEN, B.S. and KISSELL, R.E. (1985). Poult. Sci. 64: 1430-1437.

SCOTT, J.T., CREGER, C.R., FARR, F.M. and LINTON, S.S. (1977). Nutr. Rep. Int. 15: 139-144.

SLAGTER, P.J. and WALDROUP, P.W. (1986). Poult. Sci. 63: 1810.

SNETSINGER, D.C. and ZIMMERMAN, R.A. (1974). In: "Energy Requirements of Poultry", pp. 185-199, editors T.R. Morris and B.M. Freeman (Brit. Poult. Sci., Edinburgh).

STEEN, I. and STEEN, J.B. (1965). Acta. Physiol. Scand. 63: 285-291.

STOCKLAND, W.L. and BLAYLOCK, L.G. (1974). Poult. Sci. 53: 1174-1187.

VORECK, V.O. and KIRCHGESSNER, M. (1980 a). Z. Teirphysiol. Tierernahrg. V. Futtermittelkde 43: 65.

VORECK,, V.O. and KIRCHGESSNER, M. (1980 b). Z. Tierphysiol. Tiererhahrg. V. Futtermittelkde 43: 74.