General enquiries on this form should be made to:
Defra, Science Directorate, Management Support and Finance Team,
Telephone No. 020 7238 1612
E-mail: research.competitions@defra.gsi.gov.uk

SID 5 Research Project Final Report

- **Note**
  In line with the Freedom of Information Act 2000, Defra aims to place the results of its completed research projects in the public domain wherever possible. The SID 5 (Research Project Final Report) is designed to capture the information on the results and outputs of Defra-funded research in a format that is easily publishable through the Defra website. A SID 5 must be completed for all projects.

  A SID 5A form must be completed where a project is paid on a monthly basis or against quarterly invoices. No SID 5A is required where payments are made at milestone points. When a SID 5A is required, no SID 5 form will be accepted without the accompanying SID 5A.

- This form is in Word format and the boxes may be expanded or reduced, as appropriate.

- **ACCESS TO INFORMATION**
  The information collected on this form will be stored electronically and may be sent to any part of Defra, or to individual researchers or organisations outside Defra for the purposes of reviewing the project. Defra may also disclose the information to any outside organisation acting as an agent authorised by Defra to process final research reports on its behalf. Defra intends to publish this form on its website, unless there are strong reasons not to, which fully comply with exemptions under the Environmental Information Regulations or the Freedom of Information Act 2000.
  Defra may be required to release information, including personal data and commercial information, on request under the Environmental Information Regulations or the Freedom of Information Act 2000. However, Defra will not permit any unwarranted breach of confidentiality or act in contravention of its obligations under the Data Protection Act 1998. Defra or its appointed agents may use the name, address or other details on your form to contact you in connection with occasional customer research aimed at improving the processes through which Defra works with its contractors.

Project identification

1. Defra Project code: OF0327

2. Project title:
   Validation of the HEN biological model for laying hens and an assessment of nutritional issues in organic poultry production

3. Contractor organisation(s): ADAS UK Ltd

4. Total Defra project costs: £ 76190

5. Project: start date .... 01 August 2002

   end date .... 31 July 2005

6. It is Defra's intention to publish this form.
   Please confirm your agreement to do so...YES ☒ NO ☐

   (a) When preparing SID 5s contractors should bear in mind that Defra intends that they be made public. They should be written in a clear and concise manner and represent a full account of the research project which someone not closely associated with the project can follow.

   Defra recognises that in a small minority of cases there may be information, such as intellectual property or commercially confidential data, used in or generated by the research project, which should not be disclosed. In these cases, such information should be detailed in a separate annex (not to be published) so that the SID 5 can be placed in the public domain. Where it is impossible to complete the Final Report without including references to any sensitive or confidential data, the information should be included and section (b) completed. NB: only in exceptional circumstances will Defra expect contractors to give a "No" answer.

   In all cases, reasons for withholding information must be fully in line with exemptions under the Environmental Information Regulations or the Freedom of Information Act 2000.

   (b) If you have answered NO, please explain why the Final report should not be released into public domain

Executive Summary

7. The executive summary must not exceed 2 sides in total of A4 and should be understandable to the intelligent non-scientist. It should cover the main objectives, methods and findings of the research, together with any other significant events and options for new work.

Introduction

Regulation EC1804/1999 sets out the minimum standards for organic livestock production and UK organic poultry producers have to adhere to for organic poultry. There are several aspects of Regulation EC1804/1999 which are technically and practicably challenging with regards to organic poultry production and most of these relate to feeding organic poultry. The greatest problems relate to the need to feed mainly organic ingredients, there is a future requirement to feed 100% organic ingredients, and the banning of synthetic amino acids in feeds for organic poultry.

The issues raised by the introduction of Regulation EC1804/1999 are: 1) how do we match the supply of energy and nutrients to the bird's needs for health, welfare and performance in a UK organic poultry production system? 2) Do we fully understand the bird's amino acid needs for metabolic processes and can we meet them when feeding 80% or more organic ingredients? 3) Do UK-grown organic ingredients have lower crude protein and amino acid contents than their non-organic counterparts? If so, this will exacerbate any difficulties in amino acid supply to the birds. 4) What are the implications of Regulation EC1804/1999 in terms of ingredient supply for organic poultry production?

These issues were addressed in this project. Firstly by measuring on-farm the hen's feed metabolisable energy intake responses to temperature in outdoor production systems and examining whether a model (the ADAS HEN model) of inputs (feed metabolisable energy, protein and amino acids) and outputs (egg numbers and weight) could be validated for use in organic egg production systems. If so, this would provide a user-friendly approach for practical decision making at farm level. Secondly, by examining the published literature on recommended nutrient requirements for non-organic poultry and assessing the applicability of the findings to organic poultry. Thirdly, by sampling organically grown crops (wheat, peas and beans) and determining their contents of crude protein and amino acids. Fourthly, by estimating the size of the UK organic poultry flocks and their requirements for organic ingredients.

Objectives

1. To validate the HEN model for organic egg production so that the feed energy value relative to protein content may be better matched with feed intake, and energy and nutrient requirements in differing outdoor temperatures.
2. To scope the technical issues relating to the nutrition of organic pullets, laying hens, table birds and breeder flocks.
3. To review the essential amino acid requirements for maintenance, growth, immune system development, behaviour, laying performance, sexual maturity and the risk of prolapse and interpret the

relevance of published conventional data to organic poultry production.

4. To examine whether or not there are differences in the contents of crude protein content, lysine, methionine and threonine of organic and non-organic wheat, peas and beans (by analysis).
5. To examine the implications of changes in Regulation EC1804/1999 and Standards (e.g. organic pullet rearing and organic breeder flocks) on the volumes of organic feed ingredients needed for sustained UK organic poultry production (chickens) based on the current sector size.

Methodology

Approach 1 Measurements were made of feed intake, rate of lay, egg weight, house temperature and outside temperature in three UK commercial flocks of free range hens during late autumn/winter. The feed was sampled and the metabolisable energy value was determined. The data were statistically analysed to determine whether there was a relationship between feed metabolisable energy intake and temperature.

Approach 2 Representatives of some of the UK's major producers of organic eggs and organic table chickens were interviewed and the findings were reported. Wherever possible, the technical issues raised by producers were substantiated by reference to the literature. The literature was examined to see if technical problems may be overcome using existing scientific knowledge.

Approach 3 The literature on the essential amino acid requirements of poultry for maintenance, health and performance was reviewed. Diet formulation simulations were completed and the resultant estimated nutrient contents of practicable diets for organic poultry were compared with target nutrient requirements according to published data. Any discrepancies between the practicable estimated nutrient content and the target nutrient content were highlighted and the implications of over or under supplying a nutrient were discussed. An assessment of the potential role of the pasture as nutrient source was undertaken.

Approach 4 Samples of organic wheat, peas and beans were obtained for the harvest year 2003 from several locations within England and Wales so as to take into account the effects of different agronomic conditions. The samples were analysed for dry matter and amino acid contents. The findings were compared with published results for non-organic crops.

Approach 5 The additional quantities of organic ingredients needed to sustain the estimated 2004-level of organic eggs and table chickens produced per annum in the UK when moving from 80% to 100% organic provenance, and when requiring organic pullets and organic breeder flocks were calculated. Industry estimates of UK organic bird numbers needed were used.

Results

Approach 1 Hens in outdoor production systems failed to display a consistent significant relationship between feed metabolisable energy intake and temperature. These results indicate that the HEN model is not applicable to free range production systems, and thus the model could not be validated for organic laying hens.

The extent of relative change of feed metabolisable energy intake with temperature was small, perhaps indicating that the feed metabolisable energy intake response was already approaching the maxima, or that the variability of temperature in outdoor production systems masked the robust relationships derived in non-organic caged hens.

Approaches 2 and 3 There is current a reliance on permitted non-organic sources of protein for feeding organic poultry, and particularly for organic laying hens. There is concern within the UK organic poultry industry that as the proportion of permitted non-organic ingredients in the ration falls deficiencies of methionine will increase. Methionine deficiency will reduce bird performance, and there may be negative effects on the immune system and behaviour (injurious feather pecking). In general, attempts to maximise the dietary methionine content have resulted in an over supply of crude protein. This will impact on the rate of nitrogen excretion from organic poultry, and the risk of nitrogen pollution to the air and water environments will be increased. The results of the diet formulation simulation studies substantiated industry claims.

The potential contribution of the pasture (grass, insects and worms) to the nutrition of organic poultry is not negligible (except in winter), but it is probably small, and under 5% of crude protein requirements.

Approach 4 The determined crude protein and amino acid contents of organic wheat (soft wheat) and beans were lower than published values for non-organic wheat and beans. Organic peas tended to have similar crude protein, lysine and threonine contents as non-organic peas, but there was a trend for methionine contents to be lower in organic peas.

Approach 5 Estimates of the volume of 'organic replacement protein' needed to sustain the 2004-level of

UK organic egg and table chicken production when moving from 80% to 100% organic provenance were calculated to be about 5 000 t/annum for laying hens and about 450 t/annum for table chickens.

The quantities of organic full-fat soya, sunflower meal, 'replacement protein' and fishmeal needed for organic pullet rearing and breeder hens, so as to sustain the 2004-sector sizes for organic eggs and table chickens were calculated to be about 2 800 t/annum, 400 t/annum, 850 t/annum and 370 t/annum, respectively (based on 100% organic provenance). In addition, it was estimated that about 8 000 t/annum of organic wheat and about 2 000 t/annum of organic wheatfeed were needed for this purpose.

Implication of findings and future work

1. There is an inability to optimise the dietary ratio of metabolisable energy to protein for hens in outdoor production systems, as the hen's feed metabolisable energy intake responses to low fluctuating outdoor temperatures have not been defined. The implications of this are tempered with respect to organic egg production as the priority when formulating diets is to meet, as far as possible with the limited range of ingredients available, the organic hen's methionine and lysine requirements, which in practice is resulting in too much crude protein being fed.
2. Feeding excess crude protein will increase the rate of nitrogen excretion from organic poultry, and there will be an increased risk of nitrogen pollution to the air and water environments.
3. Without additional organic methionine-rich protein sources, methionine deficiencies will become more pronounced and more widespread in organic poultry production as the level of permitted non-organic proteinaceous ingredients in the diet fall. This will impact on bird health and welfare.
4. The possibility of lower methionine contents in organically produced wheat, peas and beans will exacerbate problems of methionine supply.
5. There is an urgent need to identify novel sources of organic methionine-rich protein for feeding organic poultry. This is being addressed in Defra-funded project OF0357 'Organic egg production – A desk study on sustainable and innovative methods for meeting the hen's protein requirements'

The project addressed Defra's policy of supporting the sustainable development of organic poultry production in the UK. The project has provided both Defra and the industry with information about the key scientific and technical problems, and some possible solutions to these problems. Where there are gaps in knowledge it has highlighted future research needs. The move to 100% organic provenance for organic poultry feeds is an important issue for UK consumers.

Project Report to Defra

8. As a guide this report should be no longer than 20 sides of A4. This report is to provide Defra with details of the outputs of the research project for internal purposes; to meet the terms of the contract; and to allow Defra to publish details of the outputs to meet Environmental Information Regulation or Freedom of Information obligations. This short report to Defra does not preclude contractors from also seeking to publish a full, formal scientific report/paper in an appropriate scientific or other journal/publication. Indeed, Defra actively encourages such publications as part of the contract terms. The report to Defra should include:
   - the scientific objectives as set out in the contract;
   - the extent to which the objectives set out in the contract have been met;
   - details of methods used and the results obtained, including statistical analysis (if appropriate);
   - a discussion of the results and their reliability;
   - the main implications of the findings;
   - possible future work; and
   - any action resulting from the research (e.g. IP, Knowledge Transfer).

