MATCHING THE NUTRITIONAL REQUIREMENTS TO PERFORMANCE IN BROILER BREEDER HENS

by

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PREFACE

The experimenatal work described in this thesis was carried out in the Department of Animal Science and Poultry Science, Faculty of Agriculture, University of Natal, Pietermaritzburg, from March 1995 to December 1996, under the supervision of Professor Rob M. Gous.

These studies represent original work by the author and have not otherwise been submitted in any form for any degree or diploma to any University. Where use has been made of the work of others it has been duly acknowledged in the text.

L.L. Goddard

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ABBREVIATIONS

AME	-	apparent metabolisable energy
CV	-	coefficient of variation
LFBW	-	lipid-free bodyweight
ME	-	metabolisable energy
SE	-	standard error

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ABSTRACT

Quantitative food restriction during the rearing and laying period has become the standard management procedure in commercial broiler breeder operations to control the rapid growth rate of broiler breeders. This raises problems with the amount of each nutrient to be supplied each day. Food allowances are manipulated according to the pattern of egg production. Birds are fed a generous allowance early in lay followed by a period of mild regulation over peak production and a subsequent reduction in allowance as egg production declines in the later part of lay. In the past little work has been done on developing the theory of determining the nutrient requirements of broiler breeders. Consequently, this generally accepted method of feeding these breeders is without a sound theoretical basis.

The objective of this study was to address two aspects concerned with meeting the requirements of broiler breeder hens during the laying period, specifically in the later stages of lay. The first is the obesity in broiler breeders that results from an excessive intake of energy and leads to a decrease in egg production. The second is the rapid decline in egg production in ageing hens.

Individual data were collected from broiler breeder hens in two experiments. The first to determine the extent to which broiler breeder hens could be made to utilize excess body lipid reserves whilst maintaining laying performance. The second to measure the responses to lysine at different ages and to determine if the efficiency of utilization of lysine changes at different ages.

Results from the first experiment indicated that broiler breeders can utilize their body fat reserves as an energy source providing that their protein intake is sufficiently high and that they could maintain egg production for at least a limited period of time. Birds fed an energy intake of 1490 kJ ME/bird d and a protein intake of 25.8 g/bird d showed no decline in egg production compared to birds fed much higher energy intakes (1900 to 2000 kJ ME/bird d). It was concluded from this experiment that if birds become overfat at any stage in their productive lives this situation can possibly be rectified by feeding them diets with low energy contents. In the later stages of lay and on cold days birds can probably be fed energy intakes below their requirements with no detrimental effect on egg production.

Results from the second experiment indicated that the efficiency of utilization of protein declines as broiler breeders age. The efficiency of utilization of lysine was significantly lower for birds of 53 and 65 weeks of age compared to birds of 31 and 42 weeks of age. This decline in efficiency with age was attributed to the fact that efficiency decreases when the rate of lay decreases to below 50%. There was therefore no indication that the protein requirements decrease as the laying year progresses although egg production declines. It was suggested that new methods of feeding broiler breeder hens later in lay be investigated because the present method of decreasing the food allowance at this time is probably not the most ideal way to achieve maximum performance.

GENERAL INTRODUCTION

With the worldwide increase in consumption of poultry meat, in recent years, the production of hatchable eggs from broiler breeding stock has become a critically important component of the poultry industry. Surprisingly, this field of poultry research has received relatively little attention. It has been assumed in many cases that the research on laying hens is applicable to broiler breeders. However, fundamental differences are apparent between these strains that should be investigated more comprehensively if the potential of broiler breeder hens is to be achieved.

Commercial laying hens have been selected for increased egg production whereas broilers have been selected for improved growth rate, and this has made the challenge of maintaining egg production in broiler parent stock difficult. The reason why broilers have been selected for improved growth rate is an economic one. The objectives being to reduce the time required to achieve market weight and to improve the efficiency of feed conversion. Some of the consequences of selecting for improved growth rate in broilers , are an increase in food consumption and an increase in the mature weight of these birds (Costa, 1981 and Robinson, Wilson, Yu, Fasenko and Hardin, 1993). Bodyweight and egg output are negatively correlated (McDaniel, Brake and Eckman, 1981b), so the major consequence of selecting for rapid growth rate in broilers is that the reproductive potential of these birds has diminished.

In order to obtain the maximum number of hatchable eggs from broiler breeders their growth rate must therefore be reduced to about half of that which could be achieved if they were fed *ad libitum*. Quantitative food restriction during the rearing and laying periods has become the standard management procedure in commercial broiler breeder operations. This raises problems concerning the amount of each nutrient that should be supplied each day, as well as problems associated with the even distribution of feed throughout the flock, neither of which is a serious problem in flocks fed *ad libitum*.

There are two major factors to be considered when addressing the problems of broiler breeder nutrition. The first is the obesity in broiler breeders that results from having been overfed, and the second is the rapid decline in egg production in ageing hens. This study was undertaken to address these two aspects.

CHAPTER 1

REVIEW OF LITERATURE

1.1 INTRODUCTION

There is very little published literature on the theory of determining the nutrient requirements of broiler breeders. Consequently, the generally accepted method of feeding these breeders during rearing and in lay is without a sound theoretical basis. Questions could be raised regarding the ideal growth curve which should be achieved during growth, and whether the practice of offering one feed to the breeders during lay and adjusting the quantity for performance gives optimum performance. Without a robust theory on which to work it is not possible to challenge these ideas.

1.2 THE REARING PERIOD

1.2.1 Ovulation rate

The reason why the food intake of broiler breeders has to be controlled early on in their life is to increase the production of hatchable eggs. The main reason for the decrease in production of hatchable eggs in broiler breeder hens fed *ad libitum* is an excess in the production of yellow follicles. This leads to multiple ovulations early in lay. Hocking, Gilbert, Walker and Waddington (1987), Bowmaker and Gous (1989) and Yu, Robinson, Charles and Weingardt (1992b) reported the presence of at least two hierarchies of ovarian yellow follicles at sexual maturity in birds fed *ad libitum* during rearing. Ovulated follicles were frequently observed in the body cavities of these birds and two or more yolks were often observed in the oviduct at the same time. This leads to a loss of ovulated follicles. It also leads to the production of double yolked eggs and unusable eggs with poor shell formation. Some birds were observed with as many as three or four large follicles of similar weight present at first egg which led to the production of triple yolked eggs between 24 and 28 weeks of age.

Restricting the food intake of broiler breeder hens limits the number of yellow follicles that are present in the bird at any one time. The estimated drop in the number of normal yellow follicles from restricted feeding rather than feeding *ad libitum* throughout rearing is about 5.6 follicles per bird (Hocking, Waddington, Walker and Gilbert, 1989). The number of yellow follicles at first egg declines linearly with time on restriction. Food restriction up to the age of 22 weeks results in about half the drop in numbers of yellow follicles compared with the number produced when restriction continues to point of lay (27 to 32 weeks of age) (Hocking *et al.*, 1989).

The growth of follicles greater than one millimetre in diameter starts at about 14 to 16 weeks of age in *ad libitum* fed birds and only at about 22 to 24 weeks of age in birds which are restricted (Hocking *et al.*, 1989). Estimated ages for the start of yellow follicle growth is 0.4 weeks later than for the start of white follicle growth in *ad libitum* fed birds and three weeks later in restricted birds (Hocking *et al.*, 1989).

Food restriction therefore reduces the incidence of erratic ovipositions, defective eggs and multiple ovulations (Yu *et al.*, 1992b).

1.2.2 Sexual maturity

Lee, Gulliver and Morris (1971) and Balnave (1973) demonstrated in a review of the literature for laying stock that

i. food restriction delays sexual maturity,
ii. the more severe the feed restriction the greater the delay in sexual maturity and
iii. restricted birds reach a higher peak of egg production and maintain a higher subsequent rate of lay than birds fed *ad libitum.*

Several authors (Lee *et al.*, 1971, Leeson and Summers, 1982, Robinson, Robinson and Scott, 1991, Pearson and Herron, 1982 and Hocking *et al.*, 1989) have shown that restricting the food intake of broiler breeders

i. delays sexual maturity and
ii. improves subsequent laying performance

Delays in sexual maturity of 2.5 weeks (Yu *et al.*, 1992b) up to 6.5 weeks (O'Sullivan, Dunnington, Smith, Gross and Siegel, 1991) have been reported.

It has been shown that it is the bird's energy intake that affects age at first egg and not its protein intake. Pearson and Herron (1982) showed that when birds were fed different protein and energy intakes from 21 weeks of age the birds on the lower energy intakes started laying later and at a lower bodyweight. There was a linear relationship between age at first egg and energy intake

$y = 196.1 - 8.68x$

$R^2 = -0.93$

where y = age at first egg (days)

and x = energy intake (MJ AME/bird d)

They also showed a linear relationship between age at first egg and bodyweight

$y = 225.5 - 0.015x$

$R^2 = -0.88$

where y = age at first egg (days)

and x = bodyweight (g)

Changes in photoperiod during the rearing period have a major effect on age at sexual maturity. It has been well established that increasing daylength stimulates sexual maturity (Morris and Fox, 1960; Shanawany 1983). The standard practice for broiler breeders is to use a lighting regime of 8L:16D until approximately 20 weeks of age and then to increase the daylength. Light periods of 6L:18D or 10L:14D have no adverse effect on reproductive performance, but using 4L:20D results in a delay in sexual maturity and a decrease in egg production (Yalcin, McDaniel and Wong-Valle, 1993). The level of food restriction presently used in commercial operations does not induce a major delay in sexual maturity where hens are photostimulated at 18 to 20 weeks of age (Robinson *et al*, 1993). Egg production usually commences about four to six weeks after photostimulation. The differences in delay in sexual maturity are due to the level of food restriction or variations in lighting regimes.

1.2.3 Bodyweight and body composition at sexual maturity

Yu, Robinson and Robblee (1992a) reared broiler breeders on an *ad libitum* or a restricted feed programme. The average bodyweight at sexual maturity was 1.9 kg for the restricted birds and 4.2 kg for *ad libitum* fed birds. The birds fed *ad libitum* had twice the amount of protein and ten times the amount of fat as restricted birds. However, the percentage of protein was not significantly different between the two groups. The percentage of fat was significantly higher for the birds fed *ad libitum*. Robinson *et al.* (1991) found that *ad libitum* fed birds were 700g heavier at 25 weeks of age than restricted birds.

Several authors have investigated the possible relationship between age, bodyweight, body composition and the initiation of sexual maturity. Some authors have shown that there is a critical threshold value for age, bodyweight or body composition required for the onset of sexual maturity (Brody, Eitan, Soller, Nir and Nitsan, 1980; Bornstein, Plavnik and Lev, 1984). Soller, Eitan and Brody (1984) reported that pullets on different treatments entered lay at similar fat-free bodyweights but differed in age, bodyweight and body fat content. This means that birds are able to achieve sexual maturity with a wide range of body fat proportions. In contrast the percentage of protein remains almost constant, not apparently affected by age or bodyweight. Wilson, Robinson, Robinson and Hardin (1995) showed that birds with the lowest protein levels showed a delay in sexual maturity indicating that a minimum threshold may have had to be reached. These birds had the highest fat content indicating that body fat levels probably do not restrict maturity.

Broiler breeders reared on diets of different energy concentrations or feeds varying in energy:protein ratios have a relatively constant protein content in the carcass at sexual maturity. However, the bodyweight and the percentage of fat in the carcass both increase with increasing energy content of the diet or as the protein content decreases. Body fat is positively correlated with energy intake and bodyweight (Gous, 1972; Bennett and Leeson, 1990a and 1990b). Energy intake is obviously the critical factor to be controlled in any food restriction programme. Any method whereby the energy intake can be reduced will result in a leaner carcass. This can be achieved either by decreasing the feeding level or decreasing the energy concentration of the feed.

This effect of decreasing bodyweight gain and thereby decreasing the body fat in the gain by restricting the energy intake during the growing period persists throughout the laying period. Birds reared on restricted energy intake lay significantly more eggs (Fuller, Potter and Kirkland, 1969; Robinson *et al.*, 1991) and have a still greater advantage in that the number of settable eggs is also increased. Such birds come into production later with less carcass fat, lay fewer small eggs and fewer oversize eggs. Early maturing birds lay more small and more oversize eggs (as measured by double yolks). There is also a positive relationship between early maturity and the number of soft and thin shelled eggs (Fuller *et al.*, 1969).

With the overall objective of the breeder manager being to maximise the number of placeable chicks per hen housed over a normal production period, then the optimal growth curve and corresponding feeding programme must be identified.

The data relating to changes in food allocation during rearing are poorly defined. The management guides published by primary breeders provide estimates of bodyweight targets for birds from hatch to end of lay. However, there is a considerable range between the upper and lower limits of such targets and the timing of the weight gain is important. For example, individuals of similar weight at sexual maturity could have gained more weight early on, while others could have gained weight late in rearing. Wilson *et al.* (1995) restricted the food intake of broiler breeders to follow one of three different bodyweight targets from one to 24 weeks of age. The three different targets were:-

i) *Standard* - to maintain the birds at the target weight recommended by the primary breeder
ii) *Early slow* - birds provided with lower than usual food allocation from week one to 20. From week 20 to 26 they were given more food than the *standard* group
iii) *Early fast* - the birds were fed more feed than the *standard* group from week one to 20 and then they were fed the same as the standard group from 20 weeks

There were no significant differences in bodyweight at 24 weeks. At 56 weeks the *early slow* birds were significantly heavier than the *standard* birds. The *early slow* birds entered lay with less protein and more carcass fat than the *early fast* birds and they produced significantly fewer settable eggs than the *early fast* and the *standard* birds. Hatchability was significantly higher for the *early fast* birds than for either of the other two groups.

1.3 THE LAYING PERIOD

1.3.1 Energy requirements

1.3.1.1 Bodyweight and body composition

McDaniel *et al.* (1981b) showed that at 32 weeks of age bodyweight was negatively correlated with hen-day production, fertility and hatchability. By 40 weeks of age these correlations had increased considerably. At 53 weeks of age these correlations remained the same or increased in degree. They also showed that bodyweight is positively correlated with egg weight but it must be remembered that eggs that are too large are not desirable because they are inferior to smaller eggs in terms of the surface area available for oxygen uptake in the incubator. They have a smaller surface area:volume ratio.

Birds fed different protein and energy intakes show increased bodyweight gain with increased energy intake. Bodyweight gain increases linearly with increased energy allowance. These differences in bodyweight are due mainly to differences in fat deposition. Protein intake during lay does not affect bodyweight or weight gain (Pearson and Herron, 1981; 1982).

Pearson and Herron (1981) fed broiler breeders daily allowances of 1.88, 1.73 or 1.52 MJ AME at two different protein intakes (27 or 21.3 g). The effect of energy intake on egg production was quadratic and the highest egg output occurred at 1.73 MJ/bird d. Egg production was not affected by protein intake. The lowest protein intake of 21.3 g/bird d was obviously sufficient to meet the birds requirements for egg production. Egg weight showed a linear relationship with dietary energy and protein. The highest egg weight occurred at the highest energy and protein intakes (1.88 MJ and 27 g).

Most of the energy intake of laying birds is used for maintenance, with about one third available for production. The low rate of egg production on the lowest energy allowance (1.52 MJ AME/d) was probably because of a failure of the allowance to meet the birds' energy requirements for egg production. The increase in rate of egg production as the allowance increased from 1.52 to 1.73 MJ AME/d is explained by an increase in the energy available for egg production (Pearson and Herron, 1981).

The decrease in rate of egg production at 1.88 MJ AME/d was probably because the extra energy available led to an increase in bodyweight which depressed egg production. Most of the differences in bodyweight between the 1.88 MJ and the 1.73 MJ was accounted for by differences in the amount of fat (Pearson and Herron, 1981).

Pearson and Herron (1981) also showed that, during the later stages of lay the highest hatchability occurred at the low energy intakes. They also showed that there was a decrease in fertility towards the end of lay which was associated with high energy intake during the laying period, because it occurred on the treatments with the highest mean bodyweight throughout lay.

Force - moulted broiler breeders do not show a significant correlation of bodyweight with fertility and hatchability (McDaniel *et al.*, 1981b). The reason for this is explained by the fact that bodyweight and its negative correlation with fertility and hatchability is due to an accumulation of fat. During the moulting process bodyweight is reduced because of food restriction and the majority of this reduction in bodyweight is due to a loss of body fat.

1.3.1.2 Meeting the energy requirements of broiler breeders

The energy intake of laying hens is used for maintenance expenditures and for productive processes. The energy demanding processes of the body appear to be divided into three types (De Groote, 1974; Emmans, 1974):-

1) Inevitable and primary expenditures: maintenance and thermoregulation.

2) Syntheses which are usually performed when food intake is in excess of that required to meet primary expenditures ie. egg production
3) Deposition of body fat which occurs when food is supplied in excess of the needs for primary expenditures and egg production

It is difficult to prescribe accurately the daily energy allotments for broiler breeders because their energy requirements change according to their egg production and with fluctuations in environmental temperature. The food allowance needs to be adjusted accordingly because they cannot increase their food intake if their energy requirements increase because their food intake is restricted. If energy intake is limiting it may fail to meet the requirements for maximum egg output. If energy is supplied in excess of that required for maintenance and egg production the excess energy is deposited as carcass fat. This leads to a marked reduction in egg production, fertility and hatchability (McDaniel *et al.*, 1981b; Pearson and Herron, 1981). The effects of temperature on energy requirements have been well established (Balnave, 1973). Birds have a zone of thermoneutrality, over which metabolism is minimal. Within this zone birds control their heat loss by physical means. When the temperature falls below this zone the bird maintains its body temperature by increasing its heat production, mainly by chemical means and this increases its requirement for energy. The maintenance energy of cockerals increases by approximately 8.4 kJ/kg d °C when the temperature decreases from 34 °C to 15 °C (Emmans, 1974).

Establishing energy intakes based on previous flock averages with adjustments for temperature and age, at different times can therefore either grossly overestimate or underestimate the true needs of hens. However, Gous, Emmans and Fisher (1992) showed that fattened broilers can make use of excess body lipid reserves providing that their protein intake is sufficiently high to allow this. The possibility of broiler breeder hens being made to utilize their excess body lipid reserves as an energy source and the effect on laying performance needs to be investigated because this may help to solve some of the difficulties in meeting the changing energy requirements of broiler breeder hens.

1.3.2 Amino acid requirements

1.3.2.1 Protein content of eggs

A typical egg weighes about 58 to 60 g and contains 7 to 7.5 g protein (11 to 12%). About 3.1 g (42%) is yolk protein, synthesized in the liver and about 4 g (54%) is albumen protein synthesized mainly in the magnum region of the oviduct. The remaining 3 to 4% of the protein is in the shell and its associated membranes (Fisher, 1980; MacDonald and Morris, 1985; Smith, 1978a and1978b).

Lunven, Le Clement De St Marcq, Carnovale and Fratoni (1973) established that there is a consistency in the amino acid composition of hens' egg protein and also that the composition was not significantly affected by breed or by varying the quantity of dietary protein.

1.3.2.2 Protein deposition in the egg

Egg protein represents about 30% of the daily crude protein intake (Fisher, 1994). In the modern hen, a continuous reproductive state is maintained for at least one year. Egg production and therefore protein deposition can be explained by means of the concept of an ovulatory cycle. Eggs are laid at later hours of each day on two or more consecutive days to form a clutch, and there is an interval of one day or more, when no egg is laid, between the clutches (Fraps,1955). If the clutches are separated by intervals of one day they are referred to as 'closed cycles'. The minimum rate of egg production (rate = number of eggs/number of days) that can be sustained in closed cycles is 0.5 or 50%, continuous one-egg clutch and one-day interval. Lower rates of lay must involve pause intervals of greater length than one day (Fisher, 1980).

For birds laying in closed cycles, yolk protein synthesis and deposition is a continuous process and occurs at a constant rate (Fisher, 1980). With laying hens, the ovary will contain between four and six follicles in the 'rapid' stage of development eight days prior to ovulation, and during this period the mass of individual follicles increases almost linearly with time (Fraps, 1955).

There is some periodicity in the synthesis of egg white proteins. The ovumucoids and ovumucin and the shell and its associated membrane proteins, synthesized during secretion of the egg, are deposited simultaneously as the egg passes through the oviduct (Fisher, 1980). The remaining egg white proteins (the ovalbumins) are synthesized and stored prior to deposition on the egg, at a constant rate over each interval between the passage of successive eggs (Fisher, 1980) (Figure 1.1).

