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SID 5 Research Project Final Report

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Project identification

1. Defra Project code: **AC0223**
2. Project title: **Extended lactations to reduce greenhouse gas emissions from dairy cows**
3. Contractor organisation(s): Dr. G. E. Pollott, Royal Veterinary College, Royal College Street, London, NW1 0TU
4. Total Defra project costs (agreed fixed price): £68,481
5. Project: start date 3/01/10

   end date 21/07/10

6. It is Defra's intention to publish this form.
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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.

The aim of this study was to see if the use of extended lactations (~450 d) in UK dairy herds could reduce greenhouse gas emissions (GHGE) from the current levels. The approach used was to review the literature on extended lactations, define the characteristics of lactation length in UK dairy herds, and use this information in both a farm and national dairy model to estimate GHGE. Various alternative scenarios would be modelled to test both the sensitivity of the results and the effects of varying some basic parameters of dairy herds.

Research into the use of extended lactations was very limited but three studies indicated some of the characteristics of extended lactations and demonstrated that nutrition, milking regime, genetics and calving season all affected yields from extended lactations. Persistency (the rate of decline in daily milk yield after the peak of lactation) was considered a key feature of an extended lactation, successful extended lactations having a higher persistency i.e. a slower rate of decline. Systems of production involving concentrate feeding were more successful at utilising extended lactations than grazing systems. Most extended lactation systems produced a similar amount of milk per year to a 'normal' system and were not found to be less economic.

An analysis of the relationships between calving interval, a trait highly correlated to lactation length, found that longer calving intervals were associated with higher milk yields per lactation, higher peak milk yield but a lower level of persistency. Persistency was heritable and so could be used in an appropriate selection programme to increase persistency without necessarily increasing peak yield.

An analysis of lactation length in the UK dairy herd over the last 20 years was undertaken. In this study lactation length was measured as the day of last test-day record and probably underestimates true lactation length by ~15 d. Mean lactation length has increased from 352 d in 1990 to 395 d in 2007 and the spread of lactations lengths also increased over this time period. An analysis of herd/year lactation length characteristics found a greater spread of mean lactation lengths in 2007 compared to 1990. The SD of herd/year lactation lengths indicated that a considerable number of farms have a higher mean lactation length but a relatively low SD, indicating a conscious move towards managing herds for longer lactations. The wider use of extended lactations has led to a more even calving pattern throughout the year than was

previously the case.

A dairy herd model was used to investigate the effect of using lactations of 305, 370 and 440 days on herd structure and GHGE, given maintenance of the current annual milk output. A base scenario was used for comparative purposes which was constructed from the model herd used for deriving the economic weights for the UK PLI index. Data from UK dairy herds were analysed to determine the relationships between key lactation parameters and to derive the characteristics of lactations of the three lengths modelled.

Initial use of the model indicated that as lactation length increased milking cow and follower numbers decreased, However GHGE increased as lactations became longer. This was due to the emissions from the milking herd increasing at a faster rate than the reduction due to smaller herd sizes. The lower milk yield during the last few months of lactation carried a greater overhead cost of emissions, in order to maintain the cow per kg of milk produced.

Changes in the persistency of lactation were shown to alter the GHGE such that improvements in persistency decreased emissions. The level, of change was relatively small and a 20% improvement in persistency only decreased GHGE by about 3% for lactations of 440 days.

Improvements in longevity and changes in the number of followers required both have an effect on the herd via the replacement rate required to maintain herd numbers. Changes in replacement rate were also modelled. A move from a 25% replacement rate to 20% once again had a small positive effect on GHGE resulting in a reduction of about 0.5%.

The most promising way to reduce GHGE from dairy herds appeared to be through increased milk yield. A move from the current scenario to the level of the top 10% of lactation yields reduced GHGE by 12% for herds using 440-d lactations. This was accompanied by a reduction in the herd size from 127 to 97 milking cows. If such a change could be made in conjunction with improvements in persistency then further reductions in GHGE would be possible. Greater reductions in GHGE were made when using the shorter lactations, 19% for 370-d and 25% for 305-d lactations.

A number of negative effects of longer lactations were identified from the research both reviewed and carried out as part of this project. These were increased fat % in milk, higher somatic cell counts, lower casein content and a saltier taste to the milk. These effects were mostly small.

Although this research project has used a considerable amount of information associated with extended lactations very little of it has come from commercial UK herds managed to achieve 18-month calving intervals. In this sense there are huge knowledge gaps on the use of extended lactations. Critical features of extended lactations that need more research include fertility and longevity of cows involved in extended lactations, particularly if the move towards higher milk yields is seen as the way to reduce GHGE from the dairy sector. The combination of higher yields and longer lactations will highlight conception rate as a more critical fertility trait, rather than calving interval. By removing the imperative to get cows back into calf as soon as possible after calving then culling for poor fertility may be reduced and so longevity may increase.

An economic assessment of extended lactations based on real UK data is also required so that producers have some idea of the real costs of moving to extended lactations. This assessment will need to take into account the effects of different levels of milk yield and persistency

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).

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.