Introduction

Regulation EC1804/1999 sets out the minimum standards for organic livestock production and UK organic poultry producers have to adhere to for organic poultry. There are several aspects of Regulation EC1804/1999, which are technically and practicably challenging with regards to organic poultry production and most of these challenges relate to feeding organic poultry. Most notably, minimum standards were set for the proportion of organic ingredients in feeds for organic poultry and lists of approved ingredients (e.g. Annex II, Part C for conventional products of plant origin and Annex II, Part D Sections 1.1 and 1.2 for trace elements and vitamins, respectively) were published. Ingredients may only be used in organic feeds if they are listed. Importantly, synthetic amino acids were not included (Annex II, Part D) and so they could no longer be fed to organic poultry.

Since the ban on feeding meat and bone meal there had been a dependence on the use of synthetic lysine and methionine for meeting the chicken's needs for maintenance, health, welfare and performance. This is because plant proteinaceous products are mostly deficient in lysine but particularly deficient in methionine. Fishmeal, which is rich in these nutrients, may only be fed in small quantities because of the risk of egg or meat taint and often it is avoided because of food safety concerns. The ban on feeding synthetic amino acids to organic poultry was important. There are implications for the welfare, health and performance (biologically and economically) of organic chickens if their metabolic needs for essential amino acids can not be met.

The technical difficulties raised by banning the feeding of synthetic amino acids to organic poultry were confounded by the requirement to feed a minimum of 80% organic ingredients (on a dry matter basis per annum). There are fewer organic plant proteinaceous products available than non-organic plant proteinaceous products and there was some concern that the protein and amino acid contents of organic ingredients might be lower than for their non-organic counterparts. Furthermore, the derogation on feeding 100% organic ingredients expired on 24th August 2005 (note: a new derogation has recently been published which allows a gradual move towards 100% organic feed, this expires on 24th August 2011).

Thus, several technical issues/questions related to the feeding of organic poultry arose after the introduction of Regulation EC1804/1999. These were:

1. How to match the supply of energy and nutrients to the bird's needs for maintenance, health, welfare and performance in a UK organic poultry production system?
2. Do we fully understand the bird's amino acid needs for maintenance, health, welfare and performance and how close can we get to meeting these needs when feeding 80% or more organic ingredients?
3. Do UK-grown organic ingredients (wheat, peas and beans) have lower crude protein and amino acid contents than their non-organic counterparts?
4. What are the implications of Regulation EC1804/1999 in terms of ingredient supply for organic poultry production?

The issue of protein and amino acid supply was thought to be most difficult for organic laying hens. Thus, there has been greater emphasis in this project on feed intake and protein and amino acid supply for organic laying hens than for other classes of organic poultry.

There is a vast body of scientific literature on the amino acid requirements of laying hens for maintenance, growth and egg mass output but this was derived using non-organic hens housed in cages. One component of this project was to validate information derived for non-organic caged laying hens and to assess its applicability to organic laying hens in outdoor production systems.

By the early 1980s the volume of quantitative poultry science literature relevant to the technical management of hens was already prodigious. The understanding of the factors affecting egg mass output (feed metabolisable energy intake) at different ambient temperatures, and protein and essential amino acid intake, particularly lysine, methionine and tryptophan) was progressing fast. However, if the information was to be used within the egg industry a means of assessing the implications of key independent variables on egg numbers and egg weights was needed. This would then enable a means of predicting the effects of variables on gross margins. It was considered that biological models offered a way forward.

At the time UK poultry scientists were developing two approaches to modelling. The first approach was the construction of causal models built upon fundamental biological principles (e.g. Fisher *et al.,* 1983). These models were based upon robust concepts, and the parameters had biological meaning, but the models were often complex and difficult to use.

The second approach to modelling was based on quantitative literature reviewing. This approach was less fundamental, and the models therefore required more frequent updating as poultry hybrids changed and as new data became available, but they could be produced relatively quickly. A model of egg production was constructed by ADAS by arranging algebraic response curves in an appropriate biological sequence (detailed later) and then attaching monetary values to the inputs and outputs (Charles, 1984). The model, named HEN, used methodology which had been recommended by Dillon (1977). In the case of the response to amino acid intake the complexities of using the method of Fisher *et al.* (1973), which at the time required main frame computers, were avoided by the use of inverse polynomial approximations. The use of inverse polynomial functions to describe responses to nutrient intake was later confirmed by Curnow (1986). Regular updates and enhancements have been made, using both published information and unpublished data from ADAS Gleadthorpe. Current versions are programmed in *Microsoft Excel* for ease of use.

The use of a sequence of responses in the HEN model raised the question of the possibility of interactions between factors altering the predicted results. This was later addressed by Hill *et al*., (1988) who carried out a large experiment on multiple nutritional and environmental factors in order to test the model and to test for interactions. Significant interactions were found to be rare, except for the important interaction between temperature and dietary amino acid content. However this interaction was already understood when the model was constructed, and had been built into the algorithm. The recognition of the importance of the interaction, both in modelling and in the practical application of the model, followed earlier work such as that of Payne (1966) and of Emmans and Charles (1977).

In the 1960s, 70s and early 80s most commercial egg production was indoors and intensive. Thus, the feed intake and performance responses of laying hens to warm temperatures in the range of about 15^{o}C to 25^{o}C were rigorously and exhaustively investigated. The results of several sets of experiments were impressively consistent (Bray and Gessel, 1961; Payne, 1966; Mowbray and Sykes, 1971; Davis *et al*., 1972; Emmans and Charles, 1977; Marsden *et al*., 1987). Reviews were provided by Emmans (1974), Charles and Walker (2002), and Al-Saffar and Rose (2002). The consistency in results between experiments permitted practical recommendations to be made with confidence. The biological and economic optimum temperature for layers indoors was generally agreed to be around 21^{o}C to 22^{o}C, which is substantially warmer than the conditions mostly experienced by organic layers outdoors in the UK.

The feed metabolisable energy intake responses to the ranges of temperature experienced by UK organic hens were not investigated and therefore the published biological models do not offer users predictions of feed metabolisable energy intake across the range of temperatures relevant to organic production.

The original model as published in 1984 starts with estimations of feed metabolisable energy intake, and thence *ad libitum* feed intake, as driven by temperature and dietary metabolisable energy concentration. Feed intake is adjusted for any effects of feather condition and feeding system. Feed intake is then used to calculate the intake of the first two limiting amino acids (methionine and lysine), and inverse polynomial response curves are applied to measure their effects on egg output. These calculations estimate the maximum egg output for a flock, which was then depressed by any sub-optimal levels of photoperiod and light intensity. Feed costs and egg prices by grade are used to evaluate the effects of variables on gross margin of egg sales less feed cost.

The original published versions of the model, and the practical updates of the first 19 years, were constructed around the published, and some unpublished, science and technology of non-organic cage egg production. Almost all of the applications of the model during these years have been to the non-organic intensive sector. Some of the variables considered are irrelevant to organic production (e.g. intermittent lighting, light intensity, ahemeral lighting programmes). However the key variables and algorithms are relevant to organic egg production because they consider the biological responses of hens to factors affecting the birds regardless of production system. The estimation of feed metabolisable energy intake and feed intake from temperature and dietary metabolisable energy value remains a suitable starting point, and the use of feed intake to calculate amino acid intake and thence response to amino acids remains a sound basis for predicting egg output and egg weight.

In practical applications of the model for evaluating management options the important variables are the nutritional variables resulting from changes in diet formulation and feed cost. Dietary metabolisable energy value and protein and amino acid contents are the key variables in practical diet formulation and the model considers these. These are just as relevant for organic egg production and it was thought useful if the model could be used to test the biological and economic consequences of such options for organic flocks. Thus, the HEN model was validated for organic laying hens. This was done by measuring feed metabolisable energy intakes in UK outdoor hens during the late-autumn, winter and early-spring months and temperature was measured at frequent intervals throughout a 24-hour period within the house and outdoors on range. The data were statistically analysed to test for a relationship between feed metabolisable energy intake and temperature (a weighted mean so as to allow for daytime ranging and night-time roosting indoors), either in real time or lagged. If a simple relationship between feed metabolisable energy intake and weighted temperature existed then this could be used to theoretically optimise the supply of feed metabolisable energy relative to protein and other nutrients at different times of the year. One application of this information might be to reduce the amount of nitrogen excreted and therefore the risk of nitrogen pollution to the air and water environments.

Other components of the project were: 1) a scope of the technical issues relating to the nutrition of organic poultry (laying hens, table chickens, pullets and breeders); 2) a review of the literature on the essential amino acid requirements of poultry and an interpretation of the relevance of the published data to organic poultry production; 3) a scope of whether the protein and amino acid (lysine, methionine and threonine) contents of UK-grown organic wheat, peas and beans differed to the published values for non-organic grown crops, and; 4) an assessment of changes in Regulation EC1804/1999 on the volumes of organic crops needed for feeding UK organic poultry.

Objectives

1. To validate the HEN model for organic egg production so that the feed energy value relative to protein content may be better matched with feed intake, and energy and nutrient requirements in differing outdoor temperatures.
2. To scope the technical issues relating to the nutrition of organic pullets, laying hens, table birds and breeder flocks.

3. To review the essential amino acid requirements for maintenance, growth, immune system development, behaviour, laying performance, sexual maturity and the risk of prolapse and interpret the relevance of published non-organic data to organic poultry production.
4. To examine whether or not there are differences in the crude protein content and digestible amino acid contents (lysine, methionine and threonine) of organic and non-organic wheat and peas (by analysis).
5. To examine the implications of changes in Regulation EC1804/1999 and Standards (e.g. for organic pullet rearing and organic breeder flocks) on the volumes of organic feed ingredients needed for sustained UK organic poultry production (chickens) based on the current sector size.

Extent to which the objectives have been met
Objectives 2 to 5 have been met in full. Objective 1 was undertaken and the work was delivered but the scientific findings did not enable the HEN model to be validated for organic laying hens, the reasons for this are discussed.

Methodology
Approach 1 (work to meet objective 1) 'Validation of the HEN model for organic laying hens'
Accurate knowledge of daily feed metabolisable energy intake (MJ/hen.day) by free range laying hens was needed and this required the measurement of daily feed intake (g/hen.day) and the determination of feed metabolisable energy values (MJ/kg). The latter was derived by sampling the feed on-farm and measuring the crude protein, oil, starch and sugar contents. The feed metabolisable energy values (MJ/kg) were calculated using the Hartell equation:
Metabolisable energy (MJ/kg) = (0.1551 x %crude protein content) + (0.3431 x % oil content) + (0.1669 x %starch content) + (0.1301 x %total sugar content).

This was done on three commercial sites (s) and for one flock per site, referred to as s1, s2 and s3 over a target period of 28 days and on three occasions (p1, p2 and p3) during late autumn/winter as this was expected to give the outdoor temperature conditions of interest (i.e. below 15°C).

Feed intake in laying hens is not usually measured accurately on a daily basis by commercial producers, and so it was necessary to identify a number of free range egg producers who had the measuring equipment to do this, and who were willing to be involved in the project. This was done, but the flocks studied were in non-organic free range egg production systems. Importantly, this was not thought detrimental to the objective of the study as the hen's feed metabolisable energy intake responses to temperature are independent of organic status. Furthermore, difficulties in meeting the hen's essential amino acid needs for maintenance and egg production when feeding an organic ration might have confounded the study as there is some evidence of birds over consuming feeds which are slightly deficient in an amino acid (MacLeod, 2004). Gross deficiency or excess, which can be summarised as an amino acid imbalance, usually leads to a reduction in intake (MacLeod, 2004 citing D'Mello, 1994).