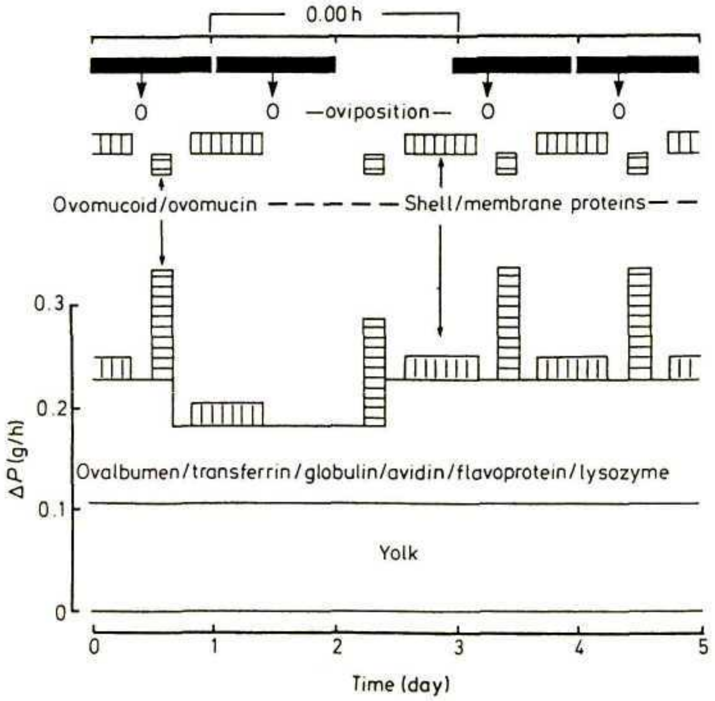

Figure 1.1. An estimate of the rate of protein synthesis/deposition in laying hens (from Fisher 1980). The upper part of the diagram shows the approximate timing of oviposition (O), egg white and shell secretion on succesive days, assuming a sequence: 4-egg clutch, 1-day interval, 3-day clutch. The lower part shows possible average rates of protein deposition. The values used to construct the figure are from Smith (1978a and b).

1.3.2.3 *Efficiency of utilization of protein*

As birds age their egg output declines, and this had led to the belief that their protein requirements decline as the laying year progresses.

Fisher and Morris (1967) fed laying hens one of three diets containing 12, 14 and 16% crude protein from 23 to 63 weeks of age. They divided the laying year into three periods, one period of 10 weeks followed by two periods of 15 weeks each. In each period the diet had a significant effect on rate of lay. Egg output showed a linear relationship with protein intake. There was no indication that the amount of protein needed to maximize egg output was any less in one period than in another, although the level of maximum output decreased as the year progressed.

Jennings, Fisher and Morris (1972) measured the response to graded levels of dietary protein at two different ages. The pullets were fed six diets, containing 7 to 14% protein (supplying a range of protein intakes from 5 to 20 g bird/d) for 10 weeks from the age of 28 weeks. They were then fed the same six diets and an additional diet with 16% protein from the age of 62 weeks. More protein was required at the end of the laying year than at the beginning to sustain a given level of egg output (Figure 1.2).

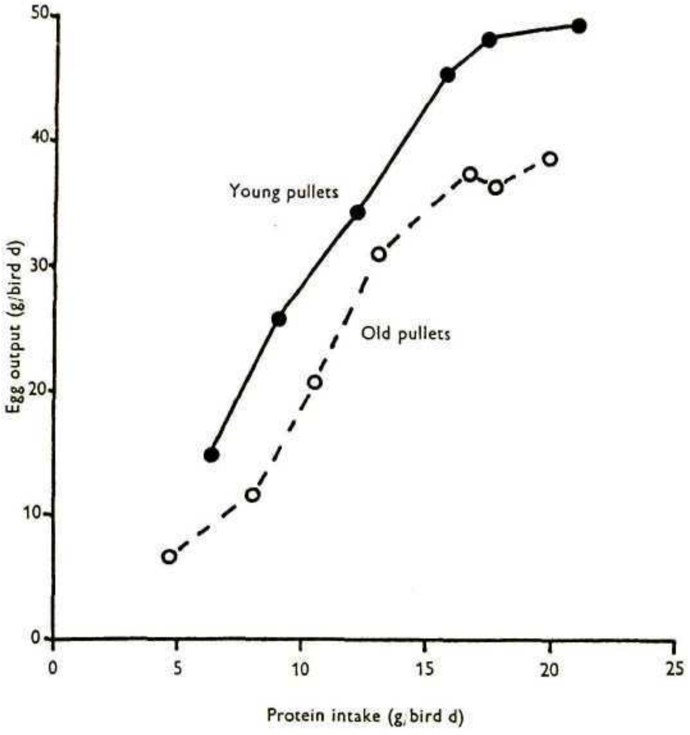

Figure 1.2. The response to graded levels of dietary protein at two different ages. (From Jennings *et al.*, 1972).

A possible explanation for this decrease in egg output without a corresponding decrease in protein requirement could be the extra maintenance requirements of older birds, but in the above two experiments the changes in bodyweights were negligible.

Wethli and Morris (1978) studied the responses of a flock which had been brought into a highly-productive state after moulting to see if this decline in efficiency is a function of age *per se* or of rate of lay. If efficiency is a function of age, such a flock would have been less efficient than a pullet flock. If efficiency is a function of rate of egg output hens at the peak of the second cycle of egg production would be as efficient as young pullets. The latter was found to be the case (Figure 1.3). They also concluded that the tryptophan requirement does not decrease during the laying year, despite a decline in rate of egg output.

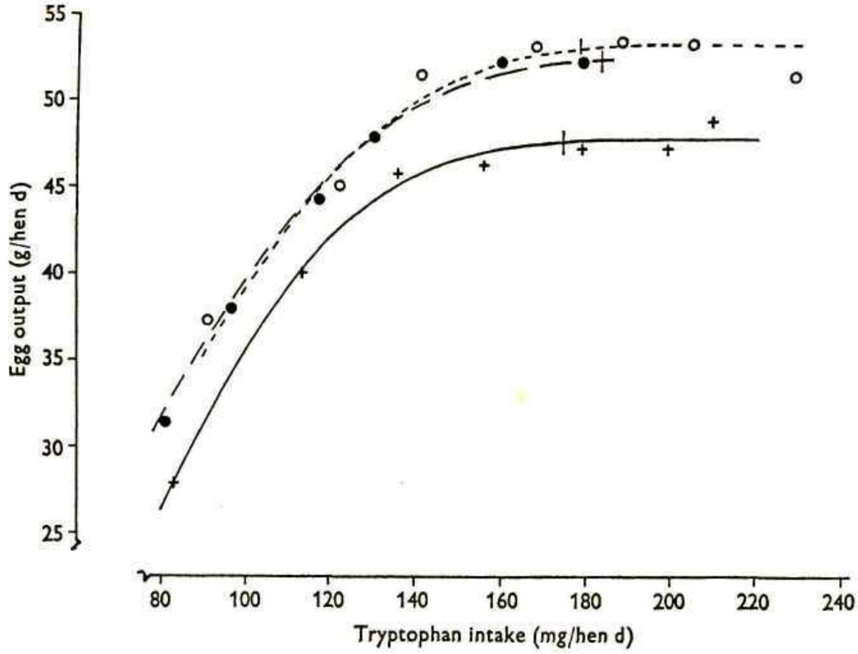

Figure 1.3. Responses to diets supplying different concentrations of tryptophan. (From Wethli and Morris, 1978). The fitted response curves were derived by using the Reading Model (Fisher, Morris and Jennings, 1973). Young pullets, • - - - •; older pullets, + — +; moulted hens, o - - - o. Vertical marks on the response curve represent optimal tryptophan intakes.

It can therefore be concluded that the efficiency of utilization of protein declines in older birds because egg output declines although their requirement for protein does not. It can be seen that all the research that has been conducted on the efficiency of utililization of protein has been done using laying hens. The question of declining efficiency in ageing broiler breeders needs to be investigated. This is an especially important factor when considering broiler breeder nutrition because the food intake of broiler breeders is restricted and the food allowance is manipulated in accordance with the changing requirements for egg production. It is therefore imperative to establish the amino acid requirements for all stages of their production cycle because if amino acids are limiting there will be a decrease in the rate of lay (Bowmaker and Gous, 1991).

Broiler breeder hens achieve lower peak rates of lay and exhibit poorer persistency of lay compared with egg-type hens (Robinson et al., 1993) (Figure1.4a). Robinson, Hardin and Robblee (1990) showed that low producing hens were characterized by both reduced clutch length and increased pause intervals. The reason why egg production is poorer in broiler breeder hens compared with egg-type hens is because they have shorter prime sequence lengths and therefore more pause intervals (Robinson *et al.*, 1993) (Figure 1.4b). It has been suggested that the reduction in hen-day egg production seen with advancing age is attributable to a reduction in length of laying sequence from the time of peak egg production, and to an increase in the incidence of inter-sequence pauses of greater than one day duration (Robinson *et al.*, 1990).

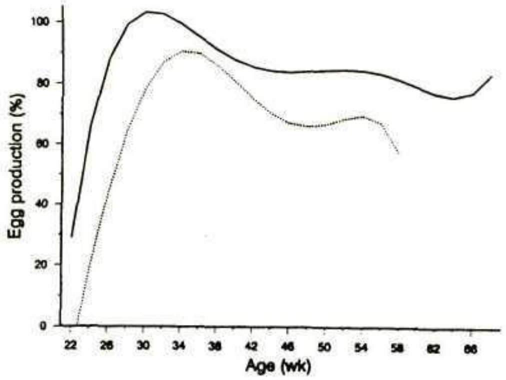

Figure 1.4a. Profiles of percentage egg production for laying hens (—) and broiler breeder hens (·····). The laying hens consumed food *ad libitum* and the broiler breeder hens were food-restricted to typical industry levels. (From Robinson *et al.*, 1993).

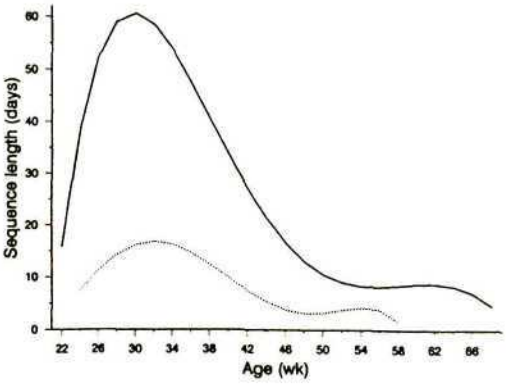

Figure 1.4b. Profiles of sequence length for laying hens (—) and broiler breeder hens (·····). The laying hens consumed food *ad libitum* and the broiler breeder hens were food-restricted to typical industry levels. (From Robinson *et al.*, 1993).

When birds have pause intervals of greater than one day duration the rate of egg production falls below 50% and closed cycles cannot be maintained. When this happens the efficiency with which dietary protein is utilized declines. Declining efficiency is therefore probably more of a problem in broiler breeders. There is an increase in the number of poor layers when compared to egg-type birds, especially as the birds get older. The reason for this decline in efficiency is that variations in protein deposition greater than those shown in Figure 1.1 occur, either because the deposition of egg white is more discontinuous or because yolk protein synthesis itself becomes phasic (Fisher, 1980).

Evidence that yolk protein synthesis becomes phasic can be seen by the fact that poor production in older broiler breeders has been attributed to birds with fewer developing yellow follicles. At 45 and 60 weeks of age egg production is lower than at younger ages because the number of yellow follicles is fewer (Hocking *et al.*, 1987). Yellow follicles are more numerous and more closely ranked in hierarchies in 26 week old hens than in 82 week old hens (Williams and Sharp, 1978).

1.3.2.4 Relationship between protein intake and rate of egg output

Most of the factors which affect the response to protein will also have a direct effect on production itself. Thus the general problem of variations in protein requirement can be studied by looking at the relationship between rate of output and the level of protein intake required to support it under different conditions. We can thus study the effects of different factors on the protein requirements of laying birds by comparing the curves relating protein intake to egg output under different conditions.

The Reading Model (Fisher *et al.*, 1973) was designed to describe the response of groups of laying hens to different levels of amino acid intake. The model is based on the assumption that a bird's required intake of amino acid is proportional to its bodyweight and its potential egg output. It is assumed that each individual bird has a characteristic maximum level of egg output (E_{max}) and that, for each bird when $E < E_{max}$, then

$A = aE + bW$

where A is the amino acid intake in mg/bird d

E is the egg output in g/bird d

W is the bodyweight in kg

a is the amount of amino acid in mg required to produce 1 g of egg output

b is the amount of amino acid in mg required to maintain 1 kg of bodyweight

It is also assumed that $A < bW$, when $E = 0$, thus excluding negative egg production. These relationships are illustrated in Figure 1.5a. The response for a group of birds is derived as the average of the individual responses. The group response shows three characteristics, a straight line leading through a curve to a flat plateau (Figure 1.5b). The shape and position of the line are a function of the following parameters: $\overline{E}_{max}$, the mean maximum egg output; variation in E_{max}; $\overline{W}$, the mean bodyweight; variation in W; r_{ew}, the correlation between E and W; a and b, the quantities of amino acid associated with a unit of E and a unit of W respectively.

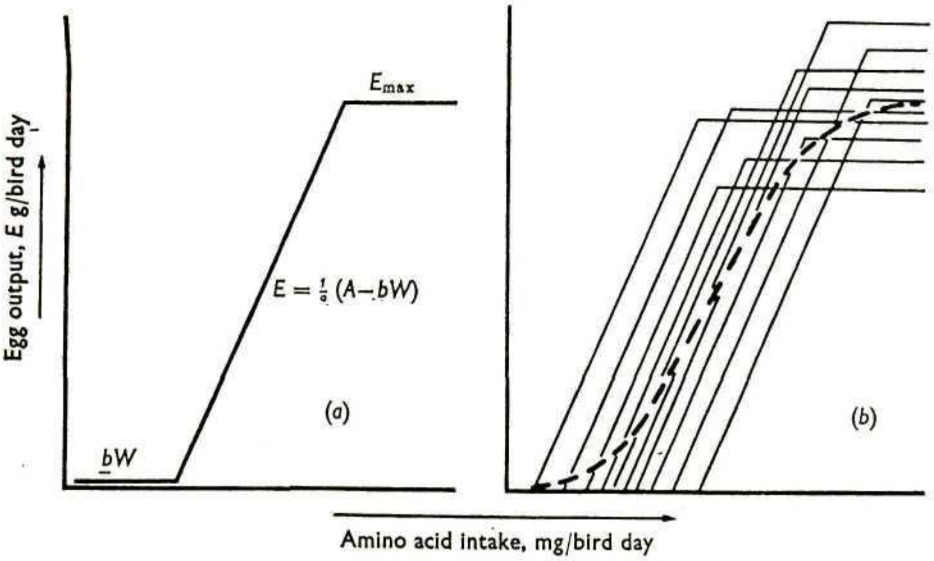

Figure 1.5. The model proposed for the response of laying hens to amino acid intake (a) the response of an individual bird (b) individual (—) and mean (– –) responses for a small group of birds. See text for meaning of symbols. (From Fisher *et al.*, 1973).

The equations for determining the amino acid intake required to sustain a given level of egg output and bodyweight, derived by fitting the Reading Model (Fisher *et al.*, 1973), have been compared for broiler breeders (Bowmaker and Gous, 1991) and laying hens (MacDonald and Morris, 1985) (Table 1.1).

Table 1.1. Requirements for amino acids for broiler breeders and laying hens obtained from fitting the Reading Model

		lysine intake	lysine requirement (mg)
Bowmaker and Gous (1991)	Broiler breeders	16.88E + 11.2W	793
MacDonald and Morris (1985)	Laying hens	9.99E + 73W	669
		methionine intake	methionine requirement (mg)
Bowmaker and Gous (1991)	Broiler breeders	7.03E + 1.52W	321
MacDonald and Morris (1985)	Laying hens	4.77E + 31W	306

The coefficient for egg production and the maintenance coefficient in the above response equations differed for broiler breeders and laying hens. The maintenance coefficient for both lysine and methionine was much lower for broiler breeders whilst the coefficients for egg production were much higher. The reason why the coefficient for egg production is higher for broiler breeders than for laying hens could be explained by the fact that broiler breeders have a much poorer rate of laying (more pause days) than laying hens, *i.e.* the efficiency of utilization of amino acid is poorer and therefore they appear to require more of the amino acid per gram of egg output. The reason why the coefficients for maintenance are lower is that the two coefficients are negatively correlated. It would be very useful to compare the response curves for broiler breeder hens at different ages (stages of production). It cannot be assumed that the coefficients for maintenance and egg production are the same at all stages. It is important to know the optimum amino acid requirements for each stage of production. The maximum egg output declines in older birds because they have a much poorer rate of laying (more pause days) than younger hens ie. the efficiency of utilization of amino acids is poorer.

1.3.2.5 Determining the efficiency of utilization of amino acids

The efficiency with which amino acids are utilized for egg production can be determined by comparing the estimates of the coefficient for egg output with the amount of amino acid deposited in the egg (Table 1.2). The efficiency of conversion of dietary amino acid to egg protein for laying hens has been calculated to range between 0.74 and 0.85 (Fisher, 1980; MacDonald and Morris, 1985). The efficiency of utilization for broiler breeders was found to be only 0.47 for lysine and 0.5 for methionine (Bowmaker and Gous, 1991), but not all these birds were laying at a rate of > 50%.

Table 1.2. Efficiency of utilization of amino acids for laying hens and broiler breeders

	amino acid	'a' (mg/g egg)	egg (mg/g)	efficiency
Macdonald and Morris (1985)	Lysine	9.99	7.90	0.79
Macdonald and Morris (1985)	Methionine	4.77	3.51	0.74
Fisher (1980)	Methionine	4.36	3.67	0.84
Bowmaker and Gous (1991)	Lysine	16.88	7.90	0.47
Bowmaker and Gous (1991)	Methionine	7.03	3.51	0.50

'a' = an estimate of the amount of amino acid required to produce 1 g of egg output

In order to test the hypothesis that broiler breeders laying in closed cycles have the same net efficiency for egg production as laying hens, Bowmaker and Gous (1991) performed an analysis in which birds laying fewer than 14 eggs in the final 28 day period ie. birds laying at less than 50%, were excluded. For lysine the coefficient for egg production decreased from 16.88 to 13.9 and the maintenance coefficient also decreased from 11.2 to 0.56. For methionine the coefficient for egg production decreased from 7.03 to 5.36 and the maintenance coefficient increased from 1.52 to 1.87. These adjusted coefficients give an efficiency of 0.57 for lysine and 0.65 for methionine, values closer to those suggested above for laying hens.

In order to test the hypothesis that the efficiency of utilization declines in ageing broiler breeders when their rate of lay declines to below 50%, efficiency could be calculated for individual birds at different ages. This could be done by establishing the amount of protein deposited in the egg output and the amount of protein that is available for this egg output.

The efficiency of utilization of the limiting amino acid for egg production appears to be relatively constant when different breeds of laying fowl are compared at the same age. Large differences in protein utilization can be demonstrated when birds are compared at different stages of lay. This is very important when considering broiler breeders because they have much lower rates of egg production than laying hens (Fisher, 1980).

1.3.2.6 Rate of lay and egg weight

It has been shown that when broiler breeders are fed diets limiting in an amino acid, rate of lay declines considerably at the lower intakes of that amino acid. Egg weight also declines as the amino acid supply is reduced (Morris and Gous, 1988; Bowmaker and Gous, 1991). However egg weight does not decrease to the same extent as rate of lay.

Morris and Gous (1988), using data from a wide range of published trials showed that egg weight and rate of lay were affected to the same extent until the amino acid supply was reduced to 0.9 of that required for maximum output. Egg size did not fall below 0.9 of its maximum value until amino acid supply was well below 0.5 of the optimum value, whereas rate of lay was only about 0.7 of its potential value when amino acid intake was 0.5 of the optimum. (Figure 1.6).

Bowmaker and Gous (1991) showed that egg weight and rate of lay were affected to the same extent until the amino acid supply was reduced to 0.64 of that required for maximum output. As amino acid supply was reduced further, rate of lay declined almost linearly to a low of 0.2 of the maximum, whereas egg weight, at the lowest point, was 0.8 of the maximum.

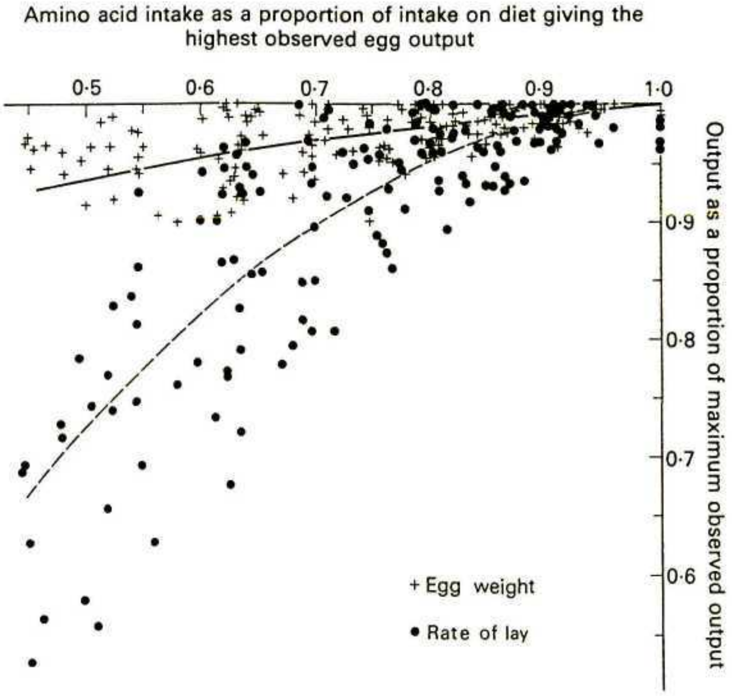

Figure 1.6. The relationship between intake of a limiting amino acid and rate of lay (----) or egg weight (—). (From Morris and Gous, 1988).