For s1 and s2, two flocks were actually studied at each site as the hens studied in p1 were depopulated before the start of p2. It is usual practice in non-organic and organic egg production systems to depopulate the hens from about 68 weeks to 80 weeks of age. For s3, the same flock was studied throughout. In each case the hybrid used was the Hyline Brown Egg Layer.

The numbers of eggs laid daily and the mean weight of the eggs laid on one day per week were measured and recorded. Temperature (dry bulb air temperature) was measured using TinyTalk temperature probes and this was recorded at 30 minute intervals both in the house (INT) at two standardised positions (above the litter at hen height in an area adjacent to the nest boxes (INT1) and above the slats at hen height (INT2)) and at one position in the paddock (OUT) using one or two probes (OUT1 in p 1 and 2, and OUT1 and OUT2 in p3). Composite samples of manure were collected from the droppings pit and the contents of dry matter, total nitrogen, ammonium-nitrogen and uric acid-nitrogen, and the pH value were determined. The producer recorded the time of day that the popholes were opened and closed, and they estimated the percentage of the flock going outdoors on a daily basis.

As the mean daily temperature experienced by the flock of hens was influenced by INT1 and INT2, and OUT, and by the proportion of the flock ranging outdoors it was necessary to calculate a 'weighted mean temperature' (Tw). This was undertaken by calculating four components of temperature exposure for either all of the flock (i.e. during no access to range, and during darkness) or a proportion of the flock (i.e. during access to range, or non access to range but during the photoperiod).

Estimates of the proportion of the flock ranging outdoors varied but were between 10% and 50%. Thus, Tw was calculated twice: 1) on the basis of 10% of the flock ranging outdoors during daytime access, and; 2) on the basis of 50% of the flock ranging outdoors during daytime access.

It was assumed that during the time of range access the hens indoors used the litter area adjacent to the nest boxes and the slatted area evenly. The same assumption was made for the periods of no range access, but while the house lights were on. As the majority of hens roost on perches at night (Keeling, 2004) only INT2 was considered to be relevant to the calculation of thermal degrees during darkness.

The steps in calculating Tw (°C/hen.day) are given below. For simplicity the example shown is for occasions when only OUT1 was used.

i) Total degrees outdoors (TotOUT) during ranging per 30 minute period for 10% or 50% of the flock:
OUT (°C) x 30 x 0.1 (or 0.5) x flock size.

ii) Total degrees indoors during range access (TotINT ACC) per 30 minute period for 90% or 10% of the flock:
((INT1 (°C) + INT2 (°C))/2) x30 x 0.9 (or 0.1) x flock size.

iii) Total degrees indoors during no access (TotINT NO ACC) to range but with the house lights on per 30 minute period:
((INT1 (°C) + INT2 (°C))/2) x30 x flock size.

iv) Total degrees indoors during no access to range but during darkness (TotINT DARK) per 30 minute period:
INT2 (°C) x30 x flock size.

v) Total degrees experienced by the flock for each 30 minute period (Tot FLOCK):
(TotOUT) + (TotINT ACC) + (TotINT NO ACC) + (TotINT DARK).

vi) Tw (°C/hen.day) for 10% or 50% of the flock ranging:
(Tot FLOCK /30)/flock size.

Note that the calculation of Tw (°C per hen per day) corresponded chronologically with the 24-hour period over which feed usage was measured.

Statistical analyses
Statistical analyses were undertaken using either Statistica v 5.5 (Anon. (1999), Statistica v 6.0 (Anon. (2001), Minitab v 11(Anon. 1995) or Genstat v 8.0 (Anon.(2005).

i) Regression analyses
Linear regression analyses were performed on all of the unadjusted temperature series (INT1, INT2 and OUT) to check whether the data were compliant with expectations (e.g. INT1 and INT2 should be highly correlated).

The temperature series OUT, INT1, INT2, Tw10% and Tw50% were each used in linear and quadratic regression as the independent variable against the corresponding feed metabolisable energy intake data, for each s and p. Each regression, was assessed, *inter alia*, by its fitted plot, statistical significance of the regression, and the percent variance explained, and its 'biological sense'.

ii) Tolerance charts
Feed metabolisable energy intake data (all s and p) were collated for bins of 4˚C between 4˚C and 16˚C, and for bins of 5˚C between 5˚C and 20 ˚C and tolerance charts produced for 90% of the population with 90% confidence (Dixon and Massey, 1969); such charts are used for chronobiological data (Wilson *et al.,* 1981).

iii) Time Series analysis
a) Time series plots
These were produced for each series of temperature (INT1, INT2 and OUT2) and feed metabolisable energy intake to determine if rhythmic components existed in the data that would improve the prediction of feed metabolisable energy intake based on INT data.

b) Cross-correlations
To determine whether the feed metabolisable energy intake responses on a particular day were related to preceding daily temperatures, and therefore could be potentially modelled and incorporated into the HEN model, cross-correlations between the aforementioned feed metabolisable energy intake and temperature series were undertaken.

<u>Approach 2 (work to meet objective 2) 'Scope the technical issues relating to the feeding of organic pullets, laying hens, table chickens and breeder flocks'</u>
The work was a desk study, which involved: 1) interviewing representatives of some of the UK's major producers of organic eggs and organic table chickens and reporting the findings; 2) substantiating, wherever possible the technical issues raised by producers by reference to the literature, and; 3) examining the literature to see if technical problems may be overcome using existing scientific information.

A series of interviews was conducted during the winter of 2003/2004 with key representatives of some of the UK's major producers of organic eggs and organic table chickens. The major producers were targeted because they have the greatest potential to impact on the UK supply of organic poultry products. It was important to see how these companies were reacting and responding to recent and future changes in derogations. Furthermore, the companies chosen have a track record in addressing and solving technical issues in poultry production.

Approach 3 (work to meet objective 3) 'The essential amino acid requirements of chickens for maintenance, health and welfare' (abbreviated)
A review of the literature on the essential amino acid requirements of chickens (laying hens, pullets, table birds and meat-type breeders) for maintenance, health and performance was undertaken. Diet formulation simulation studies were completed for non-organic and organic laying hens (layer ration 2 fed during mid-lay), pullets (chick ration fed from day old up to between five and eight weeks of age), table chickens (grower ration fed between about 11 days and 28 days of age) and meat-type breeder hens (breeder layer 1 ration fed during early lay). The computer-aided approaches used are described below. Ingredients were offered for inclusion within each ration type. The list of ingredients used was as follows: wheat, wheatfeed, barley, sunflower meal (expeller), peas, beans, lucerne, prairie meal, Kellogs maize germ, maize gluten 60/2, maize gluten 20, full-fat soya, fish meal, grass, poultry fat blend, vegetable oil, minerals and vitamins. It was assumed that organic wheat, wheatfeed, sunflower meal (expeller) and full-fat soya are readily available and that they will comprise at least 80% of the diet (note: a minimum of 80% organic provenance on a dry matter basis was allowed at the time of the study). Organic potato protein was not used in the diet formulations as this was thought not to be freely available in the UK at the time of the study.

An approximate price was attributed to each ingredient and this influenced to some extent its use in the feeds. It was for reasons of cost that organic maize was not offered. The prices of the feeds are not reported however, as they will fluctuate depending on market conditions.

The target specifications for each of the rations (layer 2, pullet chick, grower and breeder layer 1) were set prior to formulation, and this included a range of tolerances for energy and major nutrients (Tables 6, 7, 8 and 9 Annex 1, respectively).

The target nutrient specifications used for brown-egg layers and pullet chicks were higher than those given by the NRC (1994). However, it is important to note that the recommendations given by the NRC (1994) are estimates derived from recommended requirements for smaller white-egg layers and pullets. Furthermore, they are for caged hens and it is usual practice to aim at achieving a slightly higher body weight when destined for use in outdoor production systems. The target nutrient specifications given in Table 6 (Annex 1) for brown-egg layers were typical of those used in the UK for non-organic free-range brown-egg layer hybrids. In the case of pullet chicks, the target nutrient specifications given in Table 7 (Annex 1) were similar to those given by Lohmann for their brown pullet chicks, but less than those given by HyLine for their Variety Brown pullet chicks. Thus, a compromise on the target nutrient specification for brown pullet chicks was used.

For organic table chickens the targets specified for crude protein, lysine and methionine contents (Table 8, Annex 1) were less than those given by the NRC (1994). This is because the NRC (1994) nutrient recommendations assume the use of 'fast growing' broiler hybrids and both non-organic traditional free range table chicken production and organic table chicken production require the use of 'slow growing' hybrids. Whether or not the targets specified for lysine, and in particular methionine allow for optimal health (e.g. immunocompetence) in 'slow growing' hybrids is not known.

The target nutrient specifications for organic breeder hens (Table 9, Annex 1) were marginally higher than those given by Leeson and Summers (1997). Difficulties exist in determining the appropriate target nutrient specification for organic breeder hens, as feed will need to be provided on *an ad libitum* basis. This and other issues related to feeding organic breeder hens were considered in detail in Defra-funded project (www.defra.gov.uk/science/project_data/DocumentLibrary/OF0336/OF0336_2174_FRP.doc).

For each class of stock a non-organic diet was formulated, which was thought to be non-limiting to performance and health. Each of the diets was then reformulated, but using only organic and permitted ingredients. In some cases it was not possible to meet all of the target diet specifications, and so it was necessary to assess which of the criteria were more important. The diets were then reformulated to meet the revised criteria.

The resultant estimated nutrient contents of practicable diets for organic poultry were compared with target nutrient contents according to published requirements (Lohmann, 1991; NRC, 1994; Hy-Line UK Ltd, 1997; Leeson and Summers, 1997). Any discrepancies between the practicable estimated nutrient content and the target nutrient content were highlighted and the implications of over or under supplying a nutrient were discussed.

Lastly, an assessment of the potential role of the pasture and macroinvertebrates in contributing to the bird's protein and amino acid intake was undertaken.

Approach 4 (work to meet objective 4) 'To to determine the crude protein and amino acid contents (lysine, methionine and threonine) of organic wheat, peas and beans and to assess the implications in terms of feeding organic poultry

Samples of organic wheat (11, cultivars Paragon, Hereward and Clare), peas (6) and beans (4) were obtained for the harvest year 2003 with the assistance of Gleadell Agriculture Ltd. The samples were obtained from several locations within England (South West, East Anglia, North East, South East) and Wales so as to take account of different agronomic conditions. The samples were analysed for dry matter, crude protein, total lysine, methionine, threonine and available lysine contents. The findings were compared with published results for conventional crops, as it was not possible to obtain conventionally grown crops from the same site.

Approach 5 (work to meet objective 5) 'The implications of changes in Regulation EC1804/1999 and Standards (e.g. organic pullet rearing and organic breeder flocks) on the volumes of organic feed ingredients needed for sustained UK organic poultry production (chickens) based on the current sector size'

To assess the effects of changes in Regulation EC1804/1999 on the volumes of organic ingredients needed to sustain production it was necessary to:
i) estimate the current size of the UK organic laying hen flock and the number of UK organic table chickens produced per annum;
ii) estimate the number of replacement organic pullets and the required size of the UK organic breeder flock for meat-line chickens;
iii) estimate feed intake and the volume of organic feed needed for organic laying hens and organic pullets;
iv) estimate feed intake and the volume of organic feed needed for organic table chickens and organic breeder flocks (meat-line chickens);
v) estimate the quantities of organic ingredients (cereals and proteinaceous ingredients) for organic laying hens and organic table chickens when moving from 80% to 100% organic provenance;
vi) estimate the quantities of organic ingredients (cereals and proteinaceous ingredients) for organic pullets and organic breeder flocks at 100% organic provenance.

Information on the approximate split between the cereal (energy component) and proteinaceous components of the diet as derived in the simulated diet formulations undertaken in Approach 3 and reported below were used in sections v) and vi) of this study.