1.4 CONCLUSION

The task of determining the nutrient requirements of broiler breeders and making recommendations for optimal nutrient intakes is somewhat problematic. Broilers have been selected for improved growth rate, and the food intake of broiler breeders, therefore, has to be restricted throughout the rearing and laying periods to below *ad libitum* intake as bodyweight is negatively correlated with egg production (McDaniel *et al.*, 1981b).

The current method of food restriction employed in commercial broiler breeder operations is to offer the birds one feed throughout the laying period and to adjust the food allowance according to the egg production. The food allowance is increased until peak production is reached and then it is reduced as egg production declines. Little published evidence is available to suggest that optimum performance is achieved with this pattern of feeding.

One of the problems with this approach is the difficulty of adjusting nutrient supply in sync with the changing requirements of the birds. It has been shown that if broiler breeders are overfed and their energy intake is in excess of that required for maintenance and egg production, they show an increase in bodyweight and that this increase in bodyweight is due to an increase in fat deposition. This accumulation of body fat leads to a decrease in reproductive performance (Pearson and Herron, 1981). However, it has been shown that fattened broilers do utilize their excess fat reserves as an energy source providing the dietary protein is sufficiently high to allow this (Gous *et al.*, 1992). It is therefore possible that broiler breeders could be made to utilize their body lipid reserves as an energy source. If this is possible it means that if these birds are overfed, resulting in obesity, at any stage of their production cycle, it may be possible to rectify this situation by decreasing their energy intake to below requirement. It also means that if the energy supplied to the birds is below requirement, for example on a cold day, it may not be as serious a problem as previously thought.

A second problem with this approach is that it has been shown in laying hens that the efficiency of utilization of protein declines in older birds and their protein requirements therefore do not decrease as birds age even though there is a decline in egg output (Wethli and Morris, 1978; Fisher, 1980). The current method of decreasing the food allowance of broiler breeders after peak production is reached may not be the most ideal way to feed these birds because although their energy requirements decline at this stage there is no evidence to suggest that their protein requirements decrease. Therefore, decreasing the food allowance and thereby decreasing their protein intake at this stage may cause their egg production to decline faster than it should.

This study was designed, firstly, to measure the extent to which broiler breeders could be made to utilize their excess body lipid reserves in order to maintain laying performance, and secondly, to measure the efficiency of utilization of protein in broiler breeder hens at different stages of the laying period in an attempt to determine their optimum economic protein intake throughout lay.

CHAPTER 2

THE RESPONSE OF OVERFAT BROILER BREEDER HENS TO FEEDS DIFFERING IN PROTEIN AND ENERGY CONTENT

2.1 INTRODUCTION

It is accepted that if broiler breeders are overfed they deposit the excess energy as carcass fat and show a marked reduction in egg production, fertility and hatchability (Pearson and Herron, 1981; McDaniel *et al.*, 1981b). At present it is thought that this situation cannot be rectified, the conventional wisdom being that if food intake is reduced in order to encourage the birds to make use of lipid reserves, egg production will decline. It is also thought that if broiler breeders are underfed, for example on cold days, there will be insufficient energy available to maintain their egg production at its potential. However, Gous *et al.* (1992) showed that fattened broilers do utilize their excess fat reserves as an energy source provided the dietary protein intake is sufficient to allow this. The objective of this experiment was to determine the extent to which overfat broiler breeders could be made to utilize excess body lipid reserves whilst maintaining laying performance.

It was decided to use birds that had been overfed and were therefore overfat and to feed these birds diets varying in protein and energy contents. It was necessary to use individual rather than group responses, due to the fact that there would be a great deal of variation in food intakes and therefore nutrient intakes within a group.

2.2 MATERIALS AND METHODS

2.2.1 Birds and management

Seventy overfat (mean bodyweight - 3912g) broiler breeder hens (Ross 788) aged 47 weeks were transported overnight from Gauteng. One died during transport and the remaining 69 were kept on the floor with plenty of drinking water for one day. A vitamin and mineral premix was added to the drinking water. The birds were then transferred to individual cages in a light - tight house (10m x 7.7m x 3.5m). The wire cages which measured 75 cm x 48cm x 33cm, were arranged in six rows, back to back , each row having two levels of 48 cages. Only the lower level cages were used and one cage was left vacant between each bird. Each cage was supplied with one nipple drinker and drip-cup and one feeder (10cm x 30cm). The house was cross-ventilated by using six fans. It was made light-tight with baffles over the fan openings and it was insulated. The lighting regime was 16L:8D throughout the trial.

Initially the birds dropped some body feathers and it appeared that they might have been starting to moult. Egg production was monitored for two weeks. Egg numbers did not drop but remained at an average of about 60 %, so it was decided to start the feed treatments at 49 weeks of age. Five birds were sacrificed at this time and these were analyzed for fat, protein, moisture and ash. The remaining 64 birds were divided into 11 groups (ten groups of six and one group of four) according to their egg production for the previous two weeks. (Table 2.1).

Table 2.1. The range in rate of lay for the 11 groups

Number of groups	Range in rate of lay (%)
1	64 - 78
4	57 - 64
2	50 - 57
1	43 - 50
1	35 - 43
1	14 - 28
1	> 7

2.2.2 Treatments and feeds

Prior to the start of the experiment the birds had been kept on a restricted food program, being fed 172 g/bird d of a commercial broiler breeder feed (11.9 MJ ME/kg, 0.578% lysine and 2.5% calcium).

During the experimental period the birds were given one of two feeds - 1) protein content of 18.30 g/kg; energy content of 10.50 MJ ME/kg (HP/LE); 2) protein content of 13.03 g/kg; energy content of 12.50 MJ ME/kg (NP/NE) (Table 2.2). These feeding treatments were chosen so that the protein intakes would be the same for treatments (1) and (5) (approx. 20 to 21 g/bird d) and the energy intakes would be the same for treatment (2) and (4), (approx. 1400 to 1500 kJ/bird d). The two feeds were analysed for AME, protein, calcium, phosphorus and amino acid content. Each of the two feeds was fed at three different rates of allocation, making six feeding treatments (Table 2.3).

Each bird in a group was randomly allocated to one of the six feeding treatments.

Table 2.2. The composition (g/kg) of the two feeds

Ingredient	NP/NE		HP/LE	
Maize	580		300	
Sunflower	59.4		200	
Soyabean oilcake	20.0		12.0	
Fishmeal	23.0		21.0	
Wheat bran	210.0		380.0	
Oil	40.0		20.0	
Monocalcium phosphate	3.0			
Limestone	61.7		61.6	
Salt	3.2		2.5	
L-Lysine HCl	0.1			
DL-Methione	0.2		0.5	
Vitamin and minerals	1.5		1.5	
Analysis	Calculated	Actual	Calculated	Actual
AME (MJ/kg)	12.50	12.51	10.50	10.79
Protein (N x 6.25)	13.03	13.70	18.30	18.50
Lysine	5.78	5.89	7.78	8.32
Methionine	2.68	2.73	3.57	3.42
TSAA	6.92	——	6.92	——
Tryptophan	1.42	——	2.20	——
Arginine	——	9.28	——	13.30
Threonine	——	4.65	——	6.30
Isoleucine	——	5.94	——	7.97
Phe + tyr	——	10.06	——	13.34
Valine	——	4.02	——	10.14
Calcium	——	29.2	——	31.0
Phosphorus (available)	——	5.4	——	7.2

Table 2.3. The six dietary treatments

Treatment	Code	Allocation (g/bird d)	Feed	Protein (g/kg)	Energy (kJ ME/kg)
1	HP120	120	HP/LE	183.0	1050
2	HP140	140	HP/LE	183.0	1050
3	HPa	*ad libitum*	HP/LE	183.0	1050
4	NP120	120	NP/NE	130.3	1250
5	NP160	160	NP/NE	130.3	1250
6	NPa	*ad libitum*	NP/NE	130.3	1250

2.2.2.1 Feeding procedure

For treatments in which the birds were fed *ad libitum* the food for each bird was weighed out and placed in buckets on the floor in front of each cage. In the case of the restricted treatments the required food allowance for each day was weighed out into plastic bags and one plastic bag of food was fed each day. In the case of the *ad libitum* treatments three kilograms of food were weighed out into the buckets from which food was withdrawn when necessary.

2.2.3 Measurements

2.2.3.1 Bodyweight

Empty bodyweight was measured once a week. From the birds on the *ad libitum* treatments food was removed at 4:00 p.m. the day before weighing and the birds on the restricted treatments were not fed on the day until after weighing.

2.2.3.2 Food intake

In the case of the restricted treatments food remaining at the end of the day was not removed. Any food remaining at the end of the week was removed, weighed and discarded. Food intake was calculated by multiplying the relevant allocated amount by seven and subtracting the amount remaining at the end of each week. In the case of the *ad libitum* treatments the food remaining in the bucket was weighed weekly. Food intake was calculated by subtracting this from the original three kilograms. The bucket of food was then made up to three kilograms again.

2.2.3.3 Egg numbers and egg weight

Egg numbers were recorded daily. All the eggs were weighed on three consecutive days of each week. Egg output was calculated for each week by multiplying the daily average eggs laid per hen by the mean egg weight for the week.

2.2.3.4 Sacrificing of birds

At the end of the trial 24 birds were sacrificed (four birds per treatment). The abdominal fat pad was removed from each bird and weighed. The ovary was also removed and weighed. The number of follicles greater than six millimetres in diameter was recorded.

Five birds were chosen for carcass analysis on the basis of the distribution of the weights of their abdominal fat pads. They were chosen to represent the leanest, the fattest and three degrees of fatness between these extremes based on the fat pad weights. These carcasses were then analyzed for fat, protein, moisture and ash. This was done so that the weight of the abdominal fat pads could be regressed on the carcass fat content and therefore the carcass fat content of all the birds sacrificed could be estimated by regression.

2.2.4 Length of experiment

The trial ran for a total of seven weeks.

2.2.5 Statistical analyses

The changes in body mass, rate of lay, egg weight and egg output over time, were analysed by fitting a polynomial regression model to the data.

Regressions were performed of rate of lay on egg weight and of rate of lay, egg weight and egg output on body weight. A quadratic term was included which was dropped if it was not significant at the 5% level.

The mean response over the final four weeks was calculated for rate of lay, egg weight, egg output, bodyweight and change in bodyweight. An analysis of variance was performed on these means and Fisher's LSD comparisons were used to establish which treatments were significantly different from each other.

The mean response over the final four weeks was also calculated for food intake, protein intake and energy intake.

A regression analysis was performed of all the variables (rate of lay, egg weight, egg output and change in body mass) on protein intake and energy intake to establish the relationship between the protein and energy intakes and the responses. The model fitted was:-

$$\text{Response} = PR + PR^2 + PR^3 + ME + ME^2 + ME^3 + PR.ME$$

where PR = protein intake
and ME = energy intake

Any terms that were not significant at the 5% level were dropped.

For the five birds that were sacrificed and analysed at the beginning of the trial a regression of carcass fat on bodyweight was performed. A regression of carcass fat on bodyweight, for the 25 birds sacrificed at the end of the trial was performed.

For the five birds that were sacrificed and analysed at the end of the trial a regression analysis was performed of carcass fat content on abdominal fat content. This regression equation was used to calculate the carcass fat content from the abdominal fat contents, of the remaining 19 birds that were sacrificed at the end of the trial. An analysis of variance was then performed on these carcass fat contents and abdominal fat contents. Fisher's LSD comparisons were used to see which treatments were significantly different from each other.

2.3 RESULTS

The individual results were grouped according to treatment and are presented in Appendix 1. Three birds, which stopped eating during the trial and looked sick, were excluded from the analysis.

Considerable variation existed in body weights between individuals both between and within treatments. The highest body weight recorded was 4716 g, in week three on treatment NPa. The lowest body weight recorded was 2981 g, in week five on treatment HP120. Associated with the body weight data is the change in body weight. Some of the birds gained weight throughout the trial whilst others lost weight. The highest mean weight loss was 17.1 g/bird d, during week one on treatment HP120. The highest weight loss for this week on this treatment was 39.0 g/bird d. The highest mean weight gain was 26.9 g/bird d, also during week one on treatment NPa. The highest weight gain for this week on this treatment was 44.9 g/bird d.

The rate of lay for most of the birds was very erratic, increasing and decreasing throughout the trial. Nine birds stopped laying altogether during the trial. In six cases (three of which were on one of the 120 g/bird d treatments) this coincided with the loss of large amounts of body feathers, indicating a moult. At least one of the birds on treatments HP140, HPa, NP160 and NPa reached a rate of lay of 85.7% (six eggs/week) for at least one week of the trial. Only two birds reached a rate of lay of 100% during the trial and only for one week.

The highest egg output of 76.4g/bird d was attained in week one on treatment HPa. The highest egg weight of 90.7g was attained in week five, also on treatment HPa.

Some of the birds on the *ad libitum* treatments consumed well over 200 g/bird d. For example the mean for week five on treatment HPa was 223.3 g/bird d and one of the birds had a food intake of 272.6 g/bird d for this week on this treatment.

The mean rate of lay, egg weight, egg output and body mass for each treatment plotted against time are shown in Figures 2.1 to 2.4.

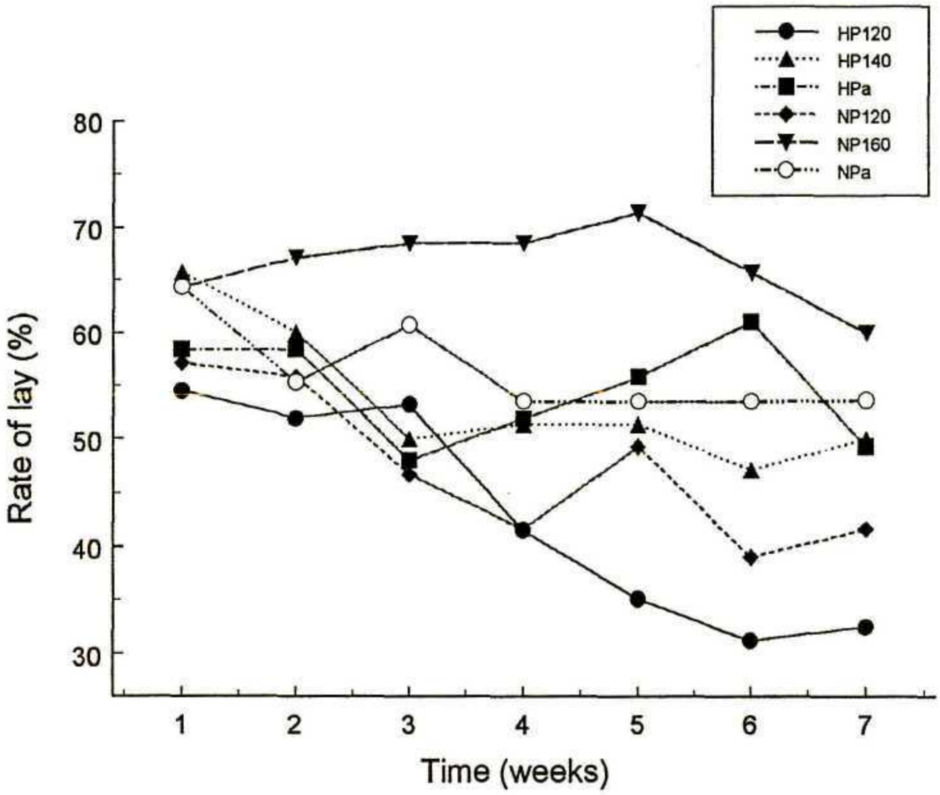

Figure 2.1. Mean rate of lay for each treatment over time.

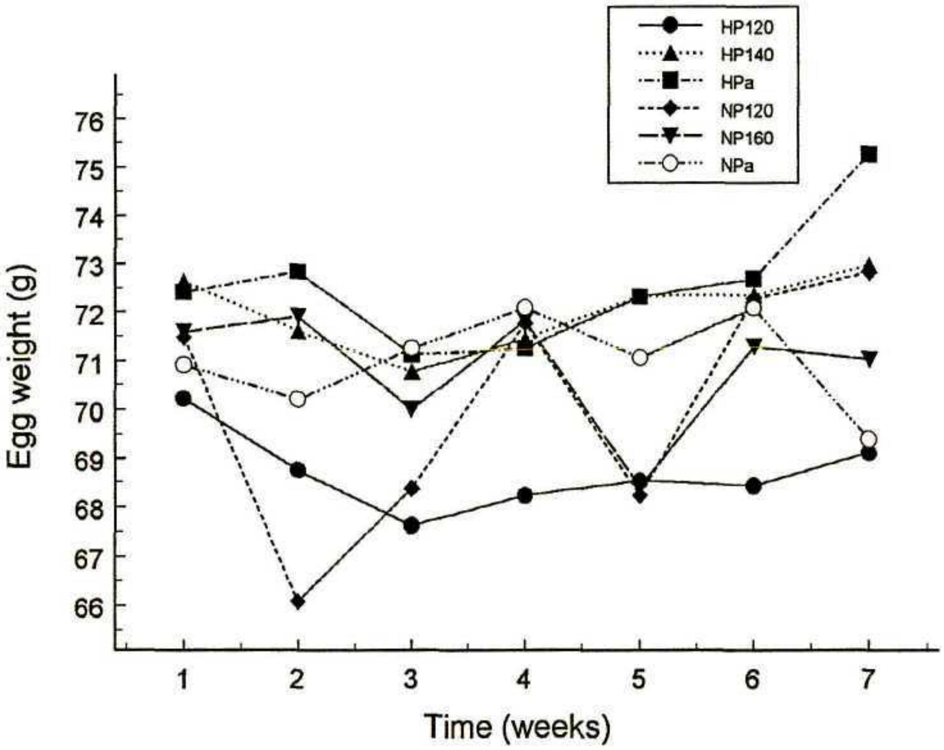

Figure 2.2. Mean egg weight for each treatment over time.

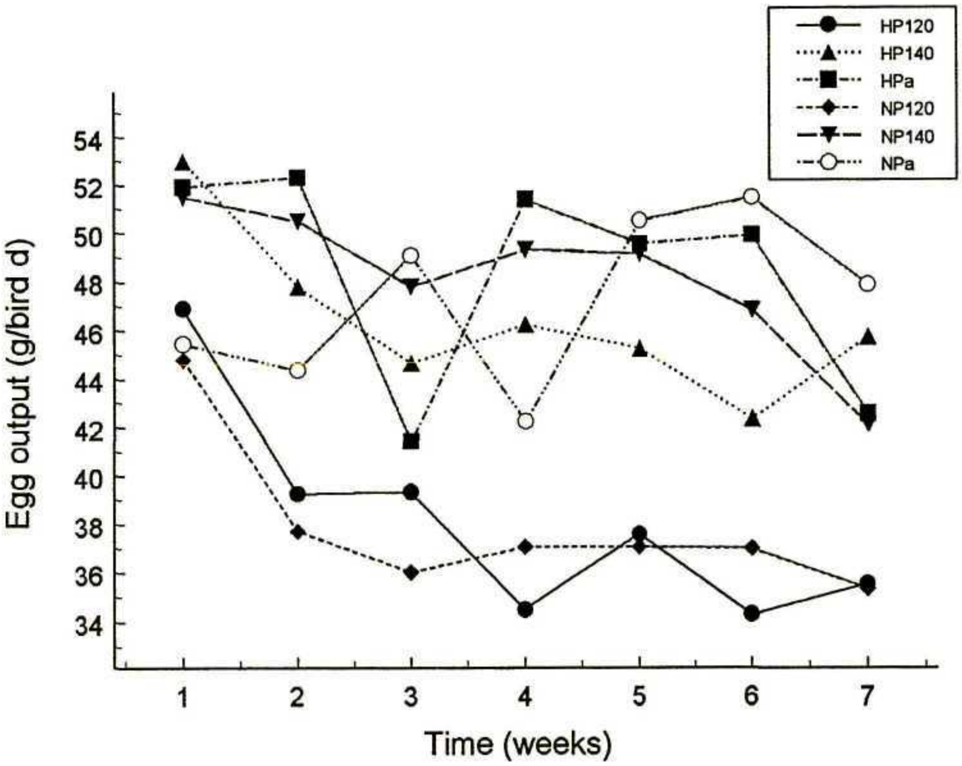

Figure 2.3. Mean egg output for each treatment over time.