Results

Approach 1 (work to meet objective 1) 'Validation of the HEN model for organic laying hens'

Within the constraints of this report it is not possible to detail all of the results. Thus, the approach has been to detail the most important findings and to provide an overview of the general findings.

The actual duration of monitoring sometimes differed slightly from the target duration of 28 days due to practical constraints associated with using commercial production sites. The duration of monitoring for periods 1 to 3, respectively were: timespans of 31, 24 and 25 days for s1; timespans of 28, 28 and 22 days for s2, and; timespans of 23, 27 and 16 days for s3.

The ages of the flocks at the start of monitoring are shown in Table 1 (Annex 1). Feed dry matter content (g/kg), estimated metabolisable energy values (MJ/kg dry matter) and feed metabolisable energy intake (MJ/hen.day) are given in Table 2 (Annex 1).

Except for s3 p3, the rates of lay and mean egg weights were as expected for the ages of the hens studied. The performance of hens at s3 during p3 was below average, and their poor health resulted in an earlier than planned depopulation date. Feed metabolisable energy intake for s3 p3 was less than expected (Table 2, Annex 1) and this was taken into account during the analysis of results.

Manure dry matter (%), total nitrogen (% dry weight (dw)), ammonium-nitrogen (%dw) and uric acid-nitrogen (%dw) contents are given in Table 3 (Annex 1).

The manure dry matter and total nitrogen contents were mostly less than or at the lower range of values reported by Nicholson *et al.,* (1996) for non-organic free range hens (35.7% – 77.0% and 4.2%dw – 7.6% dw, respectively). Manure ammonium-nitrogen contents were either within the range reported by Nicholson *et al.,* (1996) for non-organic free range hens (0.7% dw – 2.2%dw) or greater, but the uric acid-nitrogen contents were all less than the values reported by Nicholson *et al.,* (1996) (1.7%dw – 2.0%dw). The readily-plant-available nitrogen supply (ammonium-nitrogen plus uric acid-nitrogen, MAFF, 1994) was high in the manure sampled at s2 p1 and s3 p3.

Regression analyses

Temperature data

In general, INT1 and INT2 followed each other in profile (Table 4, Annex 1) and to a lesser extent external temperature (OUT1) was reflected in the internal temperatures (INT1 and INT2). The relationship between indoor temperature at the two different locations was as expected and so was the effect of outdoor temperature on indoor temperature. The results demonstrate the existence of microclimates within a poultry house. Temperature at a given location is influenced by bird heat output and the temperature of 'new' air (i.e. air entering the house from outdoors).

Feed metabolisable energy intake *versus* non-composite outdoor and indoor temperature
There were no significant regressions between feed metabolisable energy intake (MJ/hen.day) and INT2 (°C) (p>0.05) as shown in Table 5. There were significant regressions between feed metabolisable energy intake (MJ/hen.day) and OUT1 (°C) for s1p3 only, and between feed metabolisable energy intake (MJ/hen.day) and INT1 (°C) for s3p2 only (both p<0.05, Table 5).

It was interesting that for a happenstance control (s3p1) where hens did not have access to range during the 23-day monitoring period (confinement during the period of nest-box training is a relatively common commercial management technique, which is done to reduce the number of floor eggs), there was no significant linear or quadratic regression between feed metabolisable energy intake (MJ/hen.day) and INT2 (°C) (p>0.05).

Tolerance charts
There were no discernible trends in the metabolisable energy intake data with respect to Tw when either 10% or 50% of the hens ranged outdoors (Tw10% and Tw50%, respectively) and when using bins of either 4°C or 5°C for Tw.

Time series analysis
Time series plots
Time series plots were produced for each data series of temperature (INT1, INT2 and OUT2) and feed metabolisable energy intake. Each datum was expressed as a percentage of its respective series mean. To facilitate description the decreasing order of magnitude for the first day was INT2, INT1, feed metabolisable energy intake and OUT1. Typicality was not the profiles themselves, but rather the inconsistent way the variables related to each other. INT1, INT2 and OUT1 oscillated around a relatively constant feed metabolisable energy intake value.

Cross-correlations of feed metabolisable energy intake and temperature
The feasibility of a lag in the hen's feed metabolisable energy intake response to temperature was considered. If there was a lag of one or more days, then this information, along with autoregression, might have enabled the development of a one-step ahead prediction model. This approach has been used for other chronobiological data (Dunstan *et al.,* 1982).

No consistent relationships emerged between feed metabolisable energy intake and temperature (Tw10% or Tw50%). Thus, feed metabolisable energy intake on a given day was not affected by the temperature experienced one or more days earlier.

Infradian rhythmic components of feed metabolisable energy intake
Birds of different ages might have different feed metabolisable energy intake chronobiological responses, and developing birds of the same age might have different feed metabolisable energy intake chronobiological responses. However, time series analysis failed to reveal any consistent spectral frequencies that would improve the predictive ability of the HEN model.

In summary, there were no consistent feed metabolisable energy intake responses to temperatures experienced by hens in outdoor production systems in the UK during winter months. These results indicate that the HEN model is not applicable to free range production systems, and thus the model could not be validated for organic laying hens.

<u>Approach 2 (work to meet objective 2) 'Scope the technical issues relating to the feeding of organic pullets, laying hens, table chickens and breeder flocks'</u>
The outcome of this objective was a 47pp report titled 'An assessment of nutritional issues in organic poultry production' (Owen and Gordon, 2004 available by emailing enquiries@adas.co.uk and specifying Defra project code OF0327 and the title of the report). The results given below are a précis of the most important findings and the reader is referred to the full report for further information.

Raw materials currently used in commercial organic poultry feeds
A list of raw materials used and their provenance was provided by Owen and Gordon (2004). Examples of the compositions of commercial organic diets, which were current at the time of the study, were given by Owen and Gordon (2004). This demonstrated the use of the above ingredients. However, in isolation they do not provide a guide to the importance of some of the non-organic ingredients. This is because the important 'protein balancers' (betaine, potato meal, maize gluten and fishmeal) often do not comprise a large proportion of the ration. They are

however, critical sources of methionine, this being the second limiting amino acid for growth and egg production.

At the time of the study, there was a great deal of concern that when the derogation on the provenance of organic feed ends (published date 24th August 2005, but recently revised so as to allow the feeding of permitted non-organic ingredients to organic poultry in reducing quantities up to 24th August 2011), and the non-organic 'protein balancers' can not be used, existing problems with trying to supply sufficient methionine to meet the birds' needs will be exacerbated. It was noted that at the time of the study there were no organic sources of any of the aforementioned 'protein balancers', and this was unlikely to be resolved in the near future.

Problems with protein and amino acid supply
Protein and amino acid supply was thought to be the most serious nutritional issue facing organic poultry producers. Producers reported that the ban on feeding synthetic amino acids had created a number of problems in terms of producing balanced organic poultry feeds. Organic feeds were now deficient or marginal in the two first limiting essential amino acids, commonly lysine and methionine (McDonald *et al.,* 2002), but high in crude protein. This resulted in a higher intake of nitrogen, which was being associated with more litter quality problems.

The need to feed more crude protein is against 'best practice' as applied in the non-organic sector, and there will be implications in terms of nitrogen output. The latter will need to be taken into account so as to avoid the risk of nitrogen pollution when the manure is applied on land.

A major producer concern arising from feeding diets marginal in essential amino acids, and in particular methionine, was an increased risk of injurious feather pecking, and cannibalism. There is evidence within the literature supporting this. Low dietary methionine contents have been implicated in incidences of injurious feather pecking and cannibalism. Neal (1956) reported a correlation between low dietary methionine contents and cannibalism in layers. Hughes and Duncan (1972) noted more pecking damage in pullets fed a ration containing a lower than normal methionine content.

A recent study at Harper Adams University College by Rose *et al.,* (2004) found that birds fed diets not containing synthetic amino acids had poor feather cover, and feather loss was most common in the area under the tail. Assessments of activity and behaviour indicated that hens fed this diet made more aggressive pecks towards other hens.

Injurious feather pecking is a serious welfare problem, which leads to physical damage, and in the case of cannibalism death may result. Some of the companies interviewed gave examples of high mortality rates as a result of cannibalism following the ban on feeding synthetic amino acids (rates of between 20% and 40% were quoted but this was mostly in flocks housed at the higher stocking densities as allowed by derogation). Their early experience has been that some non-beak trimmed pullet flocks needed to be beak trimmed after coming into lay because of cannibalism. Beak trimming at this age is seen as a last resort intervention because of the development of neuromas (Gentle, 1986), and consequent pain upon feeding (Gentle *et al.,* 1990).

The Code of Recommendations for the Welfare of Livestock Laying Hens states that pullet chicks should be beak trimmed at less than 10 days of age, in accordance with the Veterinary Surgery (Exemptions) Order 1962 (SI1962/2557). The view of the producers in this study was that pullet chicks for use in UK organic egg production systems should be beak trimmed so as to reduce the risks of injurious feather pecking and cannibalism, and the risk of poor welfare and trauma.

One organic egg producer had reared replacement pullets on organic diets not containing synthetic amino acids as an in-house study of potential problems. In general, the pullets were variable in weight and they were mostly below the breed target live weight for age recommendations. Low body weight at the start of lay increases the risk of prolapse, and this can increase the risk of aggressive behaviour including vent pecking and cannibalism. Egg size will also be reduced, and this will continue throughout lay (Leeson and Summers, 1997).

Problems with cannibalism have not just been restricted to organic laying flocks. Some UK organic table chicken flocks had also needed to be beak trimmed for this reason.

Thus, anecdotal evidence strongly suggests that the current strains of both egg and meat birds cannot thrive on diets that are marginal in essential nutrients without behavioural, welfare and health problems.

Since the ban on feeding synthetic amino acids, there has been a greater UK reliance on the use of non-organic maize gluten. The amino acid profile of maize gluten complements that of soya bean meal, maize gluten being richer in sulphur containing amino acids than soya bean meal, and soya bean meal being richer in lysine than maize gluten (Larbier and Leclercq, 1994). In Approach 3 of this project the amino acid contents of a large number of ingredients were tabulated (see report by Gordon, 2004a titled 'The essential amino acid requirements of poultry for maintenance, health and performance in an organic production system' available by emailing enquiries@adas.co.uk and specifying Defra project code OF0327 and the aforementioned report title).

This partial solution is only for the short term however, as there is no source of organic maize gluten and no likelihood of one. The findings of study have re-iterated the urgent need for organic sources of methionine-rich proteinaceous ingredients for feeding organic poultry.

Approach 3 (work to meet objective 3) 'The essential amino acid requirements of chickens for maintenance, health and welfare' (abbreviated)
The outcome of this objective was a 284pp report titled 'The essential amino acid requirements of poultry for their maintenance, health and performance in an organic production system' (Gordon, 2004a). The reader is referred to the full report for further information which is available by emailing enquiries@adas.co.uk and specifying Defra project code OF0327 and the aforementioned title of the report.

Categories of amino acids
Birds are not capable of synthesising some amino acids and so these must be provided within the diet. For this reason they are called essential amino acids (Larbier and Leclercq, 1994). They can be divided into three categories: 1) those which cannot be synthesised at all because respective transaminases are absent (e.g. lysine and threonine); 2) those which can be synthesised from precursors but at a rate that is insufficient (e.g. leucine, valine and isoleucine), and; 3) those that may be synthesised within general metabolic processes but at a rate that is insufficient to meet needs (e.g. arginine and histidine). Methionine may be synthesised in the body through the methylation of homocysteine with betaine being the methyl donor (Simon, 1999 citing Finkelstein, 1990 and Ziesel, 1990). This does generally not occur at a rate which is sufficient to enable optimum growth and it is dependent on the availability of choline, betaine, folic acid, vitamin B_{12}, methionine, cysteine, cystine and other amino acids such as serine and glycine (Simon, 1999).

Semi-essential amino acids are those that may be synthesised from essential amino acids (Larbier and Leclercq, 1994). They are cysteine and tyrosine, which are derived from the essential amino acids methionine and phenylalanine, respectively.

Non-essential amino acids are those that birds' can easily synthesise for themselves either from intermediary metabolites or from other non-essential amino acids (Larbier and Leclercq, 1994). The former group include alanine, glycine, serine and aspartic and glutamic amino acids. For the latter, proline is synthesised from glutamic acid.

Protein and amino acid contents of the chicken and egg
Bird body and egg amino acid contents were quoted by Gordon (2004a) as a basis for understanding the bird's needs for unit growth or unit egg synthesis.

Carcass protein content increases with age of the bird (Larbier and Leclercq, 1994). If the feathers are included in the analysis then day old chicks have a protein content of 16.3%, and this has increased to 20.8% and 20.5% for males and females, respectively at 42 days of age. There is another very small increase by 70 days of age when the protein content of males is 21.0% and that of females is 20.6%.

The concentrations of amino acids in the carcass protein and feather protein of young chicks, broilers and Leghorn hens were given by Gordon (2004a). The data cited by Gordon (2004a) suggests that there are similarities between the carcass amino acid contents of all classes of chickens, though lysine is an exception, for which the difference between young chicks and broilers is 3.4 g/100g protein. The latter may be a consequence of increased breast meat yields in modern broiler hybrids, since breast muscle is rich in lysine (Moran, 1995 citing Roth *et al.,* 1990). Body protein is richest in arginine, leucine, lysine and phenylalanine, whereas feathers are rich in most of these, but less so for lysine, and more so for the sulphur amino acids.

Eggs are made up of three very distinct components: the shell, white (albumen) and yolk (Larbier and Leclercq, 1994). The proportion of the egg as shell is between 8% and 10%, and the white and yolk comprise 60% and 30%, respectively (*loc.cit.*).

Whole eggs have a protein content of 120 g/kg and of this the yolk accounts for 42%, albumen 55% and the shell 3% (Leeson and Summers, 2001).

The proteins of egg yolk and egg white are important. They play key roles in the development of the chick embryo, and for humans they are important in nutrition and in food manufacture. Egg yolk has a particular taste much sought after for biscuit and pastry manufacture, and it has emulsifying properties which are employed extensively in the production of mayonnaise, biscuit creams and meat balls (Larbier and Leclercq, 1994). The foaming properties of specific components of the albumen are important in baking and confectionary, and perhaps particularly so in organic food manufacture, as other means of achieving this in non-organic foods may not be permitted.

The amino acid content of whole eating eggs, egg yolk and egg white was published by Larbier and Leclercq (1994) and the information was cited by Gordon (2004a). Whole eggs are richest in aspartic acid, serine, glutamic acid, leucine, valine, lysine and arginine.

The recommended requirements for amino acids for growth in chickens and egg production
The NRC (1994) published recommended requirements for amino acids for broilers, broiler breeders (hens and cockerels), laying hens and pullets and these were cited by Gordon (2004a). Other sources of information used included published nutrient intake recommendations for laying hen hybrids commonly used in the UK in free-range egg production systems including organic production systems (Lohmann, 1991; Hy-Line UK Ltd, 1997; Leeson and Summers, 1997).

Diet simulation studies for organic poultry
Laying hens
The composition of the formulated rations (layer 2) for non-organic free range laying hens and organic laying hens are given in Tables 10 and 11 (Annex 1). The calculated nutrient contents of the rations, plus the target nutrient specifications are given in Table 6 (Annex 1).

The non-organic layer 2 ration was mainly comprised of wheat, soya, sunflower meal, vegetable oil and limestone. Synthetic methionine was used so as to ensure an adequate supply of this nutrient. The rest of the ingredients were minerals, electrolytes and vitamins.

The non-organic layer 2 ration met the hens' recommended needs for nutrients and the metabolisable energy value of the diet was within the target range specified. Furthermore, the crude protein content of the diet was towards the lower end of the specified range (179.5 g/kg crude protein, *versus* a target of between 170.0 g/kg and 220.0 g/kg crude protein). If fed, this would be helpful in controlling the rate of nitrogen excretion from hens, as high crude protein intakes are associated with increased rates of nitrogen excretion.

The organic free-range layer 2 ration differed from the non-organic ration in that the soya used was full-fat, and maize gluten was used, plus higher quantities of sunflower meal than in the non-organic ration in an attempt to meet the hen's methionine needs. The ration was, however, deficient in lysine and methionine (7.9 g/kg lysine, *versus* a target minimum of 8.6 g/kg lysine and 3.7 g/kg methionine, versus a target minimum of 4.1 g/kg methionine) and it was marginally deficient in its supply of metabolisable energy (11.67 MJ/kg *versus* a target minimum of 11.70 MJ/kg). Furthermore, the crude protein content was much higher than the non-organic free range layer 2 ration (199.3 g/kg crude protein, *versus* 179.5 g/kg crude protein, respectively), and the total phosphorus content of the organic layer ration exceeded the maximum target value (6.0 g/kg total phosphorus, *versus* a target maximum of 5.5 g/kg phosphorus). The rates of nitrogen and phosphorus excretion would be higher when feeding the organic ration than when feeding the non-organic ration. Furthermore, the slightly low metabolisable energy value of the organic diet may exacerbate the rate of nitrogen and phosphorus excretion if hens consume more feed in an attempt to meet their metabolisable energy requirements for maintenance and egg output.

Pullets
There was a range of ingredients in the non-organic pullet chick ration (Table 12, Annex 1) but wheat comprised about 65% of the ration. Soya, maize gluten feed, sunflower meal, fishmeal and peas all contributed protein but there was still a need to supplement with synthetic methionine.

The non-organic chick starter ration was slightly higher in crude protein and potassium compared with the targets specified for these nutrients (193.7 g/kg crude protein, *versus* a target of 180 g/kg crude protein and 8.0 g/kg potassium, *versus* a target of less than 7.0 g/kg potassium). Fortunately at this age, the intake of the feed is low as the chicks are small and so the increased rate of nitrogen excretion associated with this is not expected to have a large impact over the whole rearing period. The moderately high potassium content of the non-organic chick starter ration may affect water intake and the wetness of droppings.

Wheat accounted for about 66% of the organic pullet chick ration (Table 13, Annex 1). The ingredients contributing protein to the ration were full-fat soya, maize gluten (60/2), sunflower meal and fishmeal.

The crude protein content was higher than for the non-organic ration (209.7 g/kg crude protein, *versus* 193.7 g/kg crude protein, respectively), but lysine and methionine were marginally deficient in the organic ration (9.0 g/kg lysine, *versus* a target of 9.2 g/kg lysine and 3.9 g/kg methionine, *versus* a target of 4.0 g/kg methionine) (Table 7, Annex 1). Potassium was high in the organic pullet chick ration (8.1 g/kg potassium, *versus* a target maximum of 7.0 g/kg potassium) as a result of including full-fat soya and fishmeal. Perhaps of greatest concern was the high ME value of the organic pullet chick ration (12.20 MJ/kg, *versus* a target of 11.80 MJ/kg), which if fed may reduce feed intake and exacerbate any amino acid deficiencies. The fat content of the organic protein rich ingredients increased the ME value of the diet, thus the balance between providing amino acids and ME was a compromise.

Table chickens
The formulated diets for non-organic traditional free range table chickens and organic table chickens including and not including fishmeal are given in Tables 14, 15 and 16 (Annex 1) and the calculated nutrient contents plus target nutrient specifications are given in Table 8 (Annex 1).

The grower ration for non-organic traditional free-range table chickens was comprised mainly of wheat, soya, maize gluten and vegetable oil; but there was a small amount of fishmeal. Both synthetic lysine and methionine were used so as to meet the target specifications for these nutrients. The remaining ingredients were minerals, electrolytes and vitamins.

The nutrient contents of the non-organic traditional free-range grower ration were within the target ranges specified and so was the ME value. Note that the crude protein content of the ration was well below the maximum specified (179.9 g/kg crude protein, *versus* a target maximum of 210.0 g/kg crude protein).

The organic grower ration not including fishmeal was comprised mostly of wheat, soya, sunflower meal and maize gluten. The crude protein content of the ration (180.7 g/kg crude protein) was within the target range specified (between 161.0 g/kg and 210.0 g/kg crude protein), and it was very similar to that achieved for non-organic traditional free-range table chickens. The target lysine and methionine contents were not met however, in the organic grower ration (7.6 g/kg lysine, *versus* a target of 8.6 g/kg lysine and 3.0 g/kg methionine, *versus* a target of 3.1 g/kg methionine). The greatest deficiency was for lysine and if fed it would be expected to have a negative impact on live weight gain and breast meat yield. Conversely, the maximum target contents for dietary crude fibre, oil, linoleic acid and potassium were exceeded in the organic grower ration (Table 8, Annex 1). A high crude fibre content makes the diet bulky and digestibility may be reduced. The dietary oil content is important as it can impact on digestion and litter quality (Tucker and Walker, 1992). If the litter becomes greasy then droppings deposited on the litter remain in contact with the bird rather than being broken down by litter bacteria. The fat type used is also important as too much unsaturated fat can lead to the carcass being greasy. However, young birds are unable to digest saturated fats (Larbier and Leclercq, 1994).

A high dietary potassium content is undesirable as water intake is increased with high potassium contents and droppings are wetter (Tucker and Walker, 1992). This can lead to wet capped litter and an increased risk of hock burn damage.

Fishmeal was included in a reformulated organic grower ration at the expense of sunflower meal but not on a one to one replacement basis. There was a need to balance the diet for energy and nutrients and this was achieved by adjusting the dietary wheat content.

The use of fishmeal in the diet increased the crude protein, lysine and methionine contents (Table 8, Annex 1). However, the lysine content was still below the target specified (8.2 g/kg lysine, *versus* a minimum target of 8.6 g/kg lysine) and if fed it would be expected to impact on live weight gain and breast meat yield. It is important to realise that the target ranges specified for lysine and methionine are not for either optimal or maximal growth and breast meat yields; rather they are for an appropriate amino acid balance.

The dietary ME value of the ration was above the target specified (12.95 MJ/kg, *versus* a target maximum of 12.80 MJ/kg), and this if fed this may reduce intake. If so, then the deficiency in lysine may become more pronounced.

The possibility of problems due to high crude fibre, oil and linoleic contents were still apparent with the organic grower ration including fishmeal.

Breeder hens
The non-organic organic breeder layer 1 ration comprised mainly wheat, soya, sunflower meal, wheatfeed, vegetable oil and limestone (Table 17, Annex 1). The use of synthetic lysine and methionine ensured that the targets specified for these nutrients were met. Electrolytes, minerals and vitamins were added so as to ensure an appropriate supply of these nutrients to the birds. The nutrient contents of the diet were within the target ranges specified and so was the dietary ME value (Table 9, Annex 1).

Many of the ingredients used for the organic breeder layer 1 ration (Table 18, Annex 1) were the same as for the non-organic ration, except for provenance. Both of the rations were mainly comprised of wheat, soya, sunflower meal and limestone. As synthetic amino acids were not allowed in organic rations, an attempt was made to meet the bird's needs for lysine and methionine by using fishmeal and maize gluten. However, even after doing this both the lysine and methionine contents were below the minimum targets specified for these nutrients (7.1 g/kg lysine, *versus* a target minimum of 7.4 g/kg lysine and 3.3 g/kg methionine, *versus* a target minimum of 3.5 g/kg methionine) (Table 18, Annex 1). Furthermore, it is not usual to feed fishmeal to breeders because of the risk of introducing *Salmonella* to the birds.