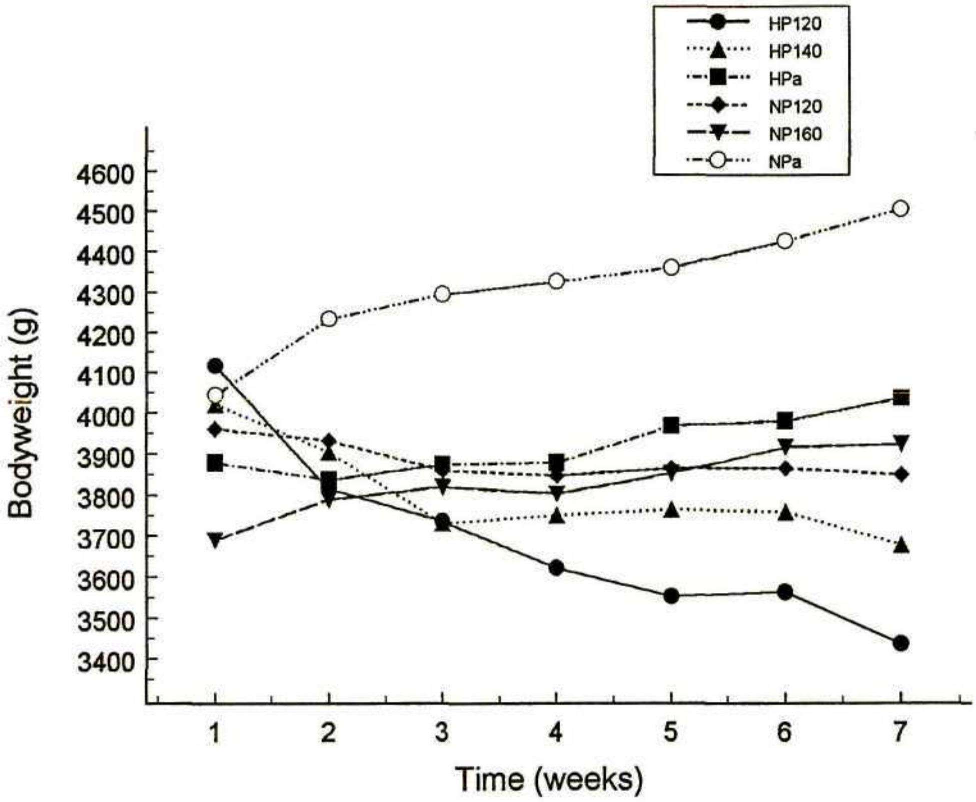

Figure 2.4. Mean bodyweight for each treatment over time.

The regression equations for the changes, in body mass, rate of lay, egg weight and egg output over time are presented in Table 2.4.

Rate of lay decreased over time for all treatments. The relationship between rate of lay and time was significantly linear ($p<0.01$). The slopes of the lines for the different treatments were the same, indicating that there were no significant differences between treatments in the rate of decrease in rate of lay.

There was no significant relationship between egg weight and time.

There was a significant cubic relationship between egg output and time ($p<0.05$). The slopes of the lines for the different treatments were all the same, indicating that there were no significant differences between treatments in the rate of change in egg output.

There was a significant linear relationship between bodyweight and time ($p<0.01$). The significant differences between the slopes of the lines for the different treatments, indicated that there were significant differences in the rate of change in bodyweight.

Treatments HP120, HP140 and NP120 showed a decrease in mean bodyweight over time. These slopes were not significantly different from each other. Treatments HPa, NP160 and NPa showed an increase in mean bodyweight over time. These slopes were not significantly different from each other.

Table 2.4. Summary of the regressions over time

Treatment	Rate of lay		Egg output				Weight gains	
	a	b	a	b	b^2	b^3	a	b
HP120	-51.24	-2.098	51.84	-11.11	2.76	-0.216	4081.5	-97.6
HP140	-62.04	-2.098	59.92	-11.11	2.76	-0.216	3985.6	-46.2
HPa	-63.11	-2.098	61.82	-11.11	2.76	-0.216	3800.6	30.4
NP120	-55.70	-2.098	51.30	-11.11	2.76	-0.216	3949.9	-16.7
NP160	-74.90	-2.098	61.61	-11.11	2.76	-0.216	3686.7	35.3
NPa	-64.75	-2.098	60.33	-11.11	2.76	-0.216	4051.0	65.5

The regression of rate of lay on egg weight was not significant.

$$rol = 23.6 - 0.443\ ew$$

$$R^2 = 1.4\%$$

The regressions of rate of lay , egg weight and egg output on body weight were not significant.

$$rol = 101 - 0.0132\ bw$$

$$R^2 = 5.4\%$$

$$ew = 71.3 - 0.00009\ bw$$

$$R^2 = 0.0\%$$

$$eo = 72.5 - 0.00852\ bw$$

$$R^2 = 6.3\%$$

The mean response over the final four weeks for rate of lay, egg weight, egg output, bodyweight and change in bodyweight are presented in Table 2.5 together with their standard error's (SE) and the coefficient of variation (CV).

The mean response over the final four weeks for food intake, protein intake and energy intake are presented in Table 2.6 together with their SE's.

Table 2.5. Mean response to all treatments over the final four week period

Rate of lay (%)	Mean	SE	CV	
HP120	35.1	25.5	0.73	a
NP120	42.9	19.4	0.45	a
HP140	50.0	25.9	0.52	a b
NPa	53.6	26.9	0.50	a b
HPa	54.6	25.5	0.47	a b
NP160	66.4	10.9	0.16	b

Egg weight (g)	Mean	SE	CV	
HP120	68.7	3.7	0.05	a
NP120	70.3	4.1	0.06	a
NP160	70.6	5.1	0.07	a
NPa	71.3	4.2	0.06	a
HP140	72.3	5.4	0.07	a
HPa	73.1	8.5	0.12	a

Egg output (g/bird d)	Mean	SE	CV	
HP120	29.4	14.3	0.49	a
NP120	31.4	15.2	0.48	a
NPa	39.3	19.0	0.48	a b
HP140	44.9	6.2	0.14	b
NP160	46.9	7.9	0.17	b
HPa	46.9	12.2	0.26	b

Bodyweight (g)	Mean	SE	CV	
HP120	3543	328.6	0.09	a
HP140	3737	458.7	0.12	a
NP120	3857	456.7	0.12	b
NP160	3874	300.8	0.08	b
HPa	3966	219.0	0.05	b
NPa	4404	316.9	0.07	c

Change in body weight (g/bird d)	Mean	SE	CV	
HP120	-10.4	5.7	0.55	a
HP140	-7.2	6.2	0.83	a
NP120	-2.0	3.1	1.55	b
HPa	3.7	4.1	1.05	b c
NP160	5.7	3.0	0.52	c
NPa	7.9	6.5	0.82	c

Treatments with the same letters are not significantly different from each other at the 5% level.

Table 2.6. Mean response in food, protein and energy intakes to all treatments over the final four week period

Treatment	Food intake (g/bird d)		Protein intake (g/bird d)		Energy intake (kJ ME/bird d)	
	Mean	SE	Mean	SE	Mean	SE
HP120	113.9	15.6	20.8	0.3	1200	16.2
HP140	138.1	2.0	25.3	0.4	1450	21.1
HPa	184.2	65.8	33.7	2.1	1930	120.6
NP120	118.9	0.9	15.5	0.1	1490	11.1
NP160	153.5	9.6	20.0	1.3	1920	12.0
NPa	163.3	26.6	21.3	3.5	2004	11.8

The regression equations for rate of lay, egg output and weight gain on protein intake and energy intake are presented in Table 2.7.

Table 2.7. Summary of the regressions of all the variables on protein and energy intake

	Rate of lay			Egg output			Weight gains		
		SE	p		SE	p		SE	p
Constant	12.9	13.82	0.356	-80.1	41.03	0.057	-26.5	2.62	0.000
PR	—	—	—	4.28	1.79	0.021	-0.38	0.09	0.000
ME	22.1	7.82	0.007	60.12	21.95	0.009	20.6	1.74	0.000
PR.ME	—	—	—	21.95	-2.01	0.031	—	—	—
R^2		12.6%			27.1%			72.2%	

Neither protein intake nor energy intake had a significant effect on egg weight. Protein intake did not have a significant effect on rate of lay. There was a significant linear relationship between rate of lay and energy intake. Rate of lay increased with increasing energy intake. The R^2 value was very low indicating a large amount of variation in rate of lay.

There was a significant linear relationship between egg output and protein intake and energy intake. Egg output increased with increasing energy and protein intake. The interaction between protein intake and energy intake was significant for egg output. The R^2 value was very low for egg output indicating a large amount of variation in egg output.

There was a significant linear relationship between the change in bodyweight and protein intake and energy intake. The gain in weight increased with increasing energy intake and decreased with increasing protein intake.

The relationship between carcass fat and bodyweight for the five birds that were sacrificed and analysed at the beginning of the trial was not statistically significant.

$$\text{car. fat} = -45 + 0.0598\ \text{bw}$$

$$R^2 = 41.9\%$$

The regression of carcass fat on bodyweight, for the 25 birds that were sacrificed at the end of the trial, was highly significant (Figure 2.5).

The relationship between carcass fat content and abdominal fat content for the five birds that were sacrificed and analysed at the end of the trial was found to be highly significant ($p<0.01$) (Figure 2.6). The mean carcass fat contents and abdominal fat contents for the 25 birds that were sacrificed and analysed at the end of the trial are presented in Table 2.8 together with their SE's. The mean ovary weights and number of follicles for these birds are shown in Table 2.9, together with their SE's.

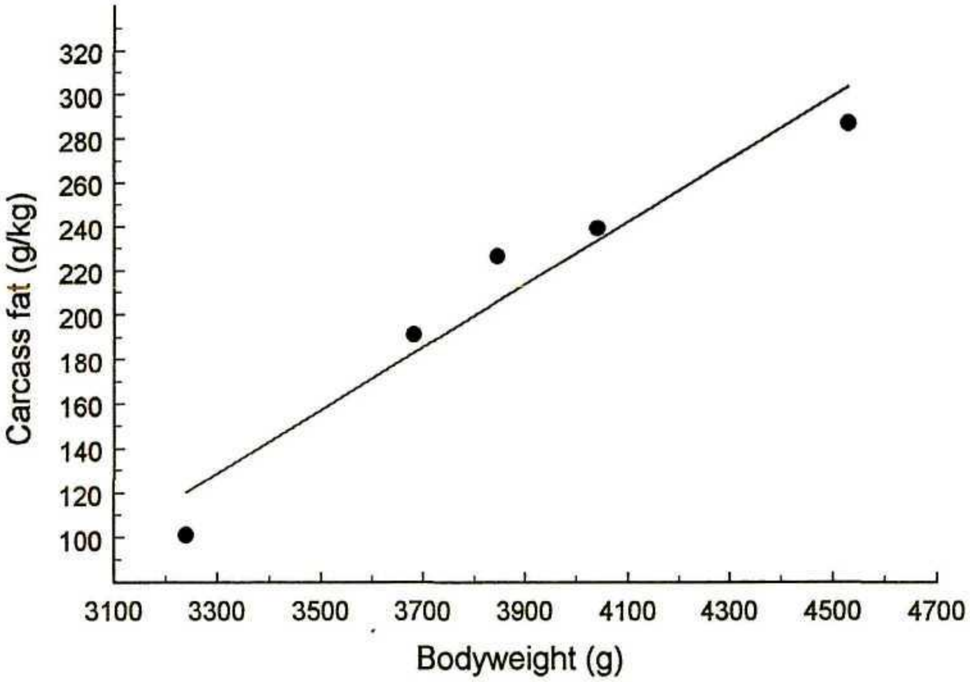

Figure 2.5. The relationship between final carcass fat (g/kg) and bodyweight (g)

car. fat = - 340 + 0.142 bw

$R^2 = 94.0\%$

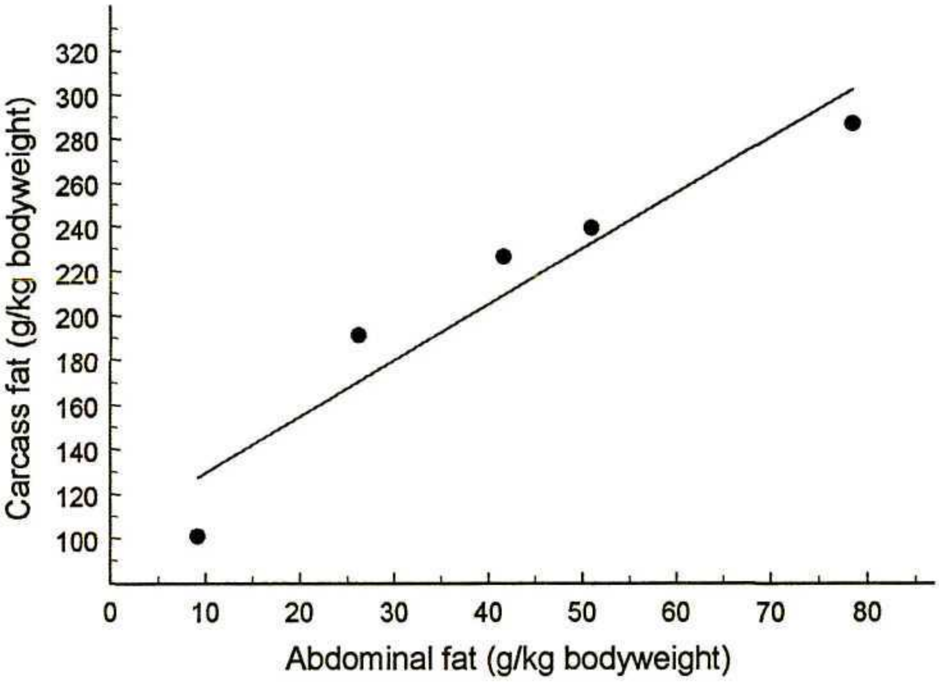

Figure 2.6 . The relationship between carcass fat content (g/kg) and abdominal fat pad content (g/kg)

car. fat = 104 + 2.53 abd. fat

$R^2 = 91.1\%$

Table 2.8. Mean final carcass fat content and abdominal fat content

Abdominal fat contents (g/kg)				Carcass fat (g/kg)			
Treatment	Mean	SE		Treatment	Mean	SE	
HP120	26.47	11.06	a	HP120	171.0	28.0	a
HP140	27.76	11.18	a	HP140	174.2	28.2	a
HPa	42.23	8.53	a b	HPa	210.8	21.6	a b
NP160	45.59	12.17	b	NP160	219.3	30.8	b
NP120	45.74	17.69	b	NP120	219.7	44.8	b
NPa	55.15	11.66	b	NPa	243.5	29.5	b

Treatments with the same letters are not significantly diifferent from each other at the 5% level.

Table 2.9. Mean ovary weight and number of follicles

Ovary weight (g)				Number of follicles			
Treatment	Mean	SE		Treatment	Mean	SE	
HP120	37.42	27.40	a	HP120	4.167	2.930	a
HP140	46.73	20.44	a	HP140	4.667	1.506	a
NP120	50.48	21.61	a	NP120	5.000	2.000	a
HPa	61.97	11.64	a	NPa	5.000	2.760	a
NP160	63.78	9.21	a	HPa	5.667	0.516	a
NPa	64.92	33.2	a	NP160	5.667	0.516	a

Treatments with the same letters are not significantly diifferent from each other at the 5% level.

2.4 DISCUSSION

The task of meeting the energy requirements of broiler breeder hens, throughout their various stages of production, is a difficult one, because their food intake is restricted. The problem of overfeeding broiler breeders is a real concern to any broiler breeder manager, because it leads to the deposition of body fat which has a negative effect on reproductive performance (McDaniel *et al.*, 1981b; Pearson and Herron, 1981). Underfeeding these birds is also a concern, especially with day to day fluctuations in temperature. If broiler breeders could be made to utilize their body fat reserves as an energy source it would certainly go a long way in alleviating these difficulties. In this experiment, feeding overfat broiler breeders diets varying in protein and energy content revealed some very interesting results concerning these issues.

The significant cubic relationship for egg output indicates that the egg output followed no pattern but was increasing and decreasing throughout the experiment. Although the slopes for treatments HP120, HP140 and NP120 were not significantly different for weight gain, mean bodyweight for treatment HP120 decreased most rapidly (97.6 g/week) followed by HP140 (46.2 g/week) and then NP120 (16.7 g/week). The reason why those on the restricted HP treatments lost more weight than those on the NP120 treatment is probably that their energy intakes were lower and their protein intakes were higher. Weight gain increased with increasing energy intake and decreased with increasing protein intake. Although the slopes for treatments NPa, NP160 and HPa were not significantly different, bodyweight for treatment NPa increased most rapidly (65.5 g/week), followed by NP160 (35.5 g/week) and then HPa (30.4 g/week). This was probably because NPa had the highest energy intake and NP160 and HPa had similar energy intakes but HPa had a much higher protein intake. The increase in weight gain with increasing energy intake was probably because the birds were fed less than their *ad libitum* requirement. Their egg output was therefore limited by protein intake, thus the excess energy was stored as body fat. The decrease in weight gain with increasing protein intake was probably due to the fact that egg output increased with increasing protein intake. The energy requirement for egg output therfore increased and there was less excess energy available for body fat reserves.

The significant interaction between energy intake and protein intake for egg output was because of the fact that at high protein intakes the birds need sufficient energy to utilize the protein for egg production. The egg weight was not significantly different for any of the treatments. This was because the protein intake and the energy intake had no effect on egg weight.

The rate of lay and egg output were significantly lower for birds on treatments HP120 and NP120 than birds on treatments NP160, Npa and HPa. However, the rate of lay and egg output for the birds on treatment HP140 was not significantly lower than for those on the NP160, NPa and HPa treatments. This shows that overfat broiler breeders can maintain their egg output at an energy intake that is much lower than has been recommended. The energy intake for treatment HP140 was only 1450 kJ/bird d. The Ross breeding company recommendation for energy intake during the laying period is 1898 to 1914 kJ ME/bird d. Pearson and Herron (1981) recommended an energy intake for broiler breeders in cages of 1730 kJ/bird d. The optimum energy intake reported by Bowmaker and Gous (1991) was 2000 kJ/bird d. The birds in this study must have been obtaining the additional energy required for egg production that was not available in the food, from their body fat reserves. The fact that the HP140 treatment had significantly lower bodyweights, abdominal fat contents and carcass fat contents confirms that they were obtaining the extra energy required for egg production from their body fat reserves.

The birds on treatments HP120 and HP140 treatments had significantly lower bodyweights and significantly lower abdominal fat contents and carcass fat contents than the birds on the other four treatments. These two treatments also had the two lowest energy intakes. Pearson and Herron (1982) found that the differences in bodyweight of birds at 64 weeks of age was associated with the energy content of the diet. Bodyweight increased with increasing energy content of the diet and the differences in bodyweight were mainly due to differences in body fat content of the birds. It can be seen in the present study that there was a strong relationship between bodyweight and carcass fat content at the end of the experimental period when the birds were 56 weeks of age. Body fat content at the end of the laying period was only measured for five of the birds but there was a strong relationship between abdominal fat pad content and carcass fat content which enabled the carcass fat content of the remaining 19 birds to beestimated. It has been shown previously that abdominal fat content and total body lipid are highly correlated (Becker, Spencer, Mirosh and erstrate, 1979; Gous, Emmans, Broadbent and Fisher, 1990).

It would appear that in order for broiler breeders to utilize their excess body fat reserves as an energy source for egg production their protein intake has to be sufficiently high to maintain egg output. Birds on treatment NP120 had an energy intake of 1490 kJ ME/bird d, which was almost the same as those on treatment HP140 but the protein intake was only 15.5 g/bird d. This was obviously insufficient protein to maintain egg output. The recommendation made for protein intake by Ross is 23.7 to 24.8 g/bird d. Waldroup, Hazen, Brussel and Johnson (1976) reported a value of 20 to 22 g/bird d of protein for maximum egg output. Pearson and Herron (1981) found that 21.3 g/bird d was sufficient for maximum egg production.

The birds on treatment NP120 did not have significantly different bodyweights, abdominal fat contents and carcass fat contents from those on treatments NP160, NPa and HPa. This implies that they did not make use of their body fat reserves as an energy source for egg production. This was probably because the energy in the diet was sufficient to meet the energy requirement for the low egg output that was a result of their reduced protein intake.

The birds on treatment HP120 also had a significantly lower egg output from those on treatment HP140. These birds had the same protein intake as that for treatment NP160 but had a much lower energy intake (only 1200 kJ ME/bird d) than treatment NP160. These birds must have made use of their body fat reserves because they had significantly lower bodyweights, abdominal fat contents and carcass fat contents. However, the energy in the diet and the energy available from body fat reserves was obviously not sufficient to maintain egg production.

It has been shown that if energy is supplied in excess of requirement at any stage during the life of a broiler breeder hen it is deposited as body fat. This leads to a decrease in egg production and fertility (McDaniel *et al.*, 1981b; Pearson and Herron, 1981; Robinson *et al.*, 1991). Decreasing the number of hatchable eggs obtained from these birds. However, there is evidence from the present study indicating that broiler breeders can draw on their body fat reserves. They can use these reserves as an energy source whilst maintaining egg production for at least a limited period of time, if their protein intake is sufficiently high to allow this. It is therefore possible that if broiler breeders are overfed at any stage of their productive lives they can be made to utilize their body fat reserves as an energy source by decreasing the energy content of the diet. This would lead to a decrease in bodyweight and could possibly mean a greater persistency in egg production.

It is thought that controlling the energy intake of broiler breeders according to their energy requirements is critically important. However, if these birds can be made to utilize their body fat reserves, as indicated in the present study, it may mean that it is not critical that their energy intake is adjusted in accordance with their requirements. It is probable that if there is a drop in environmental temperature they would be able to use their body fat reserves as an energy source to meet the extra requirements for energy, for at least a few days. Adjusting their energy intake at times like this would therefore not be critical to obtaining maximum productive output.

From this study, there is evidence to suggest that meeting the energy requirements of broiler breeders may not be as difficult a task as has been thought and controlling the day to day changes in energy requirement may not be as critical. The indications are that it is probably better to underfeed the birds than to overfeed them because they can draw on their body fat reserves and this would mean that the problems associated with obesity would be alleviated.

Further investigation needs to be undertaken to quantify the changes in body composition that take place in broiler breeders fed diets varying in protein and energy content. Researchers have shown that isotope dilution can be used to estimate total body water, and because this varies inversely with body fat content on a live weight basis the latter can be predicted from the former with acceptable accuracy. The isotopes that have been used for this technique are tritiated water (TOH) and deuterium oxide (D_2O) (Farrel, 1974; Johnson and Farrel, 1988; Farrel and Balnave, 1977).

CHAPTER 3
THE RESPONSE OF BROILER BREEDER HENS OF DIFFERENT AGES TO DIETARY LYSINE

3.1 INTRODUCTION

The task of meeting the nutrient requirements for broiler breeders is a difficult one because their food intake has to be restricted to below *ad libitum* intake and they therefore cannot manipulate their food intake according to their requirements as laying hens can. It is therefore important to supply these birds with the correct nutrient intakes during all stages of the production period in order to achieve maximum egg output.

McDaniel, Brake and Bushong (1981a) showed that increasing the food allowance up to 38 weeks of age and then gradually decreasing the allowance from 38 weeks to 58 weeks of age resulted in significantly better hen day production than leaving the food allowance constant during this period. In commercial broiler breeder operations, the birds are fed one food throughout the laying period. They are normally offered a fixed amount of this food (usually between 150 and 175 g/bird d) and this is continued until the birds are between 35 and 40 weeks of age. The general practice at this stage is to reduce the daily allowance, by one or two grams per day each week, because the egg production starts to decline (Robinson *et al.*, 1990) , the objective being to reduce the excessive intake of energy which would tend to make the birds obese (Pearson and Herron, 1980).

The problem with this approach is that the protein requirements may not decline as the birds get older. Wethli and Morris (1978) have shown, with laying hens, that the same amount of protein was required at an older age even though the egg output was much lower. The reason for this has been attributed to the fact that when there is a decrease in the rate of lay to below 50% the efficiency of utilization of protein declines (Fisher, 1980). By decreasing the food allowance as birds age, the amino acid intakes are being reduced and the question arises as to whether the decrease in egg production at this time would be as great if the amino acid supply was kept constant.

The objectives of this experiment were

1) to measure the responses of broiler breeder hens to lysine at different ages
2) to determine if the efficiency of utilization of lysine changes at different ages

In order to achieve these objectives it was decided to use four different ages of birds i.e. birds at four different stages of production and to feed them a series of amino acid limiting diets that included diets that were deficient in amino acids in order to test the marginal response to the amino acid. Lysine was chosen as the test amino acid. It was considered essential to measure individual responses rather than group responses because within a group there would be a great deal of variation in food intake, rate of lay, egg weight and bodyweight.

3.2 MATERIALS AND METHODS

3.2.1 Birds and management

Four hundred and ninety two broiler breeder hens (Ross) of four different ages were used in this experiment. (Table 3.1).

Table 3.1. Animal Description

Age (weeks)	Code	Number of birds
26	A1	132
37	A2	120
48	A3	120
60	A4	120

The birds were housed in individual cages in a light - tight house (10m x 7.7m x 3.5m). The wire cages, which measured 75 cm x 48cm x 33cm, were arranged in six rows, back to back, each row having two levels of 48 cages. Each cage was supplied with one nipple drinker and drip-cup and one feeder (10cm x 30cm). The house was cross-ventilated by using six fans. It was made light-tight with baffles over the fan openings and it was insulated. The lighting regime was 16L:8D throughout theexperiment.

3.2.2 Treatments and feeds

Prior to the start of the experiment the birds had been kept on a restricted food program. The 26 week old birds had been fed 185 g/bird d of a commercial broiler breeder feed. The 37 week old birds had been fed 178 g/bird d, the 48 week old birds , 175 g/bird d and the 60 week old birds, 155g /bird d. During the experimental period, the hens were fed one of ten dietary treatments (five lysine levels, two energy levels). A basal summit diet was formulated. Oil and sand were added to make two summit diets with different energy levels - 11.88 MJ/kg (S1) and 13.10 MJ/kg (S2). Two protein-free dilution diets were formulated with two different energy levels - 11.88 MJ/kg (D1) and 13.10 MJ /kg (D2). The two summit diets and the two dilution diets were analysed for AME, protein, available amino acids, calcium and phosphorus content (Table 3.2).

Table 3.2. Composition (g/kg) of the summit and dilution diets

Ingredient	S1		S2		D1		D2	
Maize		436.77		436.77		—		—
Maize Gluten 60		100.00		100.00		—		—
Sunflower 37		210.67		210.67		—		—
Soyabean 48		69.08		69.08		—		—
Vitamins and minerals		2.50		2.50		2.50		2.50
Limestone		64.06		64.06		64.68		64.68
Monocalcium phosphate		6.97		6.97		10.00		10.00
Salt		7.00		7.00		7.95		7.95
Sand		43.30		10.89		132.31		94.89
Oil		59.65		92.06		60.00		60.00
Sugar		—		—		295.13		332.55
Starch		—		—		295.13		332.55
Sunflower husks		—		—		132.31		94.89
Analysis	Calc	Actual	Calc	Actual	Calc	Actual	Calc	Actual
AME (MJ/kg)	11.88	12.80	13.10	14.41	11.88	10.80	13.10	11.20
Crude protein (N x 6.25)	220.50	215.30	220.50	214.70	0	8.00	0	5.60
Lysine	6.70	7.06	6.70	7.12	0	—	0	—
Methionine	4.00	3.55	4.00	3.53	0	—	0	—
Threonine	7.30	7.64	7.30	7.51	0	—	0	—
Tyrosine	2.10	5.89	2.10	5.79	0	—	0	—
Arginine	12.10	11.35	12.10	11.08	0	—	0	—
Histadine	5.20	4.96	5.20	4.95	0	—	0	—
Isoleucine	8.70	9.11	8.70	9.32	0	—	0	—
Phe + Tyr	18.40	17.16	18.40	17.12	0	—	0	—
Valine	10.30	11.24	10.30	11.26	0	—	0	—
Calcium	25.7	27.7	25.7	26.7	25.7	25.5	25.7	26.0
Phosphorus (available)	2.50	5.90	2.50	5.80	2.50	2.20	2.50	2.10

The experimental diets were mixed by blending S1 with D1 and S2 with D2 in appropriate proportions. (Table 3.3). Two tons of the basal summit diet were mixed by Meadow Feeds, Pietermaritzburg. The oil and sand were added at the research farm to make the two summit diets. The mixing of the dilution diets and subsequent blending took place at the research farm in 500kg amounts.

Table 3.3. Blending proportions of the summit and dilution diets

Feed no.	Code	Energy (MJ/kg)	Proportion of requirement Lysine	Other	Summit (%)	Dilution (%)
					S1	D1
1	D1	11.88	1.20	1.50	100.0	0.0
2	D2	11.88	1.00	1.25	83.3	16.7
3	D3	11.88	0.80	1.00	66.7	33.3
4	D4	11.88	0.60	0.75	50.0	50.0
5	D5	11.88	0.40	0.50	33.4	66.6
6	D6	11.88	0.20	0.25	16.7	83.3
7 (i)	D7	11.88	0.50	0.50	33.4	66.6
					S2	D2
8	D8	13.10	1.20	1.50	100.0	0.0
9	D9	13.10	1.00	1.25	83.3	16.7
10	D10	13.10	0.80	1.00	66.7	33.3
11	D11	13.10	0.60	0.75	50.0	50.0
12	D12	13.10	0.40	0.50	33.4	66.6
13	D13	13.10	0.20	0.25	16.7	83.3

(i) 0.0107% lysine added as 0.083% lysine-HCl

Feed 7 was made by supplementing feed 5 with 0.107 g lysine/kg in order to confirm that lysine was the most limiting amino acid in the basal feed.

The summit diets were designed to provide lysine at 1.2 times requirement and all other amino acids at 1.5 times requirement, thus ensuring that lysine was limiting in all diets in the dilution series. A factorial method was used to determine the average requirement of the flock, using the coefficients of response published by McDonald and Morris (1985), which were a value of 73 for the maintenance coefficient in mg/kg and a value of 10 for the coefficient for egg production in mg/bird d The values used to describe the average individual in the flock were a 3.5 kg bird producing 58 g egg output/d.

The first summit diet (S1) was designed to provide energy at 1900 kJ ME/d and the second one (S2) to provide energy at 2100 kJ ME/d at 160 g/d intake.

The 13 experimental diets were analysed for AME, protein, 'available' amino acids, calcium and phosphorus content.

Because production is much poorer at the end of the laying period than at the beginning (Robinson *et al.*, 1990), the diets were designed so that age groups 26 and 37 weeks were given 1.2, 1.0, 0.8, 0.6 and 0.4 times requirement and age groups 48 and 60 weeks were given 1.0, 0.8, 0.6, 0.4 and 0.2 times requirement (Table 3.4).

Table 3.4. Diets fed to each of the age groups

26 weeks	Code	37 weeks	Code	48 weeks	Code	60 weeks	Code
1	A1D1	1	A2F1	2	A3F2	2	A4F2
2	A1D2	2	A2F2	3	A3F3	3	A4F3
3	A1D3	3	A2F3	4	A3F4	4	A4F4
4	A1D4	4	A2F4	5	A3F5	5	A4F5
5	A1D5	5	A2F5	6	A3F6	6	A4F6
8	A1D8	8	A2F8	9	A3F9	9	A4F9
9	A1D9	9	A2F9	10	A3F10	10	A4F10
10	A1D10	10	A2F10	11	A3F11	11	A4F11
11	A1D11	11	A2F11	12	A3F12	12	A4F12
12	A1D12	12	A2F12	13	A3F13	13	A4F13
7 (i)	A1D7						

(i) - control

There were therefore a total of 41 treatments with 12 birds/treatment.

3.2.3 Food allocation

All birds were fed 160 g/day, this food being weighed out into plastic-coated cardboard containers up to eight days before being fed to the birds. Feeding took place at the same time each morning.

3.2.4 Measurements

3.2.4.1 Bodyweight

Bodyweight was recorded at the beginning of week one, week four, week seven and at the end of week nine.

3.2.4.2 Food intake

Food remaining in each feed trough at the end of each day was not removed but was allowed to accumulate until the end of each week whereafter it was removed, weighed and discarded. Weekly food intake was calculated by multiplying the relevant allocated amount by seven and subtracting the amount remaining at the end of each week.

3.2.4.3 Egg numbers and egg weight

Egg numbers were recorded daily. All the eggs were weighed on five days of every week. Egg output was calculated for each week of the experiment by multiplying the daily average eggs laid per hen with the mean egg weight for the week.

3.2.4.4 Egg components

One egg from each bird was taken during week 6 and again during week 9 of the trial. These eggs were weighed. They were then broken and the yolks were weighed. The shells were dried overnight in an oven and weighed. The albumen weight was determined by subtracting the yolk weight and the dry shell weight from the egg weight. This was done to determine the allometric relationship between the eggs and their components.

3.2.4.5 Temperature

Daily minimum and maximum temperatures were recorded.

3.2.4.6 Mortalities

Mortalities were recorded and the death of a bird was regarded as a "missing plot".

3.2.4.7 Sacrificing of birds

Sixteen birds were sacrificed at the end of the trial. They were chosen to represent as close as possible the means of the treatments from which they were taken, namely from a high and a low lysine level at each of the two energy levels (feeds 2, 5, 9 and 12) for each of the four age groups. The birds were analysed for protein, fat, moisture and ash.

3.2.5 Length of experiment

The trial ran for a total of nine weeks.

3.2.6 Statistical analyses

The means for all treatments were calculated for the final four weeks of the experiment, on the assumption that by this time the response of birds would have stabilised on each treatment.

3.2.6.1 Egg output - The Reading Model

The relationship between lysine intake and egg output was determined by fitting the Reading Model to the treatment means. For this purpose the data were divided into eight flocks - the two energy series for each of the four age groups. This was done to see if the responses differed between the four age groups and the two energy series. The Reading Model was fitted to the eight flocks separately whereafter the data were combined and a common curve was fitted to all the data.

3.2.6.2 Effect of lysine intake, energy intake and age on the responses

A multiple regression analysis was used to determine the effects of lysine intake, energy intake and age of bird on weight gain, egg output, egg weight and rate of lay. Use was made of dummy variables for fitting age because it is a discrete variable. Initial bodyweight was included as a covariate in the regression analysis because nutrient intake (either lysine or energy) has to be partitioned between that required for body maintenance and that required for egg production. Any excess is deposited as body fat (Emmans, 1974). The higher the bodyweight the higher the maintenance requirement, resulting in less nutrient available for egg production or weight gain.

The full model fitted was

$$\begin{aligned}\text{Response} = {} & \text{constant} + bw_i + ME + ME^2 + ME^3 + lys + lys^2 + lys^3 + ME.lys + \\ & ME_2.lys^2 + age1 + age2 + age3 + age1.lys + age2.lys + age3.lys + \\ & age1.lys^2 + age2.lys^2 + age3.lys^2 + age1.ME + age2.ME + age3.ME + \\ & age1.ME^2 + age2.ME^2 + age3.ME^2\end{aligned}$$

bw_i = initial bodyweight
ME = energy intake
lys = lysine intake

A stepwise regression procedure was used, excluding terms that were not significant ($t<2.00$) to find the best fitting model.

Age 4 was not included in the model because only three of the dummy variables can be included, when fitting a model with a constant term and four dummy variables.

3.2.6.3 Lipid - free bodyweight

For the 16 birds that were sacrificed and analysed at the end of the experiment the lipid - free bodyweight (LFBW) was calculated by subtracting the amount of fat in the carcass from the bodyweight. A regression analysis was performed of LFBW on bodyweight, lysine intake and energy intake.

3.2.6.4 Calculating efficiency of utilization of lysine

The efficiency of utilization of lysine was calculated for each individual bird in the experiment as follows:-
Efficiency = lysine output in eggs / lysine available for egg production

Calculating lysine content of eggs

1) Predicting yolk and albumen weight from egg weight

A regression analysis was performed of yolk weight on egg weight, and albumen weight on egg weight for the eggs that were broken out. The regression analyses was re-run using dummy variables for age and diet to see if these relationships were different for the different age and dietary treatments.

These equations were then used to predict the yolk weight and the albumen weight from the mean egg weight over the final four weeks for each individual bird.

2) Calculating yolk and albumen output

The yolk and albumen outputs were calculated by multiplying the mean rate of lay, over the final four weeks, with the predicted yolk weight and albumen weight respectively.

3) Calculating the lysine content of yolk and albumen

Values for the lysine composition of yolk and albumen were obtained from the literature (Lunven *et al.*, 1973) (Table 3.16).

Table 3.16. Lysine content of yolk and albumen, assuming a 60g egg contains 27g N/kg yolk and 17g N/kg albumen (Lunven *et al.*, 1973)

	Yolk	Albumen
mg lysine/g N	477	378
mg lysine/g	12.87	6.42

The amount of lysine in the yolk and albumen outputs were calculated by multiplying the amount of lysine in the yolk and albumen by the yolk and albumen outputs.

4) Lysine in egg output

The total amount of lysine in the egg output was calculated by adding the amounts of lysine in the yolk and albumen outputs.

Calculating lysine available for egg production

The lysine available for egg production was calculated as follows:-

Lysine available for egg production = lysine intake - lysine required for maintenance

The lysine required for maintenance had to be estimated. This value has been estimated by MacDonald and Morris (1985) to be 73 mg/kg of bodyweight for laying hens. Bowmaker and Gous (1991) estimated a value of 11.2 mg/kg of bodyweight for broiler breeder hens. It was decided that the best way to estimate this value was to fit several regression models of efficiency on rate of lay, using a range of values for the lysine maintenance requirement. The best fitting model would give the best estimate of the maintenance requirement. Before this could be done the relationship between efficiency and rate of lay had to be established. This was done by using efficiency values which excluded a maintenance requirement.

Firstly, a linear model was fitted and then a broken stick model was fitted to establish if this was a better fit than the linear model and to establish where the inflexion point was.

Efficiency of utilization of lysine at different ages

An analysis of variance was performed on the efficiencies using age as a factor. Fisher's LSD comparisons were used to determine which ages had similar efficiencies. A second analysis of variance was performed on the efficiencies, excluding those birds with a mean rate of lay of below 50%.

3.3 RESULTS

3.3.1 Experimental diets

The analysis of the 13 experimental diets revealed that there were not two distinct energy levels as planned but rather two energy series. The lysine and energy concentrations of the 13 diets are shown in Table 3.5. It can be seen that the energy levels were higher for diets 8 to 13 compared to diets 1 to 7 but there was some overlap.

Table 3.5. The lysine and energy concentrations of the 13 experimental diets

Diet	Lysine concentration (g/kg)	Energy concentration (kJ/kg)
1	7.06	1280
2	6.69	1247
3	5.04	1213
4	3.91	1180
5	2.52	1147
6	1.74	1113
7	2.74	1147
8	7.12	1441
9	6.20	1387
10	5.13	1334
11	3.69	1281
12	2.58	1227
13	1.50	1174

3.3.2 Mortalities

Twenty one of the 492 birds (4.3%) died during the experiment. Most of these mortalities were from the oldest age treatment (A4) (Figure 3.1) and from the diets in the high energy series. Twenty nine percent of the mortalities occurred on diets 1 to 7 as opposed to 71% on feeds 8 to 13. The fact that most of the mortalities were from the higher energy series was probably because most of the mortalities occurred after hot weather conditions and the birds on the higher energy series would have had more difficulty losing heat and therefore would have become heat stressed more easily.

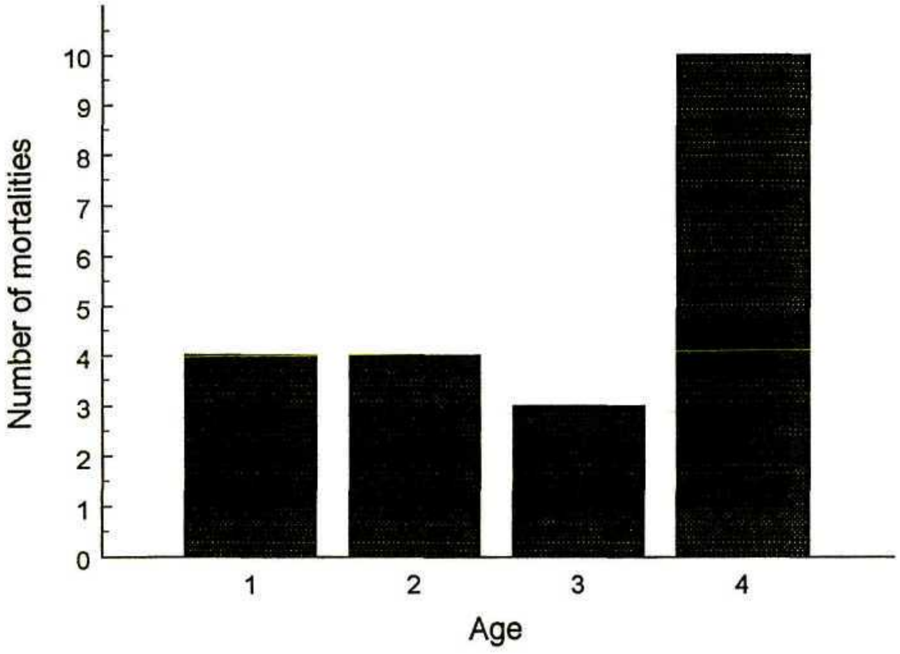

Figure 3.1. The number of mortalities from each age treatment

3.3.3 Responses

The individual results were grouped according to age and dietary treatment and are presented in Appendix 2.

The means for all treatments were calculated for the final four weeks. The main effects of the various treatments are shown in Table 3.6, whereas the interactions, together with their standard error's are shown in Table 3.7.