The ME value of the organic breeder layer 1 ration was above the maximum specified (11.78 MJ/kg, *versus* a target maximum of 11.70 MJ/kg). This may be undesirable if there is a need to control ME intake for the purpose of body weight control.

The effects of feeding diets deficient in lysine and methionine on breeder health, growth, and egg output and on progeny health and performance are not known.

The potential role of the pasture and macroinvertebrates in contributing to the protein and amino acid requirements of organic poultry
Organic hens may derive some of their nutrient requirements by foraging outdoors. The potential contribution of foraged grass to the protein requirements of organic laying hens, and the possibility of foraged insects acting as a protein rich food source was considered.

The quantity of grass eaten by chickens on pasture is not known. Intake is likely to vary with factors such as the balance of grass and herbage species present, height and stage of growth, and the management of the pasture. There may be differences between breeds of chickens in crop size as a proportion of body size and in other aspects of their propensity to consume fresh herbage on range.

Gordon (2004a) estimated the possible daily protein intake of hens foraging young fresh grass. It was assumed that hens consumed 18 g/day fresh grass (Robinson, 1948), and that the grass had a crude protein content of 156 g/kg (fresh basis) and contained 200 g/kg dry matter (MacDonald *et al.,* 2002). Protein intake was calculated to be 0.56 g/hen.day (about 2.8% of requirement for a modern layer hybrid producing 305 egg/hen housed per year, at 64.4 g/egg, and when offered a feed containing 165 g/kg of balanced protein).

It is likely that insects and earthworms are foraged by poultry and these are rich in essential amino acids. For example, Bassler *et al.,* (1999) cited work reporting the nutrient value of earthworms (Yoshida and Hoshii, 1978). The crude protein, lysine and methionine plus cystine contents were very high (610 g crude protein/kg dry matter, 42 g lysine/kg dry matter and 12 g methionine plus cystine/kg dry matter). What is not known is how much the intake of insects and earthworms might contribute towards the birds overall nutrient needs and how this might be optimised even if only on a seasonal basis.

Gordon (2004a) reviewed work by Mwalusanya *et al., (*2002) on insect intake by scavenging chickens in Tanzania for an insight into the potential dietary role of insects in UK organic poultry. The mean worm and insect crop content was 57.5 ± 5.88 g/kg in young chickens and 58.1 ± 5.88 g/kg in adult hens (Mwalusanya *et al.,* 2002). There were differences in crop worm and insect content between climatic zones with the highest value being for birds kept in the cool and wet climate (71.2 ± 7.21 g/kg). The findings were similar though for birds kept in the warm and wet climate and birds kept in the warm and dry climate (55.4 ± 7.21 g/kg and 47.1 ± 7.21 g/kg, respectively).

In UK organic poultry production systems sources of variation in insect and earthworm intake could include: weather and climate, herbage species and stage of growth, stocking density of the birds on the pasture, pasture management and the place of the pasture in a whole farm rotation. It was thought that the potential contribution of the pasture to the nutrition of organic poultry is not negligible (except in winter), but it is probably small, and under 5% of crude protein requirements. There were however, many uncertainties surrounding these estimates.

<u>Approach 4 (work to meet objective 4) ‘To examine whether there are differences in the crude protein content and digestible amino acid contents (lysine, methionine and threonine) of organic wheat, peas and beans</u>
Of the three organic wheats tested Paragon and Hereward had higher crude protein contents than Claire (mean crude protein content being 121.4 g/kg dry matter (range 108.0 g/kg dry matter to 136.0 g/kg dry matter), 117.8 g/kg dry matter (range 108.0 g/kg dry matter to 134.0 g/kg dry matter) and 98.9 g/kg dry matter (range 92.7 g/kg dry matter to 102.0 g/kg dry matter), respectively. This was similar to the findings for non-organic, treated winter wheat, harvest year 2003 as reported by the HGCA (http://hgca.com). The HGCA reported a mean crude protein content of 131.0 g/kg dry matter for Hereward, with Paragon being similar in crude protein content, and a mean crude protein content of 118.0 g/kg dry matter for Claire. Hereward and Paragon are hard wheat’s, whereas soft wheat’s such as Claire are usually used for feeding poultry.

Larbier and Leclercq (1994) reported a non-organic wheat crude protein content of 130.0 g/kg dry matter and 3.7 g/kg dry matter lysine, 2.20 g/kg dry matter methionine and 3.90 g/kg dry matter threonine. In this study, the average lysine, methionine and threonine contents of organically grown soft wheat (Claire) were 3.3 g/kg dry matter, 1.4 g/kg dry matter and 3.3 g/kg, respectively. Thus, the organic wheat lysine and threonine contents were slightly reduced compared with the values published by Larbier and Leclercq (1994) for non-organic wheat, but of greater concern was the low methionine content of organic wheat. Organic wheat is the predominant component of organic poultry rations and so a lower than expected methionine content will impact markedly on the methionine content of the ration.

Gordon and Charles (2002, Defra-funded project OF0163 'Optimising the synergism between organic poultry production and whole farm rotations, including home grown protein' (www.defra.gov.uk/science/project_data/DocumentLibrary/OF0163/OF0163_1131_FRP.doc) reviewed the protein, lysine and methionine contents of non-organic home grown proteins including peas and beans. The crude protein content of non-organic peas was variable, ranging from 156 g/kg to 325 g/kg dry matter. Lysine and methionine plus cystine contents were within the approximate ranges of 15.2 g/kg to 16.9 g/kg dry matter and 5.0 g/kg to 6.4 g/kg dry matter, respectively. Larbier and Leclercq (1994) reported an average pea lysine content of 16.9 g/kg dry matter, and methionine and threonine contents were given as 2.7 g/kg dry matter and 9.3 g/kg dry matter, respectively.

The crude protein, lysine, methionine and threonine contents of organically grown peas ranged from 207.0 g/kg dry matter to 258.0 g/kg dry matter, 14.0 g/kg dry matter to 17.1 g/kg dry matter, 1.83 g/kg dry matter to 2.42 g/kg dry matter and 8.6 g/kg dry matter to 9.4 g/kg dry matter, respectively. It appears that the crude protein, lysine and threonine contents of organic peas were similar to non-organic peas, although caution is needed as agronomic conditions are known to affect these considerably, but there was a trend for methionine contents to be lower in organic peas.

Organic beans appear to have lower crude protein, lysine, methionine and threonine contents than those published by Larbier and Leclercq (1994) for non-organic beans (average 291.0 g/kg dry matter, 18.3 g/kg dry matter, 2.3 g/kg dry matter, 10.3 g/kg dry matter, respectively). The range of values for the contents of crude protein, lysine, methionine and threonine in organically grown beans were 252.0 g/kg dry matter to 280 g/kg dry matter, 15.2 g/kg dry matter to 19.1 g/kg dry matter, 1.60 g/kg dry matter to 2.14 g/kg dry matter, and 9.3 g/kg dry matter to 9.8 g/kg dry matter, respectively.

Thus, the crude protein and amino acid contents of UK organic wheat and UK organic protein sources should be determined prior to feeding so as to avoid over estimating the supply of nitrogen and essential amino acids.

<u>Approach 5 (work to meet objective 5) 'The implications of changes in Regulation EC1804/1999 and Standards (e.g. organic pullet rearing and organic breeder flocks) on the volumes of organic feed ingredients needed for sustained UK organic poultry production (chickens) based on the current sector size'</u>

The outcome of this objective was a 67pp report titled 'Effects of changes in Regulation EC1804/1999 and UK Standards on the volumes of organic feed ingredients needed to sustain UK organic poultry production (chickens) based on the current sector sizes' (Gordon, 2004b, available by emailing enquiries@adas.co.uk and specifying Defra project OF0327 and the aforementioned title of the report). The main results are given below.

Estimates of the 2004-flock sizes for organic laying hens and organic table chickens
Estimates of the 2004-flock sizes for organic laying hens and organic table chickens are given in Table 1.

Table 1 Estimates of the 2004-flock sizes for organic laying hens and organic table chickens

Information	Value	Source
Size of UK organic layer flock	1.5 million hens	Tyers (2003, *personal communication*)
Estimated number of UK organic table chickens produced per annum	3.5 million birds	Hancock (2003, *personal communication*)

Estimates of the number of replacement organic pullets and the required size of the UK organic breeder flock for meat-line chickens
Estimates of the number of replacement organic pullets and the required size of the UK organic breeder flock for meat-line chickens needed to sustain the 2004-UK sector sizes for organic eggs and table chickens are given in Table 2.

Table 2 Estimates of the number of replacement pullets and the required size of the UK organic breeder flock for meat-line chickens needed to sustain the 2004-UK sector sizes for organic eggs and table chickens

Information	Value	Source
Number of replacement organic pullets needed per annum	1.56 million pullets	Gordon (2004b)
Number of organic breeder hens needed per annum	28 000 to 35 000 breeder hens	Gordon (2004b)
Number of organic breeder cockerels needed per annum	4 375 breeder cockerels	Gordon (2004b)

Estimates of feed intake and the volume of organic feed needed for organic laying hens and organic pullets (2004-UK sector size for organic eggs)
Estimates of feed intake and the volume of organic feed needed for UK organic laying hens and organic pullets are given in Tables 3 and 4, respectively.

Table 3 Estimates of feed intake (kg/bird)

Information	Value	Source
Mean feed intake in outdoor hens over a 52-week period	47.1 kg/bird	Nix (2004)
Estimated feed intake to 20 weeks of age for Hy-line Variety Brown pullets reared for use in outdoor systems	8.3 kg/pullet	Hy-Line Variety Brown Commercial Management Guide (1997)

Table 4 Total volume of organic feed (t/annum)

	Total volume of organic feed (t/annum)
Laying hens	70 901[1]
Pullets	12 948[2]
Total	107 636 – 108 071

[1]Assuming a 52-week laying period
[2]Assuming a 20-week rearing period (including feeding a pre-lay ration)

Estimates of feed intake and the volume of organic feed needed for organic table chickens and organic breeder flocks (2004-UK sector size for organic table chickens)
Estimates of feed intake and the volume of organic feed needed for UK organic table chickens and organic breeders are given in Tables 5 and 6, respectively.

Table 5 Estimates of feed intake in organic table chickens and organic breeders (kg/bird and g/hen.day, respectively)

Information	Value	Source
Estimated feed intake to 70 days of age for 'slow growing' organic table chickens	6.3 kg/bird	data derived from data collected in Defra project OF0153
Estimated feed intake of organic breeder hens	170 g/hen.day	Gordon (2004b)

Table 6 Total volume of organic feed (t/annum)

	Total volume of organic feed (t/annum)
Table chickens	22 050[1]
Breeder hens	1 737 – 2 172[2]
Total	107 636 – 108 071

[1]Assuming a 70-day growing period
[2]For between 28 000 and 35 000 breeder hens

It is likely that there will be an extra requirement of at least 220 t organic feed per annum for organic breeder cockerels.

Estimates of the total volume of organic ingredients needed to sustain the estimated 2004-level of UK organic egg and table chicken production when moving from 80% organic provenance to 100% organic provenance

For the purpose of this study, it was assumed that an 'organic replacement protein' of equal nutritional value to that of maize gluten was available (Gordon, 2004b). Maize gluten accounted for 70 kg/t of the organic layer 2 ration and 20 g/kg of the organic table chicken ration (Gordon, 2004a). The other dietary components where organic wheat, full-fat soya and sunflower meal (collectively accounting for 80% or more of the ration), and vitamins and minerals. The quantity of 'organic replacement protein' needed for sustaining the estimated 2004-level of UK organic egg and table chicken production was calculated (Table 7).