Table 3.6. Mean responses to the main effects (age and feed) over the final four weeks

Treatment		Lysine intake (mg/bird d)		Energy intake (MJ/bird d)		Food intake (g/bird d)		Bodyweight (g/bird)		Bodyweight change (g/bird d)		Egg output (g/bird d)		Egg weight (g/egg)		Rate of Lay (%)	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Age	1	733	305	1.90	0.29	150.1	19.1	3656	453	7.86	6.98	40.73	11.24	61.83	5.93	59.36	22.66
	2	768	308	1.92	0.28	151.0	17.5	4239	430	6.59	6.32	39.81	11.96	68.49	6.02	53.38	20.81
	3	573	309	1.73	0.47	139.7	33.5	4396	585	3.71	12.12	31.91	11.96	69.05	6.14	36.66	21.73
	4	530	296	1.58	0.50	127.9	38.1	4163	614	0.89	12.97	30.68	13.37	69.97	6.35	33.14	22.32
Feed	1	1234	81	2.00	0.13	156.2	10.2	4053	385	7.52	3.61	48.00	7.53	66.50	7.39	68.34	16.83
	2	1033	99	1.92	0.18	154.4	14.9	4260	508	9.20	4.82	41.64	11.78	68.42	5.41	56.04	23.30
	3	790	41	1.90	0.10	156.8	8.2	4242	560	7.20	4.68	42.99	10.26	68.36	6.14	57.22	20.33
	4	602	46	1.81	0.13	154.1	11.8	4123	545	6.15	4.88	36.03	9.32	66.54	5.95	48.65	22.54
	5	347	68	1.58	0.31	137.9	27.0	3910	587	2.03	9.79	27.08	7.19	64.03	7.27	35.18	15.88
	6	174	50	1.11	0.32	100.1	29.1	3682	456	-11.48	10.82	14.41	5.62	61.57	7.75	10.71	5.28
	7	406	46	1.70	0.19	148.3	17.1	3411	461	7.56	7.5	30.51	6.80	56.33	5.03	44.84	10.58
	8	1089	151	2.20	0.30	152.9	21.3	4238	527	11.55	10.41	45.57	11.00	69.54	4.61	57.14	24.77
	9	910	80	2.13	0.18	153.5	13.6	4492	443	11.43	5.14	40.52	14.36	71.40	6.22	52.06	26.08
	10	740	35	2.07	0.10	155.9	7.5	4329	469	9.38	5.26	41.15	9.38	69.90	6.39	55.32	20.92
	11	553	510	1.92	0.17	150.0	14.0	4215	567	6.76	6.74	33.31	9.51	66.78	6.83	43.51	21.82
	12	309	69	1.47	0.32	120.0	26.8	3834	655	-0.30	7.91	22.54	6.94	61.77	5.41	25.53	14.24
	13	102	67	0.80	0.53	68.2	45.1	3591	687	-16.26	17.41	18.20	7.88	63.14	4.05	7.5	3.12

Table 3.7. Mean responses to treatments over the final four week period

Age	Feed	Lysine intake (mg/bird d)		Energy intake (MJ/bird d)		Food intake (g/bird d)		Bodyweight (g/bird)		Bodyweight change (g/bird d)		Egg output (g/egg)		Egg weight (g/egg)		Rate of lay (%)	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
1	1	1216	108	1970	170	153.9	13.6	3766	239	7.59	3.21	47.49	5.38	61.75	4.32	76.43	6.56
	2	1055	39	1960	70	157.6	5.8	3690	243	8.76	3.28	49.10	13.42	64.52	2.76	74.11	23.60
	3	806	0	1940	0	160.0	0.0	3578	219	8.26	3.46	46.29	7.78	61.93	3.05	71.13	17.33
	4	611	22	1840	60	156.4	5.6	3623	441	7.71	4.79	40.00	6.68	60.84	4.20	57.74	21.53
	5	352	56	1600	250	139.6	22.2	3390	357	6.61	7.59	26.68	4.68	53.95	3.95	39.29	17.13
	7	406	46	1700	190	148.3	17.1	3411	461	7.56	7.50	30.51	6.80	56.33	5.03	44.84	3.53
	8	1056	201	2130	400	148.3	28.2	3934	458	10.94	14.01	45.92	9.76	69.42	4.44	55.36	25.96
	9	931	44	2170	100	157.0	7.5	4009	239	11.95	4.52	47.32	10.39	66.06	4.95	67.56	23.52
	10	751	23	2110	60	158.2	4.8	3900	442	9.37	4.36	43.99	5.42	62.49	4.50	68.83	16.45
	11	567	35	1960	120	153.7	9.6	3728	434	7.71	4.07	35.56	7.37	60.94	6.30	55.52	17.67
	12	300	67	1430	320	116.6	26.2	3187	661	-0.63	6.63	26.43	6.46	57.35	4.43	32.14	14.06
2	1	1251	44	2020	70	158.3	5.5	4316	294	7.46	4.10	48.42	9.17	70.45	7.18	61.61	19.92
	2	1066	10	1980	10	159.3	1.5	4348	383	8.23	5.03	41.03	11.07	69.87	5.61	54.46	19.27
	3	799	18	1920	40	158.6	3.6	4152	328	5.20	5.58	47.30	6.41	71.78	3.96	66.07	9.20
	4	603	37	1820	110	154.4	9.5	4011	342	4.48	4.43	40.02	5.15	64.43	4.12	58.63	16.64
	5	353	50	1600	220	140.0	19.8	4054	479	2.23	7.43	29.03	8.60	66.62	6.35	35.71	17.71
	8	1128	33	2280	60	158.5	4.7	4602	346	12.29	3.43	45.15	12.87	69.70	5.06	59.29	24.47
	9	891	129	2080	300	150.3	21.9	4523	334	8.45	6.47	47.85	8.58	73.58	4.07	63.21	15.80
	10	750	29	2100	80	157.9	6.1	4335	452	10.37	5.48	41.39	10.93	70.56	3.54	55.95	21.17
	11	559	68	1930	230	151.5	18.4	4209	515	5.47	8.90	35.18	4.80	65.89	4.99	52.50	9.23
	12	313	58	1490	270	121.4	22.7	3913	388	2.55	4.56	19.97	6.15	61.33	5.18	25.00	15.40

Table 3.7 (continued). Mean responses to treatments over the final four week period

Age	Feed	Lysine intake (mg/bird d)		Energy intake (kJ/bird d)		Food intake (g/bird d)		Bodyweight (g/bird)		Bodyweight change (g/bird d)		Egg output (g/bird d)		Egg weight (g/egg)		Rate of lay (%)	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
3	2	1070	0	1990	0	160.0	0.0	4664	238	12.71	2.28	36.09	5.18	68.13	3.60	46.43	14.90
	3	792	30	1900	70	157.1	6.03	4747	468	8.34	5.31	37.09	15.21	70.48	8.03	44.05	22.45
	4	595	77	1790	230	152.1	19.9	4354	480	5.26	5.66	35.03	8.02	70.68	4.34	42.86	19.23
	5	351	74	1600	340	139.6	29.7	4176	500	-1.61	11.88	25.60	7.23	65.59	4.06	36.43	12.69
	6	179	53	1140	340	103.0	30.6	3833	493	-12.31	12.47	14.69	6.04	62.50	4.36	10.71	5.46
	9	938	37	2190	80	158.1	6.2	4807	430	13.55	4.72	39.67	10.88	73.27	6.45	46.43	22.12
	10	750	13	2100	00	158.0	2.8	4655	357	9.47	4.75	40.27	9.17	72.94	5.18	50.32	18.73
	11	563	32	1900	110	152.7	8.7	4559	548	8.76	5.59	29.82	9.14	69.67	6.23	29.17	22.99
	12	328	82	1560	390	127.2	32.1	4270	630	-0.10	8.32	21.99	7.98	67.13	3.14	22.62	14.58
	13	130	71	1020	560	87.1	47.9	3858	690	-8.16	18.08	17.76	6.12	62.10	3.58	7.74	2.69
4	2	942	169	1750	310	140.8	25.3	4339	541	7.09	6.22	38.63	13.03	73.07	6.88	42.86	24.66
	3	760	72	1830	170	150.9	14.3	4515	326	6.98	3.80	41.11	6.06	69.34	2.25	46.75	16.40
	4	599	31	1800	90	153.3	8.13	4504	474	7.15	4.43	28.00	12.17	70.81	4.59	32.14	24.11
	5	332	92	1510	410	132.1	36.5	4046	676	0.80	10.70	26.78	7.92	68.70	4.11	29.64	16.41
	6	169	50	1080	310	97.1	28.7	3532	381	-10.65	9.42	14.08	5.77	60.45	11.11	10.71	5.65
	9	877	75	2050	170	147.9	12.7	4644	284	11.54	3.87	27.31	16.79	73.37	5.97	31.17	26.30
	10	701	50	1970	140	147.7	10.6	4446	238	7.99	6.98	38.43	11.63	74.39	5.22	44.05	21.80
	11	523	56	1810	190	141.9	15.2	4334	469	5.08	7.46	32.83	14.08	70.52	5.69	38.96	23.82
	12	297	71	1410	340	115.2	27.8	3949	469	-3.04	10.73	21.54	6.98	63.80	3.36	20.98	12.29
	13	200	45	1000	350	45.6	30.2	3270	556	-25.98	10.75	19.30	14.8	65.75	5.30	7.14	4.12

Diet 7 was included as a control to test that lysine was the first limiting nutrient in the basal feed. The composition of diet 7 was the same as that of diet 5 except that L-lysine HCl had been added. A t-test was performed on the mean egg outputs of age treatment A1, from diet 7 and diet 5 (Table 3.7). The significantly higher response in egg output ($p<0.01$) to diet 7 (30.51 g/bird d) compared with diet 5 (26.68 g/bird d) confirms that lysine was the first limiting amino acid.

3.3.3.1 Bodyweight

The mean initial and final bodyweights together with their maximum, minimum and standard error's are shown in Table 3.8.

Table 3.8. The initial and final bodyweights

	Initial bodyweight (g)	Final bodyweight (g)
Mean	3680	4134
Maximum	5110	5860
Minimum	1975	2140
Standard error	487.4	661.7

It can be seen that over all treatments bodyweight increased over the experimental period.

3.3.3.2 Food intake

An analysis of food intake on lysine concentration revealed that lysine concentration had a significant effect on food intake, below a concentration of 3g lysine/kg food, decreasing linearly with decreasing dietary lysine concentration (Figure 3.2).

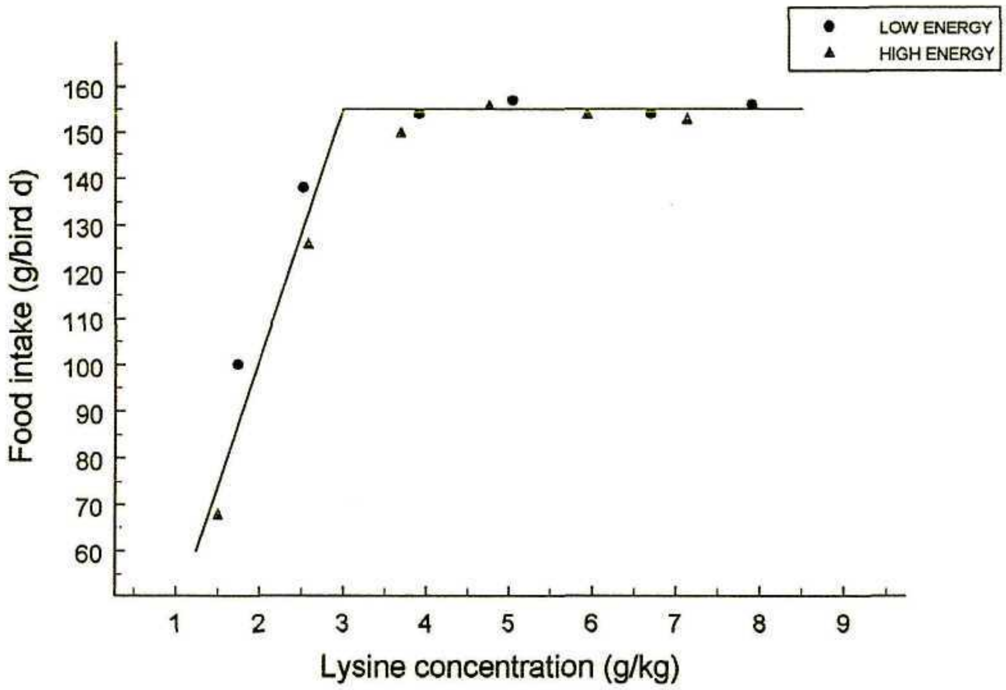

Figure 3.2. The relationship between dietary lysine concentration and food intake.

3.3.3.3 Rate of lay

A frequency distribution was constructed in which the number of birds laying at different rates (10% intervals) was plotted for each age treatment. Only birds from diets 2, 3, 4, 9, 10 and 11 were used because these diets were fed to all age groups and represented the three highest lysine levels for each energy series. The rate of lay decreased to a greater extent with decreasing lysine level of the diet than with increasing age of the bird. Therefore, if the diets with low lysine levels had been used the lysine level of the diet would have masked the effect of age (Figure 3.3).

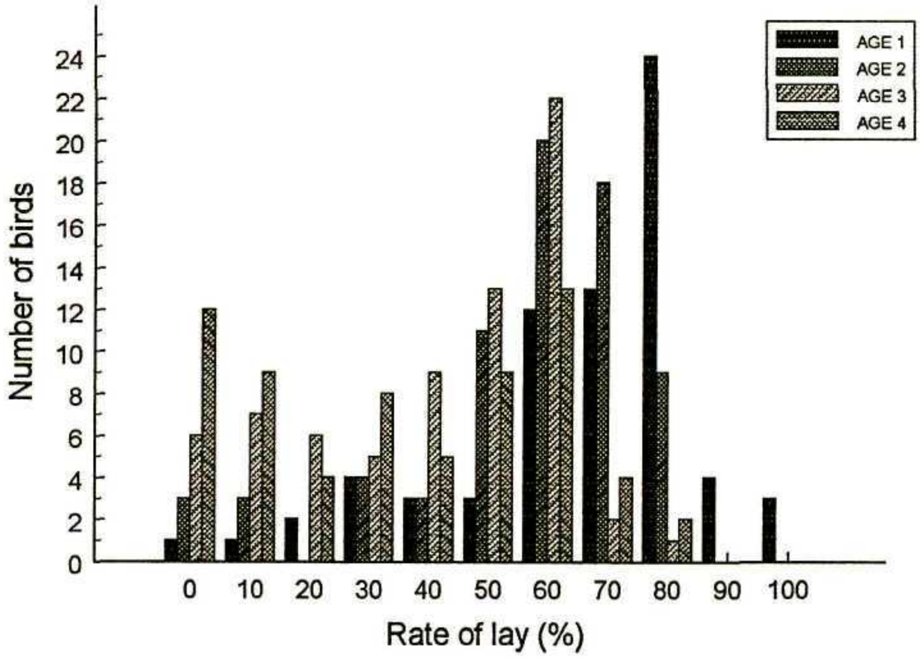

Figure 3.3. Number of birds versus rate of lay (%).

3.3.3.4 Egg output

The parameters used in fitting the Reading Model to each of the eight flocks separately are shown in Table 3.9 and when using a common curve the parameters are shown in Table 3.10. The coefficients of response derived for each of the flocks are shown in Table 3.11. The response curves fitted to the eight flocks separately are shown in Figure 3.4a and the common response curve is shown in Figure 3.4b.

Table 3.9. The parameters used in fitting the Reading Model to each of the eight flocks separately

Age	Energy	E_{max}	σE_{max}	W	σW	r_{EW}
1	High	47.47	10.0	3.88	0.429	0.0
1	Low	48.44	11.1	3.62	0.308	0.0
2	High	46.48	11.2	4.25	0.554	0.0
2	Low	45.39	10.1	4.22	0.358	0.0
3	High	41.28	10.5	4.65	0.441	0.0
3	Low	36.44	11.3	4.53	0.420	0.0
4	High	32.88	14.7	4.44	0.387	0.0
4	Low	42.89	11.7	4.50	0.403	0.0

E_{max} = maximum potential egg output of the flock (estimated by Reading Model)

σ E_{max} = standard deviation of individual maxima for members of the flock (calculated)

W = mean bodyweight of the flock (calculated)

σW = standard deviation of bodyweight (calculated)

r_{EW} = correlation between egg output and bodyweight (assumed)

Table 3.10. The parameters used in fitting the Reading Model to all eight flocks together

Age	Energy	E_{max}	σE_{max}	W	σW	r_{EW}
1	High	47.03	10.0	3.88	0.427	0.0
1	Low	47.51	10.0	3.62	0.427	0.0
2	High	47.75	10.0	4.25	0.427	0.0
2	Low	42.91	10.0	4.22	0.427	0.0
3	High	37.77	10.0	4.65	0.427	0.0
3	Low	33.09	10.0	4.53	0.427	0.0
4	High	38.97	10.0	4.44	0.427	0.0
4	Low	37.16	10.0	4.50	0.427	0.0

E_{max} = maximum potential egg output of the flock (estimated by Reading Model)

σE_{max} = standard deviation of individual maxima for members of the flock (calculated)

W = mean bodyweight of the flock (calculated)

σW = standard deviation of bodyweight (calculated)

r_{EW} = correlation between egg output and bodyweight (assumed)

Table 3.11. Coefficients of response derived for each of the flocks separately and combined

Age	Energy	Code	'a' value	'b' value
1	High	A1HE	14.38	0.01
1	Low	A1LE	14.04	0.00
2	High	A2HE	15.45	0.84
2	Low	A2LE	12.76	0.01
3	High	A3HE	15.78	0.01
3	Low	A3LE	12.84	0.00
4	High	A4HE	10.84	0.00
4	Low	A4LE	16.33	0.00
All	Both	——	13.95	0.00

'a' = an estimate of the amount of amino acid required to produce 1g of egg output

'b' = an estimate of the daily maintenance requirement of the hen, mg lysine per kg bodyweight

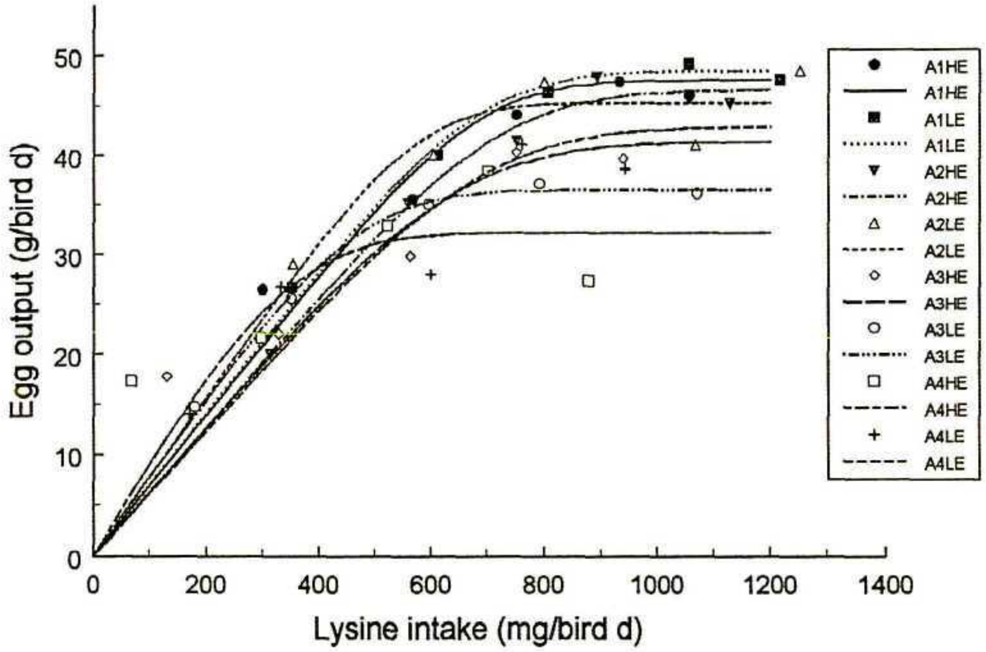

Figure 3.4a. The relationship between egg output and lysine intake (symbols), together with the fitted response curves derived from fitting the Reading Model (lines) to each of the eight flocks separately.

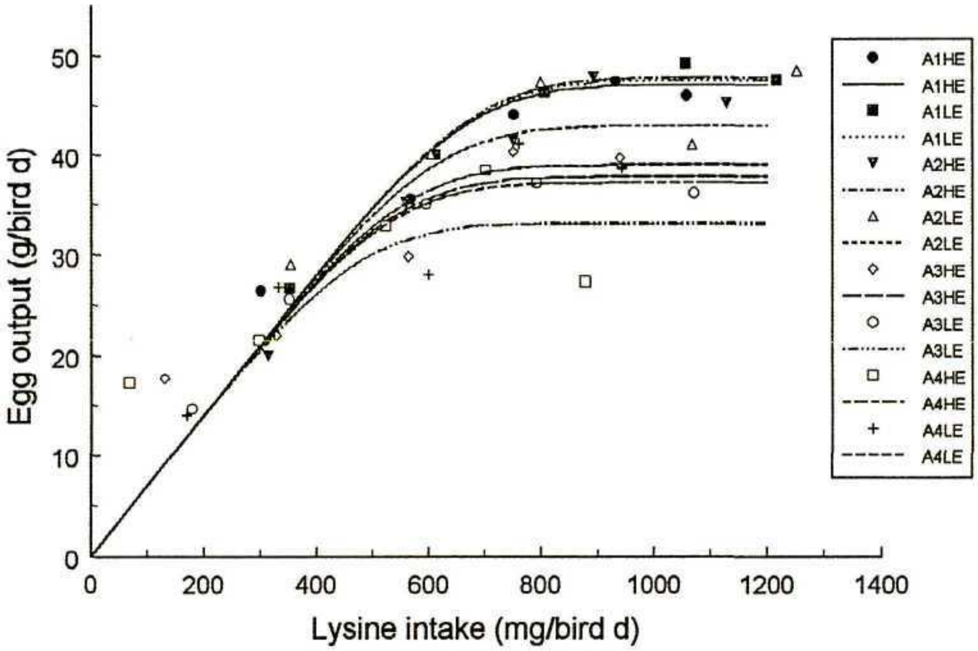

Figure 3.4b. The relationship between egg output and lysine intake (symbols), together with the fitted common response curve derived from fitting the Reading Model (lines).

3.3.3.5 Effect of lysine intake, energy intake and age on the responses

The lysine intake and energy intake were found to be highly correlated (r = 0.783).

The resultant regression equations for each dependent variable that were obtained from fitting the multiple regression model are presented in Table 3.11. The intercept and slope for age 4 were given in the output and the intercepts and slopes for the other ages were calculated from the output (Table 3.12).

The interactions between energy intake and age were not significant for any of the responses indicating that the response to energy intake was the same at all ages.

The relationship between lysine intake and weight gains was significantly quadratic. The negative slope of the linear term shows that the gain in weight decreased with increasing lysine intake. The positive slope of the quadratic term shows that at higher intakes the gain in weight increased with increasing lysine intake. The fact that the regression coefficients were significant for age1.lys and age2.lys (Table 3.11) shows that the slopes were significantly different for age 1 and age 2 compared to age 4. The slope decreased most steeply from age 1 to age 4 (Table 3.12) showing that with the same increase in lysine intake the youngest birds would have the lowest increase in weight gains and the oldest birds the highest increase in weight gains. The response in weight gains to energy intake was significantly quadratic. Weight gains increased with increasing energy intake.

The relationship between egg output and lysine intake was significantly quadratic. The positive slope of the linear term and the negative slope of the quadratic term show that egg output increased with increasing lysine intake up to an optimum lysine intake and then gradually dropped off. The fact that the regression coefficients were significant for age1.lys and age2.lys (Table 3.11) shows that the slopes were significantly different for age 1 and age 2 compared to age 4. The slope increased most steeply from age 1 to age 4 (Table 3.12) , showing that at the same lysine intake the youngest birds would have the highest egg output whilst the oldest birds would have the lowest egg output. The relationship between egg output and energy intake was significantly quadratic. The fact that the slope decreased steeply before increasing was unexpected because it means that at low intakes an increase in the energy intake led to a decrease in egg output. At high intakes, increasing the energy intake led to an increase in egg output.

TABLE 3.11. Summary of the regressions of the response variables on lysine intake, energy intake and age

	Weight gains			Egg output			Egg weight			Rate of lay			Rate of lay		
	b	SE	p	b	SE	p	b	SE	p	b	SE	p	b	SE	p
Constant	-28.54	3.08	0.000	35.62	8.927	0.000	63.436	4.834	0.000	36.547	8.496	0.000	74.51	11.85	0.000
IBW	-0.003	0.0006	0.000	-0.002	0.0013	0.030	0.0025	0.00071	0.000	-0.00618	0.002	0.002	-0.013	0.001	0.000
LYS	-0.006	0.005	0.272	-0.071	0.01251	0.000	0.032	0.0063	0.000	0.065	0.010	0.000	-----	-----	-----
LYS^2	0.000007	0.000003	0.035	-0.00003	0.000007	0.000	-0.00001	0.000003	0.000	-0.00002	0.000007	0.001	-----	-----	-----
ME	35.56	3.20	0.000	-23.42	10.54	0.027	-20.086	5.61	0.000	-----	-----	-----	-7.18	12.46	0.565
ME^2	-4.83	1.04	0.000	6.394	3.054	0.037	6.228	1.627	0.000	-----	-----	-----	11.021	3.901	0.005
AGE1	3.207	1.87	0.088	-3.182	4.069	0.435	-7.609	0.911	0.000	14.216	2.539	0.000	-----	-----	-----
AGE2	4.020	1.83	0.029	-2.553	4.028	0.527	-2.762	0.788	0.001	9.225	2.188	0.000	-----	-----	-----
AGE3	0.606	1.45	0.677	-0.262	3.783	0.945	-1.7555	0.803	0.030	1.866	2.223	0.402	-----	-----	-----
AGE1.LYS	-0.008	0.002	0.002	0.012679	0.0056	0.026	-----	-----	-----	-----	-----	-----	-----	-----	-----
AGE2.LYS	-0.008	0.002	0.002	0.012234	0.0056	0.032	-----	-----	-----	-----	-----	-----	-----	-----	-----
AGE3.LYS	-0.0006	0.002	0.787	0.002649	0.0055	0.632	-----	-----	-----	-----	-----	-----	-----	-----	-----
R^2	76.1%			47.1%			43.4%			46.1%			32.9%		

Table 3.12. The intercepts and regression coefficients for each age treatment

		Weight gains	Egg output	Egg weight	Rate of lay
Intercepts	AGE1	-25.334	32.44	55.82	50.76
	AGE2	-24.521	33.06	60.67	45.80
	AGE3	-27.935	35.36	61.68	38.41
	AGE4	-28.541	35.62	63.436	36.54
Regression coefficients	AGE1.LYS	-0.014297	0.083979	0.032123	0.06586
	AGE2.LYS	-0.014540	0.083535	0.032123	0.06586
	AGE3.LYS	-0.006754	0.073949	0.032123	0.06586
	AGE4.LYS	-0.006134	0.071300	0.032123	0.06586

The relationship between egg weight and lysine intake was significantly quadratic, with egg weight increasing with lysine intake up to an optimum lysine intake and then decreasing. The intercepts were significantly different for ages 1, 2 and 3 compared to age 4 (Table 3.11). This shows that the birds had different egg weights at different ages irrespective of their lysine intakes. The egg weight increased from the youngest to the oldest birds (Table 3.12). The slopes for the different ages were not significant, showing that the response in egg weight to lysine was not significantly different at different ages. The relationship between egg weight and energy intake was significantly quadratic, with egg weight decreasing with increasing energy at low intakes and then increasing at higher intakes.

The relationship between rate of lay and energy intake was significantly quadratic, with rate of lay decreasing with increasing energy at low intakes and then increasing at higher intakes. However, when lysine intake and energy intake were both included in the model energy intake was not significant. The relationship between rate of lay and lysine intake was significantly quadratic, with egg weight increasing with lysine intake up to an optimum lysine intake and then decreasing. The intercepts were significantly different for ages 1 and 2 compared to age 4 (Table 3.11). This shows that the birds had different rates of lay at different ages irrespective of their lysine intakes. Age 1 had the largest intercept showing that the youngest birds had the highest rate of lay and age 4 had the smallest intercept showing that the oldest birds had the lowest rate of lay (Table 3.12). The slopes for the different ages were not significant which indicated that the response in rate of lay was not significantly different at different ages.

3.3.3.6 Lipid - free bodyweight

Energy intake was not significant and it was found that the LFBW could be predicted very accurately from the total bodyweight and the lysine intake.

$LFBW = 652 + 0.0526\ bw + 0.403\ lys$

$R^2 = 95.2\%$

The correlation between bodyweight and the amount of fat in the carcass was 0.701, irrespective of age. The means for the bodyweight and the amount of fat in the carcass, together with their maximum, minimum and standard error's are shown in Table 3.13.

Table 3.13. Total bodyweight and amount of fat in carcass

	Bodyweight (g)	Fat (g)
Mean	3979	966
Maximum	4679	1286
Minimum	2987	710
Standard error	466	185

3.3.4 Calculating efficiency of utilization of lysine

Calculating the efficiency of utilization of lysine for each individual bird in the experiment revealed the following:-

3.3.4.1 Calculating lysine content of eggs

Predicting yolk and albumen weight from egg weight

The regression of yolk weight on egg weight is shown in Figure 3.5a and that of albumen weight on egg weight in Figure 3.5b. It was deemed unnecessary to transform the data to logarithms because the relationships between the variables were linear without transformation, and the equations derived using the transformed data were almost identical to those without transformation. In the case of both yolk and albumen there was no difference between the age treatments. However, in both cases, there were differences between the dietary treatments. The regression coefficients for each diet are shown in Table 3.14.

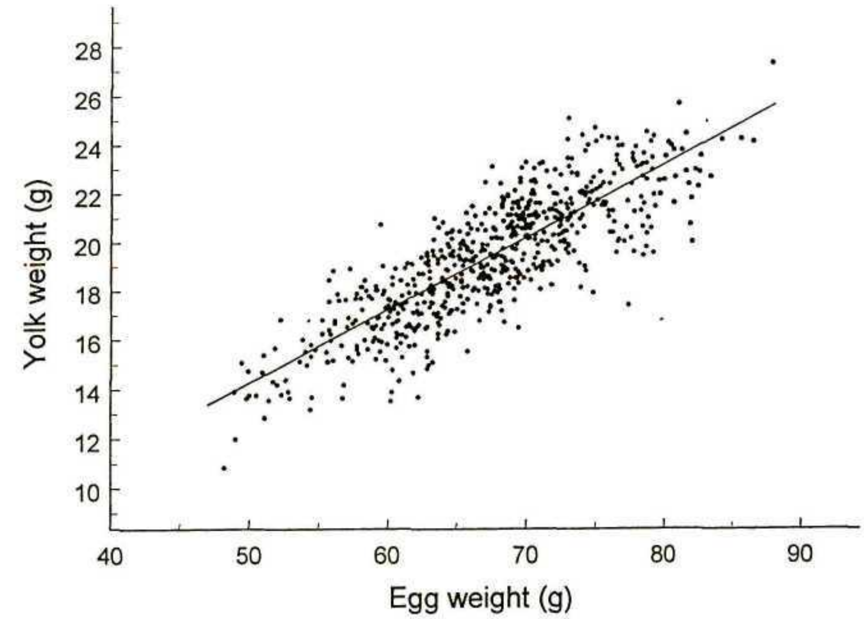

Figure 3.5a . The relationship between yolk weight and egg weight

yolk weight = -0.714 + 0.298 egg weight

$R^2 = 70.6\%$

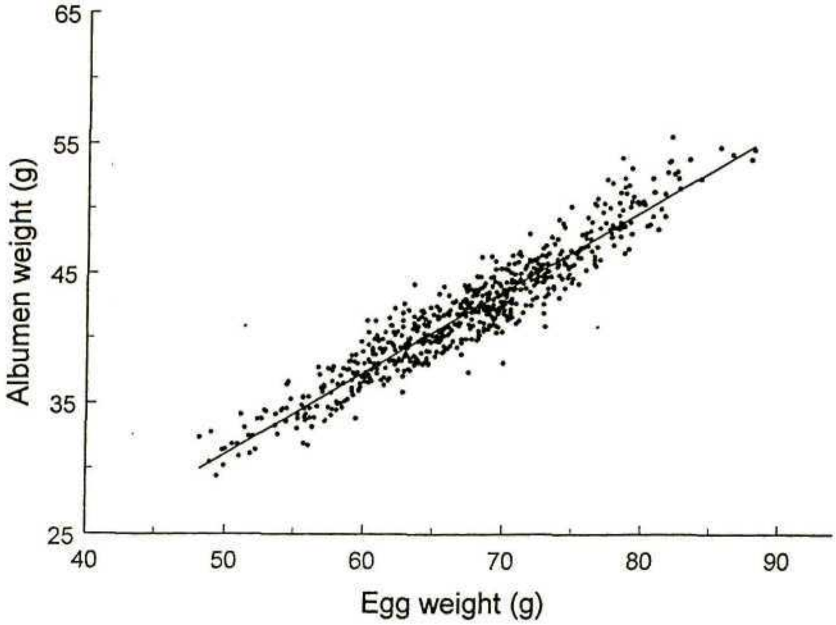

Figure 3.5b. The relationship between albumen weight and egg weight

albumen weight = -0.152 + 0.625 egg weight

$R^2 = 90.1\%$

Table 3.14. Regression coefficients for yolk weight and albumen weight on egg weight for the different diets

	Yolk weight		Albumen weight	
Diet	Constant	Egg weight	Constant	Egg weight
1	2.094	0.255	-1.310	0.645
2	-0.252	0.292	0.090	0.621
3	1.091	0.271	-2.664	0.660
4	-1.858	0.320	0.120	0.614
5	-0.204	0.283	0.271	0.628
6	-11.89	0.478	10.628	0.461
7	-1.624	0.309	1.306	0.611
8	-13.217	0.482	10.921	0.463
9	-0.599	0.296	0.867	0.613
10	-2.025	0.320	0.388	0.614
11	0.238	0.286	-1.834	0.650
12	1.702	0.254	-3.755	0.692
R	72.1%		90.3%	

An example of how the regression equations were used to predict the yolk weight and the albumen weight from the mean egg weight over the final four weeks for each individual bird according its dietary treatment is shown in Table 3.15 for mean egg weights of 70 g and 50 g.

Table 3.15. An example of how yolk weight and albumen weight were predicted from egg weight using the regression equations in Table 3.14

Diet	Egg weight (g)	Yolk weight (g)	Albumen weight (g)	Egg weight (g)	Yolk weight (g)	Albumen weight (g)
All	70	20.22	43.60	50	14.24	31.10
1	70	19.94	43.91	50	14.84	30.99
2	70	20.26	43.63	50	14.40	31.19
3	70	20.13	43.61	50	14.69	30.39
4	70	20.61	43.10	50	14.19	30.82
5	70	19.38	44.23	50	14.00	31.67
6	70	21.64	42.97	50	12.06	33.73
7	70	20.08	44.15	50	13.88	31.91
8	70	20.52	4 3.33	50	10.88	34.07
9	70	20.19	43.78	50	14.25	31.52
10	70	20.38	43.44	50	13.98	31.14
11	70	20.26	43.47	50	14.54	30.67
12	70	19.55	44.69	50	14.45	30.85

3.3.4.2 Calculating lysine available for egg production

It was suspected that the value for the maintenance requirement would be very low for the present study because of the very low values obtained by fitting the Reading Model.

The relationship between efficiency and rate of lay for the linear model was:-

$$\text{eff} = 0.162 + 0.428\ \text{rol}$$

$$R^2 = 36.4\%$$

where eff = efficiency

rol = rate of lay

he relationship between efficiency and rate of lay for the broken stick model was:-

$$\text{eff} = 0.0938 + 0.759\ \text{rol1} + 0.512\ \text{rol2}$$

$$R^2 = 44.8\%$$

The inflexion point occurred where the rate of lay was 0.5 (Figure 3.6). This model had a higher R^2 value and was therefore considered a better fit than the linear model.

When the broken stick model was used to estimate efficiencies calculated using a maintenance requirement of either 70 mg/kg or 10 mg/kg the R^2 value increased from 30.6% to 35.1%. Decreasing the maintenance value from 10 mg/kg to 2 mg/kg improved the fit still further (Table 3.17). For this reason a value of 2 mg/kg bodyweight was used.

Lipid - free bodyweight can be regarded as being more appropriate as a measure of maintenance requirement than bodyweight as fat contains no amino acids and lipid - free bodyweight could be predicted very accurately from the bodyweight. See earlier equation (Page 72).

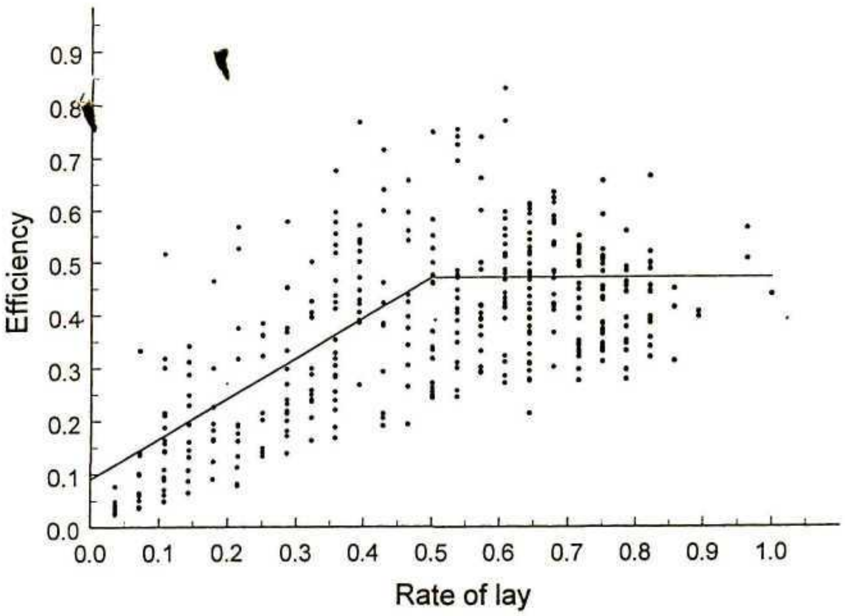

Figure 3.6. The relationship between efficiency and rate of lay

Table 3.17. The effect on goodness of fit of changing the maintenance value from 10 to 2 mg lysine/kg bodyweight

Lysine requirement mg/kg bodyweight	R^2 value (%)
10	35.1
8	36.2
6	37.3
4	38.4
2	39.4

3.3.4.3 Efficiency of utilization of lysine at different ages

The mean efficiencies for each age treatment are shown in Table 3.18.

Table 3.18. Mean efficiency of utilization of lysine for each age group

Age	Mean efficiency	
1	0.42	a
2	0.40	a
3	0.36	b
4	0.33	b

Ages with different letters are significantly different from each other ($p < 0.01$).

The mean efficiencies for each age treatment, when those birds with a mean rate of lay of below 50% were excluded are shown in Table 3.19.

Table 3.19. Mean efficiency of utilisation of lysine for each age treatment, excluding those birds with rates of lay below 50%

Age	Mean efficiency
1	0.45
2	0.45
3	0.45
4	0.49

The means were not significantly different from each other ($p<0.01$).

3.4 DISCUSSION

Many researchers have demonstrated that laying hens require the same amount of protein at an older age even though their egg output is much lower (Fisher and Morris, 1967 Jennings *et al.*, 1972 Wethli and Morris, 1978). This has been attributed to the fact that the efficiency of utilization of protein declines in ageing hens when their rate of lay declines to below 50% (Fisher, 1980).

The current method of feeding broiler breeder hens is to decrease food allowance after peak production has been reached. The objective being to reduce their excessive intake of energy which would lead to obesity. However the question of declining efficiency of utilization of protein at this stage needs to be addressed because this method of feeding may not be the most ideal way to achieve maximum rate of egg output from these birds.

In this experiment feeding broiler breeder hens of different ages a series of diets limiting in lysine revealed some very interesting results.

The birds on the diets with the highest lysine concentration ate all or almost all of their daily allowance of 160g. However, as the lysine concentration of the diet decreased, to below 3g lysine/kg food the food intake decreased. Bowmaker and Gous (1991) also observed this decrease in food intake with decreasing amino acid concentration of the diet using lysine and then methionine as the first limiting amino acids. This decrease in food intake can be seen for both energy series. In the one case where the lysine concentrations were almost identical for the two energy series the birds fed the diet with the higher energy concentration had a lower food intake. Increasing the energy concentration of a diet decreases the food intake of that diet (Emmans, 1981). The reason for this decrease in food intake with decreasing lysine concentration was the need for the animal to remain in thermal balance with its environment (Emmans, 1981). Birds generally increase their food intake as the limiting nutrient concentration is reduced, as long as the gut capacity and the environment will allow this. Where egg production is concerned, a decrease in lysine concentration in the diet will reduce the ability of the hen to lay eggs unless substantially more food can be consumed. Producing an egg is a means of losing heat, but if substantially more food needs to be consumed in order that an extra egg can be produced, the hen may not be able to manage this and hence egg production and food intake drop significantly as dietary lysine content decreases.

The high correlation between the energy intake and the lysine intake was due to the fact that the energy concentrations decreased with decreasing lysine concentration of the diet. There was a further confounding effect due to the fact that the food intake decreased with decreasing lysine concentration of the diet and therefore decreasing energy intake. The interactions between energy intake and lysine intake were not significant for any of the regression models. The lysine intake and energy intake were highly correlated and it cannot be assumed that they acted independently.

When examining the curves fitted by the Reading Model the intercepts were the same for all ages implying that the predicted lysine requirement for maintenance was the same for all age treatments. Birds with higher bodyweights are usually expected to have higher maintenance requirements. However, the higher bodyweight of the older birds in this experiment would have been due to the deposition of body fat and body fat has no maintenance requirement (Gous, 1986, pers. comm.). The values obtained in this study for the maintenance requirement per kg of bodyweight ('b') were very low. MacDonald and Morris (1985) reported a value of 79.5 mg/kg bodyweight for laying hens and Bowmaker and Gous reported a value of 11.2 mg/kg bodyweight. The values obtained in this study were all less than one. The values for the lysine requirement for 1 g of egg output ('a') seemed to increase from the youngest age to the oldest age, with some exceptions. These exceptions were probably due to poor fitting curves. An increase in the value of the coefficient for egg production implies that the requirement for lysine per g of egg output increased with increasing age. When the Reading Model was fitted to the eight flocks separately, and then together, so that the curves all had the same slope, the predicted maximum egg output was different for the four ages. The response in egg output declined with increasing age.

These results were in good agreement with the results from fitting the regression model to egg output. The egg output increased most rapidly in response to lysine intake for the youngest age treatment and most slowly for the oldest age treatment. Age 1 and age 2 had significantly higher responses to egg output than age 4. When examining the curves fitted by the Reading Model and the multiple regression model it can be concluded that the response in egg output varied between the four different age treatments.

The fact that egg output, rate of lay and egg weight decreased with increasing energy intake at low intakes could be explained by the fact that at low food intakes the birds had very low egg outputs due to low lysine levels, so excess energy would have been consumed, over and above that required for egg production. This excess energy would have been stored as body fat or lost in the form of heat. At low intakes, increasing the energy intake would have led to increased body fat deposition and increased heat production which could have led to a decrease in egg output.