Table 7 Estimates of the total volume of 'organic replacement protein' needed to sustain the estimated 2004-level of UK organic egg and table chicken production (t/annum) (1.5 million hens, 3.5 million table chickens) (t/annum)

	Volume (t/annum)
Organic laying hens	4 963
Organic table chickens	441

Thus, the move from 80% organic provenance to 100% organic provenance requires at least 5 400 t of 'organic replacement protein' per annum for sustaining the estimated 2004-levels of UK organic egg and table chicken production.

Estimates of the total volume of organic ingredients needed for organic pullet rearing and breeder flocks – based on sustaining the estimated 2004-UK sector sizes for organic eggs and table chickens and feeding 100% organic provenance
As for the organic laying hens and table chickens, the simulated diets for organic pullets and breeder hens contained maize gluten (60 kg/t pullets and 40 kg/t breeder hens), and in addition they contained fishmeal (25 kg/t for both pullets and breeder hens). The quantities of organic ingredients needed for organic pullet rearing and for feeding organic breeder hens on a scale that is sufficient to sustain the estimated 2004-UK organic sector sizes for eggs and table chickens were calculated (Table 8).

Table 8 Estimates of the total volume of organic ingredients needed for organic pullet rearing and organic breeder hens, so as to sustain the 2004-sector sizes for organic eggs and table chickens (1.5 million hens, 3.5 million table chickens) (t/annum)

Ingredient	Volume (t/annum)
Organic wheat	7 707 – 7 986
Organic wheatfeed	2 029 – 2 051
Organic full-fat soya	2 798 – 2 851
Organic sunflower meal	393 – 411
Organic replacement protein	846 – 864
Organic fishmeal	367 – 378
Organic minerals, electrolytes and vitamins	544 – 580

Discussion

There were three components to this project: 1) on-farm measurements; 2) laboratory analyses, and 3) desk studies. The discussion will focus firstly on the on-farm measurements component, i.e. validation of the HEN model for organic laying hens (Approach 1), as there are implications from the findings of this work which need to be considered when discussing the findings from other components of the project.

<u>Approach 1 (work to meet objective 1) 'Validation of the HEN model for organic laying hens'</u>
It is appropriate to first discuss the reliability of the data. The physical data collected in the study displayed sensibility, in that the litter (INT1) and slat (INT2) temperatures related quite well to each other, the former being cooler. Furthermore, outdoor temperature (OUT1) was generally reflected in the internal temperature. The hen's feed metabolisable energy intake failed to display a consistent significant relationship with either the unadjusted internal (INT1, or INT2) or adjusted (Tw) temperature series (regression analysis, tolerance charts). It was noticeable however, that the extent of relative change of feed metabolisable energy intake with temperature was small, perhaps indicating that the feed metabolisable energy intake response was already maximal (i.e. no further response was possible because of constraints due to gut fill and digesta transit time) or that the variability of temperature in outdoor production systems masked the polynomial relationship found by Charles (1984) when working with hens in controlled environment houses.

Time series analysis, generally used to elicit the structure of chronobiological data, failed to find any significant relationship between temporal parameters, such as infradian frequencies, autoregressions, autocorrelations or cross correlations, and feed metabolisable energy intake characteristics. Thus, even when an allowance was made for time, the hens failed to consistently adjust their feed metabolisable energy intake relative to temperature.

The daily feed metabolisable energy intake data was considered to be reliable as daily feed intake was measured using a calibrated tippler weigher and the feed metabolisable energy value was determined using standard procedures. It was thought that there was no value associated with attempting further exploration of the hens feed metabolisable energy intake responses to temperature using weekly estimated feed intake data and house maximum and minimum temperature data obtained from commercial flocks of free range hens.

The results of the study have not enabled the HEN model to be validated for organic laying hens. It would be inappropriate to update the HEN model so as to accommodate organic laying hens as the error values around the calculation of feed metabolisable energy intake responses to temperature would be too large to be of practical value. Furthermore, as other predicted outputs (egg numbers and egg weights) are based on the initial prediction of daily feed metabolisable energy intake at a given temperature, the error around these results would also be too large to be of practical value.

It is important however, to consider the relevant scientific literature so as to facilitate an understanding of the results, to identify knowledge gaps and to assess the wider implications of the findings. There are some important findings arising from this project. These will be discussed and this will be with reference to any changes in derogations to Regulation EC1804/1999 subsequent to the start of this project in August 2002.

The discussion of relevant scientific literature has been divided into the following topics: 1) the effect of temperature on the hen's maintenance metabolisable energy requirements; 2) defining the temperature environment of organic hens, and; 3) environmental and physical factors which modify the effective temperature experienced by hens.

Effect of temperature (dry bulb air temperature) on the hen's metabolisable energy requirements

Hens are homeotherms and they must therefore maintain a constant body temperature ($41 \pm 0.45\,^{o}$C, Larbier and Leclercq, 1994). According to data published by Webster (1994, citing work by Wathes *et al.,* 1983) hens have a thermoneutral zone of between about 18^{o}C and 23^{o}C (read from a graph). The lower value being the lower critical temperature (LCT) and the higher value being the upper critical temperature (UCT) (Charles, 1994). It is the LCT which is of greater interest in this study as UK organic hens will experience temperatures below the LCT for most of the laying year. Clark and McArthur (1994, citing work by Poczopko, 1981) gave a LCT of 16 ^{o}C for a hen aged one year and weighing 2.4 kg.

Within the thermoneutral zone metabolic heat production and energy expenditure are minimal, most productive processes are at their most efficient, and the animal is probably thermally comfortable (Charles, 1994). Below the LCT, hens must increase the rate of thermogenesis to compensate for a greater rate of heat loss to the environment (Larbier and Leclercq, 1994). This is at an energy cost to the hen, which must be met through an increased feed metabolisable energy intake if egg mass output and body weight are to be preserved.

A summary of the literature on the effect of temperature on the hen's metabolisable energy requirements for maintenance is given in Table 19 (Annex 1).

Thus, hens experiencing mean temperatures below the LCT but above 5 ^{o}C (as in this study) would have been expected to have increased their feed metabolisable energy intake in response to increased metabolisable energy demands for thermal homeostasis. There will however, be a limit to the amount of feed a hen can consume within a 24-hour period and this will depend on gut fill, feed digestibility and digesta transit time.

Defining the temperature environment of organic hens

An important practical difficulty in modelling the daily feed metabolisable energy intake responses to temperature in outdoor hens is the calculation of the environmental temperature to which the birds are exposed. This is firstly because neither outdoor temperatures nor indoor temperatures are constant, and secondly because an unknown proportion of the flock spends some of the daytime outdoors and some of the daytime indoors, whilst the remaining proportion of the flock spend all of the time indoors. Furthermore, the proportion of the flock ranging outdoors each day probably varies.

In a study of monitoring and data logging techniques Sutcliffe *et al*., (1987) referred to reviews by Marsden (1981) suggesting that when layers are subjected to diurnal temperature cycles of moderate amplitude they respond to the means of the cycles. This was considered to hold provided that the cycles were narrow enough to avoid panting in the warm part of the cycle. Based on this information, weighted mean daily temperatures (Tw) were calculated and the values obtained were used to test the relationship between daily feed metabolisable energy intake and temperature.

According to the producers a relatively large percentage of the flock ranged outdoors (estimated at up to about 50%). There is very little published information on this topic, but some of the producer estimates of the proportion of the flock ranging appeared to be high compared with findings reported by Hegelund *et al.,* (2005). They found that on average only 9% of an organic flock of laying hens ranged outdoors (*loc.cit*.). There was evidence of an effect of weather conditions on the proportion of hens ranging outdoors, with less birds ranging in windy, wet and stormy conditions. This was similar to the findings of Gordon *et al.,* (2002).

Although seemingly critical, the proportion of hens ranging outdoors had perhaps less of an impact on the calculated Tw during the winter months than expected. For example, the calculated Tw for s1p1 when 10% of the flock ranged outdoors was 15.4°C, compared with a Tw of 14.6°C when 50% ranged outdoors.

Perhaps more critical to the calculation of Tw was the location of the hens indoors during the photoperiod. This was because there were relatively large differences between INT1 and INT2, and the time spent per day indoors ranged from a minimum of about 16 hours to a maximum of 24 hours depending on range access and range use by individual birds. Whilst most hens are known to roost on perches during darkness (Keeling, 2004), and this was taken into account when calculating Tw, the mean of INT1 and INT2 was used in the calculation of Tw for the periods when the lights were on and hens either failed to range outdoors (90% and 50%, respectively) or the popholes were closed. This was because precise information on the percentage of the flock using different facilities at a given time throughout the light period was not known. However, as INT1 and INT2 were generally linearly related, if flocks behaved similarly in terms of time spent perching, dustbathing, pecking and scratching then the error about Tw is expected to have been similar across all flocks. One factor affecting the amount of time hens spent dustbathing, pecking and scratching could have been litter quality. The duration of the photoperiod might also have influenced behavioural time budgets. In this study the photoperiod ranged from 14 hours to 16 hours, the difference perhaps not being of a sufficient magnitude to have a large impact on the calculated Tw.

In general, Tw was thought to provide a better basis for estimating a flock's thermal experiences than INT alone.

Environmental and physical factors which modify the effective temperature experienced by hens
The dry bulb air temperature is normally considered to be an adequate descriptor of the thermal environment of fully feathered adult layers indoors. This is justified because indoor air speeds are normally too low to affect heat loss from fully feathered adult laying hens and relative humidity has been shown to have little effect on heat loss except when the birds are panting during heat stress. However, for organic hens, particularly if they are poorly feathered, the dry bulb air temperature may not always be an adequate descriptor. Air speeds above 0.15 m/s may increase convected heat loss (Wathes, 1978) and birds outdoors may frequently encounter wind speeds above 0.15 m/s. Rain may affect the thermal insulation of the feather coats by wetting. Wathes and Clark (1981a and b) characterised the physics of the effects of wind speed and other variables which modify heat loss.

The relevant literature and physical theory has been reviewed by several authors edited by Wathes and Charles (1994) and by Charles and Walker (2002).

Dry bulb temperature was used in this study because it was not possible to take into account the effect of wind speed, rain and feather cover on the effective temperature experienced by individuals. Hen's often seek shelter outdoors and in some cases the shelter may provide thermal benefits to the birds, such as reduced wind speeds. Gordon and Charles (2002) reported that traditional free range table chickens found conifer wig-wams attractive and birds often spent time outdoors sat underneath the trailing branches. As the cut conifers lost their needles the thermal properties of the shelter probably diminished. The stocking density underneath the wig-wam was high however, and birds in the centre of the 'huddle' would have been insulated to some extent by neighbouring birds.

It would be too complex to attempt to determine the effective Tw of a commercial flock of organic hens (i.e. a value which takes into account wind chill, radiative losses or gains, and any reduction in feather pelt thermal properties due to precipitation). Furthermore, if the HEN model were to be of practical use to UK organic egg producers a relatively simple method for determining the flock's thermal experiences was needed. The calculation of Tw as used in this study is probably too complicated for commercial application, an ideal would have been for a clear relationship between feed metabolisable energy intake and INT.

It is important to note that the commercial houses used in this study were large by organic standards and in most cases the stocking density in the house was higher than for organic egg production. The implications are that in general, during winter months the INT of organic houses will be cooler than in non-organic free range houses, as bird body heat output per square metre of floor area will be lower in organic houses.

Two key questions which are relevant not only to organic egg production but also to non-organic free range egg production have arisen from this study. Firstly, are hens unable to reliably adjust their feed metabolisable energy intake according to their needs for maintenance, egg output and growth in situations of diurnally and daily fluctuating temperatures? Secondly, are hens in UK outdoor production systems approaching maximal feed metabolisable energy intake, and therefore are they unable to respond to increasing metabolisable energy requirements for maintenance, egg output and growth? In the latter case this might be masked by average flock performances, but within the flock some hens might be performing less well because they have reached their limit in terms of feed metabolisable energy intake.