Some birds had high rates of lay. One of the birds from age treatment A1 and dietary treatment D2, had a rate of lay of 100% for seven out of the nine weeks of the experiment. A large number of the birds did not lay at all during the final four weeks of the experiment. It can be seen that as the age of the birds increased the number of birds not laying increased and the number of birds laying at a rate less than 50% increased (See Figure 3.3).

The reason why the gain in weight decreased with increasing lysine intake at low intakes is because egg output was low at low lysine intakes and as the egg output increased the energy requirement for egg production would increase and so there would be less excess energy available to be deposited as body fat. This also explains why the youngest birds had the lowest weight gains and the oldest birds the highest weight gains. The youngest birds had the highest egg output at all lysine intakes so as their egg output increased with increasing energy intake they would have had a higher energy requirement to sustain this egg output and there would have been less excess energy available to be deposited as body fat reserves. Conversely, the oldest birds with their lower egg output would have had a lower energy requirement for egg production and more excess energy would have gone into body reserves.

The relationship between efficiency and rate of lay was in good agreement with Fisher (1976 and 1980), who found that the efficiency of utilization of protein decreased when the rate of lay declined to below 50%. However, Fisher reported that the value of the efficiency when rate of lay was 50% was approximately 0.8, for laying hens. This was very different to the value obtained in the present study, where the efficiency at a rate of lay above 50% was found to be between 0.45 and 0.5. The mean efficiency of utilization for each age treatment ranged between 0.33 and 0.42. These values were lower than the values reported by MacDonald and Morris (1985) of 0.79 and Fisher (1980) of 0.84, for laying hens. However, the efficiency of utilization reported by Bowmaker and Gous (1991) for broiler breeders was much lower than these values, being 0.47 which is closer to the values found in the present study. When the birds with rates of lay of less than 50% were excluded from the analysis the values for the efficiencies increased to a range of 0.45 to 0.49. This is in agreement with Bowmaker and Gous (1991) who also found that the efficiency of utilization of lysine increased when birds with rates of lay of less than 50% were excluded from their analysis. Their value for efficiency increased from 0.47 to 0.57.

The efficiencies for the two youngest age treatments were significantly higher than those for the two oldest age treatment when all birds were included in the analysis. However, when the birds with rates of lay less than 50% were excluded from the analysis there were no significant differences between the age treatments. This indicates that the decline in efficiency of utilization of lysine in the older age treatments is due to the decline in efficiency of birds laying at a rate of lay of less than 50%. There was an increase in the number of birds with a rate of lay less than 50% as age increased (See Figures 3.3 a, b, c and d). It has been proposed that the efficiency of utilization of protein decreases when the rate of lay declines to below 50%, due to the fact that egg yolk deposition changes from being continuous to become phasic (Fisher, 1980) and the number of developing yellow follicles declines (Hocking *et al.*, 1987).

The fact that egg output decreases as broiler breeders age is due to a decrease in rate of lay as egg weight in fact increases with age. This decrease in egg output does not imply that the protein requirements of these birds decline because it is probable that the efficiency with which protein is utilized declines as the rate of lay declines, below 50%. This implies that the birds would require more protein during the later stages of lay to maintain the same egg output as at an earlier stage or that they need the same amount of protein as at an earlier stage to maintain a lower egg output. Using the coefficients, obtained from fitting the Reading Model in this experiment (Table 3.11, Pg. 71) the requirements for lysine for the youngest birds (A1) and the oldest birds (A4) on the low energy series were calculated. It was estimated that to maintain an egg output of 70 g/bird d the A1 birds required 982 mg lysine/bird d and the A4 birds required 1143 mg/bird d. For the A4 birds to maintain an egg output of only 60 g/bird d the requirement would be 980 mg lysine/bird d.

In light of the previous research and the results from this experiment decreasing the food allowance after peak production has been reached is possibly not the most ideal way of feeding broiler breeder hens. If the protein requirements do not decline as the birds age although their egg production declines, by decreasing the food allowance the birds' amino acid intakes are being reduced and this could well be causing egg production to drop off faster than it should.

Further research needs to be undertaken to establish the effects on egg production of different methods of feeding during this period. It may be possible to use a method of phase-feeding. Instead of offering only one feed from the time of peak production until the end of the laying period, the feed is changed at regular intervals. Diets with a lower energy content could be offered as production declines while keeping the amino acid contents of these feeds constant. A second possibility is to keep two separate feeds in the bulk tanks outside the poultry house, a protein source and an energy source. These two feeds could then be blended in the appropriate proportions to achieve a desirable energy:protein ratio depending on the egg production and the requirements of the flock for that egg production. In this way the energy intake of the birds could be reduced while keeping the amino acid intake constant.

GENERAL DISCUSSION

It has been realized that there are some difficulties associated with matching the nutritional requirements to performance in broiler breeder hens. These difficulties are a consequence of the fact that broiler breeding stock have been selected for improved growth rate and not egg production. This has led to an increase in the mature weight of these birds (Robinson *et al.*, 1993). It has been shown that bodyweight is negatively correlated with egg production (McDaniel *et al.*, 1981b) and therefore in order to obtain maximum production from these birds, their growth rate needs to be controlled. This is achieved by restricting the birds' food intake to below *ad libitum* intake throughout their lives. This raises problems concerning the amount of each nutrient that should be supplied each day .

Regulation of the food intake of broiler breeders during the laying period is a potential means of reducing costs and improving the efficiency of broiler chick production. Most food allowances for breeding hens have been based on the expected pattern of egg production. Thus a generous allowance early in lay is followed by a period of mild regulation over peak production, and a subsequent reduction in allowance as egg production declines in the later part of lay. There are however some problems associated with manipulating the food allowance in this manner. It seems that it is not always possible to meet the requirements for maximum production at the various stages of lay by manipulating the food allowance according to the pattern of egg production. This study was undertaken to address two aspects of this problem concerned with broiler breeder nutrition, during the laying period and specifically the period after peak production has been reached. The first aspect is the obesity in broiler breeder hens that results from birds having been overfed. The second aspect is the rapid decline in egg production in ageing hens.

It has been shown that overfeeding broiler breeders leads to the deposition of excess body fat which has a negative effect on egg production (McDaniel et al., 1981b; Pearson and Herron, 1981). Obesity has been cited as one of the main reasons for poor laying especially in ageing flocks (Hocking *et al.*, 1987). However, Gous *et al.* (1992) showed that fattened broilers do utilize their excess fat reserves as an energy source provided the dietary protein intake is sufficient to allow this.

The objective of the first experiment was to determine the extent to which broiler breeder hens could be made to utilize their excess body lipid reserves whilst maintaining laying performance. The main conclusions drawn from this experiment were that it is possible for overfat broiler breeders to utilize their body lipid reserves, at least for a limited period of time, if the protein intake is sufficiently high. Overfat broiler breeders fed an energy intake of 1490 kJ ME/bird d and a protein intake of 25.8 g/bird d showed no decline in egg production when compared with birds that were fed much higher energy intakes (1900 to 2000 kJ ME/bird d). These birds were obviously utilizing their body fat reserves as an energy source because their energy intake was much lower than those the recommended. The birds on the low energy treatment had significantly lower bodyweights, abdominal fat contents and carcass fat contents than the birds on the high energy treatments. An energy intake of 1490 kJ ME/bird d and protein intake of 25.8 g/bird d were achieved by feeding a food allowance of only 140 g/bird d. This is a much lower food allowance than is currently being fed to birds of this age (49 weeks) in commercial operations (approximately 160 to 170 g/bird d).

Many researches, in studies with laying hens, have shown that the efficiency of utilization declines in ageing hens (Fisher and Morris, 1967; Jennings *et al.*, 1972; Wethli and Morris, 1978). The objectives of the second experiment were to measure the responses of broiler breeders hens to lysine, at different ages and to determine if the efficiency of utilization of lysine changes at different ages. The main conclusions drawn from this experiment were that the efficiency of utilization of lysine declines as broiler breeders age. The efficiency of utilization was significantly lower for birds of 53 and 65 weeks of age when compared to birds of 31 and 42 weeks of age. It was shown that the efficiency of utilization of lysine declines when the rate of lay declines to below 50%. This decline in efficiency of utilization of lysine with increasing age was therefore attributed to an increase in the number of birds with rates of lay of less than 50%. The Reading Model, which was designed to predict the optimum amino acid requirements of laying hens for a given level of egg output, was fitted to the means in this study. This showed that for a given level of egg output older birds require more lysine than younger birds for the same egg output.

In light of this study decreasing the food allowance after peak production is reached may not be the most ideal way to achieve maximum egg output from broiler breeder hens. Decreasing the energy intake at this stage is essential to prevent the deposition of excess body fat which would lead to a decrease in egg production (Pearson and Herron, 1981). In fact it may be possible to decrease the energy intake to a lower level than is currently being fed at this stage because there are indications that broiler breeder hens can utilize their fat reserves and this may help to alleviate the problem of decreased egg production due to obesity. The problem with this approach is that by decreasing the food allowance at this stage, the amino acid intake of the birds is being reduced. The evidence suggests that protein intake should not be decreased at this stage because the efficiency of utilization of amino acids declines when the rate of lay decreases to below 50%, which it does in many broiler breeders as they age. The evidence suggests that the same intake of protein is required to maintain a lower rate of lay in older birds. Decreasing the protein intake at this stage would be causing egg production to decline faster than it would if the protein intake were kept constant.

Further research needs to be undertaken to establish the effects on body composition and egg production of feeding modified food mixtures especially during the later stages of lay. A method of phase-feeding could be used so that diets with different nutrient contents could be fed as the egg production declines or two separate feeds, a protein source and an energy source, could be blended in different proportions to change the energy:protein ratio of the feed. In both of these ways the energy intake of the birds could be reduced while keeping the protein intake constant. It would be very useful to make use of radioactive isotopes to quantify changes in body fat that take place when birds are fed diets with low energy contents.

REFERENCES

BALNAVE, D. (1973) A review of restricted feeding during growth of laying-type pullets. *World's Poultry Science Journal.*, **29**: 354-362.

BECKER, W.A., SPENCER, J.V., MIROSH, L.W. & VERSTRATE, J.A. (1979) Prediction of fat and fat-free live weight in broiler chickens using backskin fat, abdominal fat and live bodyweight. *Poultry Science*, **58**: 835-842.

BENNETT, C.D. & LEESON, S. (1990a) Influence of energy intake on development of broiler breeder pullets. *Canadian Journal of Animal Science*, **17**: 259-266.

BENNETT, C.D. & LEESON, S. (1990b) Body composition of the broiler-breeder pullet. *Poultry Science*, **69**: 715-720.

BORNSTEIN, S., PLAVNIK, I. & LEV, Y. (1984) Body weight and/or fatness as potential determinants of the onset of egg production in broiler breeder hens. *Poulttry Science*, **25**: 323-341.

BOWMAKER, J.E. & GOUS, R.M. (1989) Quantification of reproductive changes and nutrient requirements of broiler breeder pullets at sexual maturity. *British Poultry Science*, **30**: 663-675.

BOWMAKER., J.E. & GOUS, R.M. (1991) The response of broiler breeder hens to dietary lysine and methionine. *British Poultry Science*, **32**: 1069-1088.

BRODY, T., EITAN, Y., SOLLER, M., NIR, I. & NITSAN, Z. (1980) Compensatory growth and sexual maturity in broiler females reared under severe restriction from day of hatching. *British Poultry Science*, **21**: 437-446.

COSTA, M.S. (1981) Fundamental principles of broiler breeders nutrition and the design of feeding programmes. *World's Poultry Science Journal*, **37**: 177-191.

DE GROOTE, G. (1974) Utilisation of metabolisable energy, in: T.R. Morris & B.M. Freeman (Eds) *Energy requirements of poultry*, pp. 113-134 (British Poultry Science Ltd., Edinburgh).

EMMANS, C.G. (1974) The effects of temperature on the performance of laying hens, in: T.R. Morris & B.M. Freeman (Eds) *Energy requirements of poultry*, pp 79-90. (British Poultry Science Ltd., Edinburgh).

EMMANS, C.G. (1981) A model of the growth and feed intake of ad libitum fed animals, particularly poultry, in: G.M. Hillyer, C.T. Whittemore & R.G. Gunn (Eds) *Computers in animal production,* pp 103-110 (B.S.A.P., Thames Ditton).

FARRELL, D.J. (1974) Effects of dietary energy concentration on utilisation of energy by broiler chickens and on body composition determined by carcass analysis and predicted using tritium. *British Poultry Science*, **15**: 25-41.

FARRELL, D.J. & BALNAVE, D. (1977) The *in vivo* estimation of body fat content in laying hens. *British Poultry Science*, **18**: 381-384.

FISHER, C. (1976) Protein in the diets of the pullet and laying bird in: D.J.A. Cole *et al.* (Eds) *Protein metabolism and nutrition*, pp. 323-351 (Butterworths, London).

FISHER, C. (1980) Protein deposition in poultry, in: Buttery, P.J. and Lindsay, D.B. (Ed.) *Protein deposition in animals*, pp. 251-270 (Butterworths, London).

FISHER, C. (1994) Responses of laying hens to amino acids, in: J.P.F. D'Mello (Eds) *Amino acids in farm animal nutrition*, pp 245-280 (CAB International, Oxon).

FISHER,C. & MORRIS, T.R. (1967) Some effects of changing the protein levels during the pullet laying year. *British Poultry Science*, **8**: 153-161.

FISHER, C., MORRIS, T.R. & JENNINGS, R.C. (1973) A model for the description and prediction of the response of laying hens to amino acid intake. *British Poultry Science*, **14**: 469-484.

FRAPS., R.M. (1955) Egg production and fertility in poultry, in: J. Hammond., (Eds) *Progress in the physiology of farm animals, volume II*, pp. 661-740 (Butterworths, London).

FULLER., H.L., POTTER., D.K. & KIRKLAND., W. (1969) Effect of delayed maturity and carcass fat on reproductive performance of broiler breeder pullets. *Poultry Science*, **48**: 801-807.

GOUS, R.M. (1972) The influence of dietary protein and energy concentration on the body composition of broiler breeder pullets. *South African Journal of Animal Science*, **2**: 51-58.

GOUS, R.M. Department of Animal Science and Poultry Science, University of Natal, P O Box X01, Pietermaritzburg, 3201.

GOUS, R.M., EMMANS, G.C., BROADBENT, L.A. & FISHER, C. (1990) Nutritional effects on the growth and fatness of broilers. *British Poultry Science*, **31**: 495-505.

GOUS, R.M., EMMANS, G.C. & FISHER, C. (1992) The response of broilers to feeds differing in protein content following a period of fattening. *Thirteenth annual meeting of the Southern Poultry Science Society, Atlanta, Georgia.*

HOCKING, P.M., GILBERT, A.B., WALKER, M. & WADDINGTON, D. (1987) Ovarian follicular structure of White Leghorns fed *ad libitum* and dwarf and normal broiler breeders fed *ad libitum* or restricted until point of lay. *British Poultry Science*, **28**: 493-506.

HOCKING, P.M., WADDINGTON, D., WALKER, M. & GILBERT, A.B. (1989) Control of the development of the ovarian follicular hierachy in broiler breeder pullets by food restriction during rearing. *British Poultry Science*, **30**:161-174.

JENNINGS, R.C., FISHER,C., & MORRIS, T.R. (1972) Changes in the protein requirements of pullets during the first laying year. *British Poultry Science*, **13**: 279-281.

JOHNSON, R.J. & FARRELL, D.J. (1988) The prediction of body composition in poultry by estimation *in vivo* of total body water with tritiated water and deuterium oxide. *British Journal of Nutrition*, **59**: 109-124.

LEE, P.J.W., GULLIVER, A.L. & MORRIS, T.R. (1971) A quantitative analysis of the literature concerning the restricted feeding of growing pullets. *Bitish Poultry Sc*ience, **12**: 413-437.

LEESON, S. & SUMMERS, J.D. (1982) Consequence of oncreased feed allowance for growing broiler breeder pullets as a means of stimulating early maturity. *Poultry Science*, **62**: 6-11.

LUNVEN, P., LE CLEMENT DE ST MARCQ. C., CARNOVALE. E. & FRATONI. A. (1973) Amino acid composition of hen's egg. *British Journal of Nutrition*, **30**: 189-194.

MCDANIEL, G.R., BRAKE, J. & BUSHONG, R.D. (1981a) Factors affecting broiler breeder performance. 1. Relationship of daily feed intake level to reproductive performance of pullets. *Poultry Science*, **60**: 307-312.

MCDANIEL, G.R., BRAKE, J. & ECKMAN, M.K. (1981b) Factors affecting broiler breeder performance. 4. The interrelationship of some reproductive traits. *Poultry Science*, **60**: 1792-1797.

MCDONALD, M.W. & MORRIS, T.R. (1985) Quantitative review of optimum amino acid intakes for young laying pullets. *British Poultry Science*, **26**: 253-264.

MORRIS, T.R. and FOX, S. (1960) Increasing versus constant daylength for laying pullets. *British Poultry Science*, **2**: 59-65.

MORRIS, T.R. and GOUS, R.M. (1988) Partitioning the response to protein between egg number and egg weight. *British Poultry Science*, **29**: 93-99.

O'SULLIVAN, N.P., DUNNINGTON, E.A., SMITH, E.J., GROSS, W.B. & SIEGEL, P.B. (1991) Performance of early and late feathering broiler breeder females with different feeding regimens. *British Poultry Science*, **32**: 981-995.

PEARSON, R.A. & HERRON, K.M. (1980) Feeding standards during lay and reproductive performance of broiler breeders. *British Poultry Science*, **21**: 171-181.

PEARSON, R.A. & HERRON, K.M. (1981) Effects of energy and protein allowance during lay on the reproductive performance of broiler breeder hens. *British Poulttry Science*, **22**: 227-239.

PEARSON, R.A. & HERRON, K.M. (1982) Relationship between energy and protein intakes and laying characteristics in individually-caged broiler breeder hens. *British Poultry Science*, **23**: 145-159.

ROBINSON, F.E., HARDIN, R.T. & ROBBLEE, A.R. (1990) Reproductive senescence in domestic fowl: effects on egg production, sequence length and inter-sequence pause length. *British Poultry Science*, **31**: 871-879.

ROBINSON, F.E., ROBINSON, N.A. & SCOTT, T.A. (1991) Reproductive performance, growth rate and body composition of full-fed versus feed-restricted broiler breeder hens. *Canadian Journal of Animal Science*, **71**:549-556.

ROBINSON, F.E., WILSON, J.L., YU, M.W., FASENKO, G.M. & HARDIN, R.T. (1993) The relationship between body weight and reproductive efficiency in meat-type chickens. *Poultry Science*, **72**: 912-922.

SHANAWANAY, M.M. (1983) Sexual maturity and subsequent laying performance of fowls under normal photoperiods - A review 1950-1975. *World's Poultry Science Journal*, **39**: 38-46.

SOLLER., M., EITAN. & BRODY., T. (1984) Effect of diet and early quantitative feed restriction on the minimum weight requirement for onset of sexual maturity. *Poultry Science*, **63**: 1255-1261.

SMITH, W.K. (1978a) The amino acid requirements of laying hens: Models for calculation. 1. Physiological background. *World's Poultry Science Journal*, **34**: 81-96.

SMITH, W.K. (1978b) The amino acid requirements of laying hens: Models for calculation. 2. Practical application. *World's Poultry Science Journal*, **34**: 129-136.

WALDROUP, P.W., HAZEN, K.R., BRUSSEL, W.D. & JOHNSON, Z.B. (1976) Studies on the daily protein and amino acid needs of broiler hens. *Poultry Science*, **55**: 2343-2347.

WETHLI, E. & MORRIS, T.R. (1978) Effects of age on the tryptophan requirement of laying hens. *British Poultry Science*, **19**: 559-565.

WILLIAMS, J.B. & SHARP, P.J. (1978) Ovarian morphology and rates of ovarian follicular development in laying broiler breeders and commercial egg-producing hens. *British Poultry Science*, **19**: 387-395.

WILSON, J.L., ROBINSON, F.E., ROBINSON, N.A. & HARDIN, R.T. (1995). Effects of feed allocation on female broiler breeders. *Journal of Applied Poultry Research*, **4**: 193-202.

YALCIN, S., MCDANIEL, G.R. and WONG-VALLE, J. (1993) Effect of preproduction lighting regimes on reproductive performance of broiler breeders. *Journal of Applied Poultry Research*, **2**: 51-54.

YU, M.W., ROBINSON, F.E. and ROBBLEE, A.R. (1992a) Effect of feed allowance during rearing and breeding on female broiler breeders. 1. Growth and carcass characteristics. *Poultry Science*, **71**: 1739-1749.

YU, M.W., ROBINSON, F.E., CHARLES, R.G. & WEINGARDT, R. (1992b) Effect of feed allowance during rearing and breeding on female broiler breeders. 2. Ovarian morphology and production. *Poult. Sci.*, **71**: 1750-1761.

APPENDIX 1

Individual responses for all treatments in Chapter 2

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APPENDIX 2

Individual responses for all treatments in Chapter 3

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