There is evidence which suggests that hens are not able to accurately adjust their feed metabolisable energy intake when the dietary metabolisable energy value changes (Larbier and Leclercq, 1994). Hens provided with high metabolisable energy value diets usually over-consume energy and gain weight (*loc.cit*.). The degree of over consumption depends, however, on the genetic origin of the birds. Those birds with high energy requirements are generally less able to adjust their daily energy intakes in response to variations in dietary energy levels than those with lower energy requirements. If the biological methods for adjusting feed metabolisable energy intake (reviewed by Forbes, 1995) according to supply and demand are not entirely accurate then this suggests that hens in outdoor conditions are unlikely to be able to respond to fluctuating effective temperatures in an accurate manner.

The vast wealth of data on responses to temperature has been derived from hens housed indoors. In these studies, hens were allowed to acclimatise to the test temperature and the variation around the mean was small compared with the diurnal temperature changes experienced in outdoor production systems. Thus, the hens feed metabolisable energy intake responses to temperature in indoor conditions were robust, but they are not applicable to organic hens.

The main implication of the findings is that it will not be possible to accurately adjust the dietary supply of protein and essential amino acids relative to the dietary metabolisable energy value and expected feed metabolisable energy intake. This means that for outdoor production systems there is perhaps an increased risk of over feeding nitrogen, which has implications in terms of the risk of nitrogen pollution to air and water environments. Furthermore, the risk of nitrogen pollution to air and water environments might be higher in organic egg production systems than in non-organic free range egg production systems because of difficulties in dietary essential amino acid supply. This is discussed below.

Approaches 2 to 5 (work to meet objectives 2 to 5)
The non-organic egg industry is dependent on the use of synthetic methionine for meeting the modern brown egg-layer's needs for maintenance, health and production. This is because plant proteinaceous ingredients are mostly deficient in methionine (reviewed by Gordon and Charles, 2002, and by Gordon 2004a), and whilst fishmeal is relatively rich in methionine there are limits to its use because of egg and meat taint, and in young birds it causes gizzard erosion (Leeson and Summers, 1997). Sometimes there are further constraints on the use of sustainable sources of fishmeal which preclude its use in non-organic poultry diets (e.g. some brands retail on the basis of the hens being fed a vegetarian diet).

It is not surprising therefore, that the ban on feeding synthetic amino acids to organic laying hens has created problems. There is evidence that it is not possible to fully meet the hen's methionine needs for maintenance, health and production at 80% organic provenance. Often the dietary methionine supply is maximised by over supplying crude protein. The detrimental effects of imbalanced diets, which are high in crude protein, on egg performance, behaviour and litter quality have been realised in UK commercial organic flocks. In general, egg performance has fallen, injurious feather pecking and mortality is of increasing concern, and the litter quality has deteriorated. It is accepted that the rate of nitrogen excretion from organic hens will have increased, and this increases the risk of nitrogen pollution to the air and water environments.

Derogation allowing the use of 20% non-organic ingredients in organic poultry diets has been useful (many producers consider it essential) as it enabled the use of relatively methionine-rich non-organic ingredients, which are not currently available as organic sources. The derogation expired on 24th August 2005, but recognition of the difficulties in sourcing organic protein for organic livestock has lead to a new derogation which enables permitted non-organic ingredients to be fed at decreasing proportions of the feed dry matter content up to 24th August 2011.

Whilst, the current situation with regards to feeding organic poultry is not quite as critical as expected (due to the further derogation) it is clear that in time there will be increasing difficulties in meeting the bird's amino acid requirements for maintenance, health and performance unless novel organic sources of protein and methionine are identified. With this is mind Defra have recently funded a project (OF0357 'Organic egg production – A desk study on sustainable and innovative methods for meeting the hen's protein requirements' www2.defra.gov.uk/research/project_data/More.asp?I=OF0357&SCOPE=0&M=PSA&V=EP%3A200) which aims to identify novel protein sources (e.g. insects, algae and aquatic plants) for organic laying hens and to assess the suitability of ingredients in terms of their nutrient composition and contents of known antinutritional factors. Consideration will be given to any known effects of an ingredient on bird health and the potential impact on bird welfare, egg quality, egg nutrient content and food safety. Whether a promising novel proteinaceous ingredient might be produced in an organic farming system will be assessed and the implications in terms of the risk of nitrogen pollution to the air and water environments will be examined.

Although the above discussion focused on organic laying hens, there are health and welfare issues related to methionine deficiencies in other classes of organic poultry.

In the young bird, methionine is thought to be important in the developing immune system and the methionine requirement for health might be above that for growth (Tsiagbe *et al.,* 1987, reviewed by Gordon, 2004a). If the development of the immune system is compromised this will affect the bird's ability to fight disease challenges. An underlying principle of organic production is that the animal should be able, wherever possible, to withstand disease challenges through natural means, i.e. by optimising the development of the immune system.

There have been incidences of injurious feather pecking in UK organic table chickens, as well as in UK organic layers (Owen and Gordon, 2004). Thus, it is reasonable to surmise that there might be similar risks of injurious feather pecking in organic pullets and organic breeder flocks. Management strategies for minimising the risk of injurious feather pecking in non-organic poultry are often not applicable in organic production systems (e.g. light control), and this exacerbates the level of risk in organic flocks. In chicks destined for use in organic production, beak trimming should not be undertaken as a routine procedure (Regulation EC1804/1999), but as reported there are serious welfare implications if beak trimming is necessarily undertaken in older birds. Furthermore, there is an impending ban on beak trimming across all production systems (after 31st December 2010, Welfare of Farmed Animal (England) (Amendment) Regulations 2002 (SI 2002 No. 1646) and so alternative means of minimising the risk of injurious feather pecking are needed. Above all however, there is an onus on the industry to ensure that the diet is sufficiently rich in nutrients so as to avoid nutritional-physiological-behavioural interactions, which result in injurious behaviour and poor welfare.

Nutrient deficiencies, such as a deficiency of sulphur-containing amino acids can lead to poor feathering in all classes of poultry. This is important in outdoor production systems, such as organic production systems, as poorly feathered birds will have a high rate of heat loss. Feed metabolisable energy intake will be necessarily high so as to meet the birds high metabolisable energy requirements for maintenance and protein will be over consumed, which will increase nitrogen output.

It is important to achieve good growth and development in pullets as this affects subsequent laying performance and bird health. If pullets are small at the start of lay then this will reduce egg size during lay, but there is also a greater risk of prolapse.

For meat-line breeders, there is a great deal of uncertainty about appropriate growth profiles, and therefore, appropriate nutrient and metabolisable energy intakes. There is an indication that it may be difficult to meet the birds metabolisable energy requirement for maintenance in an outdoor system, whilst optimising nutrient intake. Some nutrient deficiencies affect the development and survival of the embryo and the growth and development of the progeny. The potential problem of energy balance in organic breeders was described in Defra-funded project OF0336 (Gordon and Hovi, 2003).

Although the pasture may provide some nutrients and metabolisable energy for organic poultry the contribution to their overall daily requirements will be variable but small. There is a need to examine methods of optimising the contribution of the sward and the pasture macroinvertebrates to the bird’s diet. However, in the UK this will probably only be possible on a seasonal basis.

Conclusions and implications of findings

1. Hens in outdoor production systems failed to display a consistent significant relationship between feed metabolisable energy intake and either the INT or Tw, even when allowing for time lags. It was not possible therefore, to validate the HEN model for organic laying hens, or to develop the model in terms of building-in one-step ahead predictive responses.
2. The extent of relative change of feed metabolisable energy intake with temperature was small, perhaps indicating that the feed metabolisable energy intake response was already approaching the maxima, or that the variability of temperature in outdoor production systems masked the robust relationships derived for indoor environments.
3. It is expected that in organic production systems, the influence of OUT on INT will be greater due to lower house stocking densities, and smaller houses than in non-organic free range egg production. This will impact on the bird’s maintenance metabolisable energy requirements.
4. There is an inability to optimise the dietary ratio of metabolisable energy to protein (amino acids) for hens in outdoor production systems, as the hen’s feed metabolisable energy intake responses to low fluctuating outdoor temperatures have not been defined. The implications of this are tempered with respect to organic egg production as the priority when formulating diets is to meet, as far as possible, with the limited range of ingredients available, the organic hen’s methionine and lysine requirements, which in practice is resulting in too much crude protein being fed.
5. Feeding excess crude protein will increase the rate of nitrogen excretion from organic poultry, and there will be an increased risk of nitrogen pollution to the air and water environments.
6. Without additional organic methionine-rich protein sources, methionine deficiencies will become more pronounced and more widespread in organic poultry production as the level of permitted non-organic proteinaceous ingredients in the diet fall. This will impact on bird health and welfare.
7. The possibility of lower methionine contents in organically produced wheat, peas and beans will exacerbate problems of methionine supply.
8. Novel sources of organic methionine-rich ingredients are needed for feeding organic poultry.
9. There are opportunities to develop hybrids which are better suited for use in organic poultry production systems in terms of behaviour and nutrient partitioning for maintenance and production.

Possible future work
There is urgent need for novel organic protein sources, which are rich in methionine and lysine. Current and future problems of amino acid supply for organic poultry are not likely to be resolved without the development and production of novel organic protein sources. Ideally, this would be achieved in UK organic production systems, as this might enable better nutrient recycling in whole farm systems including organic poultry. Shepherd and Bhogal (2002) identified a large nitrogen surplus in nutrient balance calculations for a typical five or six course UK organic rotation including organic poultry. This was due to a dependency on imported organic full-fat soya as the predominant protein source for organic poultry. These issues are being addressed in Defra-funded project OF0357 'Organic egg production – A desk study on sustainable and innovative methods for meeting the hen's protein requirements'.

Shelter outdoors will be important in reducing the effect of wind and rain on the rate of heat loss in chickens, and research should be aimed at determining the physical and behavioural benefits of different types of shelter including laternative swards. Furthermore, information on the energy balance of outdoor chickens including organic at different times of the year, and an assessment of the implications in terms of welfare and health is needed.

An understanding of the factors leading to feather loss in organic and non-organic free range production systems (by means other than injurious feather pecking) is needed as poor feathering has a marked effect on the rate of heat loss and maintenance metabolisable energy requirements.

IP and knowledge transfer
The following reports were submitted to Defra:
Gordon, S.H. (2004a). The essential amino acid requirements of poultry for their maintenance, health and performance in an organic production system. 283 pp
Gordon (2004b). Effects of changes in Regulation EC1804/1999 and UK Standards on the volumes of organic feed ingredients needed to sustain UK organic poultry production based on the current sector sizes. 67pp
Owen, R.H. and Gordon, S.H. (2004). An assessment of nutritional issues in organic poultry production. 47pp

Information arising from the project was used in workshops involving researchers and the organic poultry industry undertaken in Defra-funded project OF0336.

References
A list of the references cited in this report are given in Annex 2.

Acronyms
Details of the acronyms used in this report are given in Annex 3.

References to published material

9. This section should be used to record links (hypertext links where possible) or references to other published material generated by, or relating to this project.

Information arising from this project was used in the delivery of Defra-funded project OF0336 'Workshop and desk study to appraise technical difficulties associated with organic breeder flocks and organic hatching'. One of the outcome's of project OF0336 was a report:

Gordon, S.H., and Hovi, M. (2003). Technical difficulties associated with organic breeding and hatching. Defra, London, (project OF0336), 98pp. Available by emailing enquiries@adas.co.uk and stating Defra project OF0336 and the aforementioned title of the report.