Introduction

Under its Climate Change Act of 2008, the UK Government is committed to reducing national greenhouse gas emissions (GHGE) to 80% of 1990 levels, by 2050. Each sector of the UK economy has been committed to contributing to these reductions. In the agriculture sector, livestock systems are an important source of GHGE, particularly methane (CH_4) and nitrous oxide (N_2O). Livestock account for up to 40% of the world methane (CH_4) production, a large proportion (80%, de Haan *et al*., 1997) of which comes from enteric fermentation and a smaller proportion (20%, Safeley *et al*., 1992) from anaerobic digestion in liquid manure. Sixty-four percent of global N_2O emissions are due to agriculture, chiefly as a result of fertilizer use (organic and inorganic) but livestock species produce N_2O from manure management. There are a number of options for reducing GHGE from livestock systems. These include improving productivity and efficiency, reducing wastage at the herd level and selecting animals which individually produce less GHGE. This work is intended to follow up the unsupported suggestion by Hopkins and Lobley (2009) that the adoption of extended lactations could lead to reduced GHGE. The assumption underlying this project is that the use of extended lactations could lead to more efficient production and less wastage. It is supposed that this approach could use a two-pronged attack on GHGE by both reducing the number of stock required in the national dairy herd and improving the efficiency of the remaining cows. The project will review all information currently known about extended lactations, provide new information from an analysis of commercial UK dairy herd records, model extended lactation production at the herd and national levels and use the results to investigate the overall likely changes in GHGE from a move to extended lactations. Throughout the project any negative impacts of extended lactations and any gaps in knowledge will be identified.

The six objectives of the project were:

1. Review experiments, industry data analyses and economic modelling in UK and elsewhere into extended lactations and determine the technical (yield, milk composition, reproduction, health, welfare) and economic feasibility of extending lactation length per cow from 305 days to 450 days (15 months) so that cows calve at 18-month intervals rather than at 12-month intervals (i.e. two lactations in three years v three lactations in three years).

2. Determine the relationships between peak yield, total lactation yield, persistency and calving index in the UK dairy herd.

3. Establish the extent to which extended lactations occur by default in UK dairy herds, and reasons for its occurrence.

4. Determine whether or not the current output of milk in the UK could be sustained through the adoption of extended lactations in the national dairy herd, and if so what size of milking cow and herd replacement population would result, if the current levels of dairy cow fertility and longevity are maintained.

5. Determine the potential impact on greenhouse gas emissions from the dairy sector of the adoption of extended lactations.

6. Examine research and industry data into extended lactations to identify any negative impacts that they might have on other aspects of milk production e.g. seasonality payments, lower milk price due to higher somatic cell counts.

Objective 1.

Review experiments, industry data analyses and economic modelling in UK and elsewhere into extended lactations and determine the technical (yield, milk composition, reproduction, health, welfare) and economic feasibility of extending lactation length per cow from 305 days to 450 days (15 months) so that cows calve at 18-month intervals rather than at 12-month intervals (i.e. two lactations in three years v three lactations in three years).

Traditional dairy production has relied on an annual cycle of events, designed largely to fit with the yearly pattern of grass growth but also to simplify dairy management and to satisfy the milk buyers' requirements of a stable milk supply. Fixed calving periods in the spring or autumn were maintained by aiming for a 365-day calving interval (CI; the time between successive calvings). In order to achieve this, cows needed to have rebred after calving by about the 60^{th} day of lactation since gestation length is approximately 9 mo. A lactation length of about 305 days (10 mo) became the norm and much of the recording effort, and traits used for genetic selection, were based on this length of lactation. In recent years, the average calving interval has steadily increased and farmers have moved away from a rigid annual calving interval, and consequently calving periods are more flexible or even all year round. There are a number of reasons for this change. The relentless increase in milk yields due to breed substitution with the Holstein, and efficient genetic selection, has had a number of knock-on effects. Some cows experienced negative-energy-balance anoestrus at the time when they would have traditionally been rebred and so took longer to get back in calf. The idea of drying off a cow when she was still producing a high level of milk also seemed inefficient. Calving was seen as a stressful event for the cow and disease incidence was greatest in the first third of lactation. These factors prompted the idea of using extended lactations as a regular system, rather than as a by-product of delayed rebreeding (Bertilsson *et al.*, 1997). The limited amount of research applying to extended lactations can be grouped into three categories; experimental approaches, industry data analyses and economic evaluation.

A number of reviews have summarised the knowledge about the issues relating to extended lactations. Borman *et al.* (2004) provided background material on extended lactations in a pasture-based setting. More recently Knight (2008) reviewed extended lactations from the European dairying perspective. These two papers summarise a great deal of the research and development carried out in recent years on extended lactations. However, neither review mentions using extended lactations as a means to reduce GHGE and neither considered the current situation with respect to extended lactations in the various developed dairy industries. This review will start with an outline of the key research carried out on extended lactation related issues. It will then address key topics and pull together all the information from the literature relating to each of them.

In this work an extended lactation will be considered to be part of an 18-mo (540-d) calving interval. This means that a lactation will be about 15 to 16 mo (450 d) in length with successful service occurring about 9 mo (270 d) into the lactation.

Experimental results

Very few authors report research which set out to manage cows for extended lactations and compare them with conventional systems. Some studies managed the cows 'normally' and observed the resulting herd parameters whilst others imposed treatments designed to increase milk production from extended lactations. These included altering milking frequency, diet changes and varying calving season as options to enhance production from extended lactations. Several authors highlight a key feature of lactation, referred to as persistency. Figure 1.1 shows a typical lactation curve which starts at a moderate level of production at parturition (Day 0), rises to a peak within the first two months of lactation and then declines as lactation progresses until milk yield is further reduced by the developing pregnancy (Auran, 1974; Olori *et al*., 1997;

Pollott, 2000). Persistency refers to the rate of decline in post-peak yield and is sometimes described as the ability to maintain peak yield (McFadden, 1997). A persistent lactation is always a desired feature but especially so in extended lactations. Treatments such as 3-times-a-day milking (3X) and improved nutrition contribute to improved persistency and so may be important features of managing extended lactation systems. In the US the use of bovine somatotrophin (BST) is legal and has been shown to increase persistency (Bauman, 1992). This option is not available in the UK.

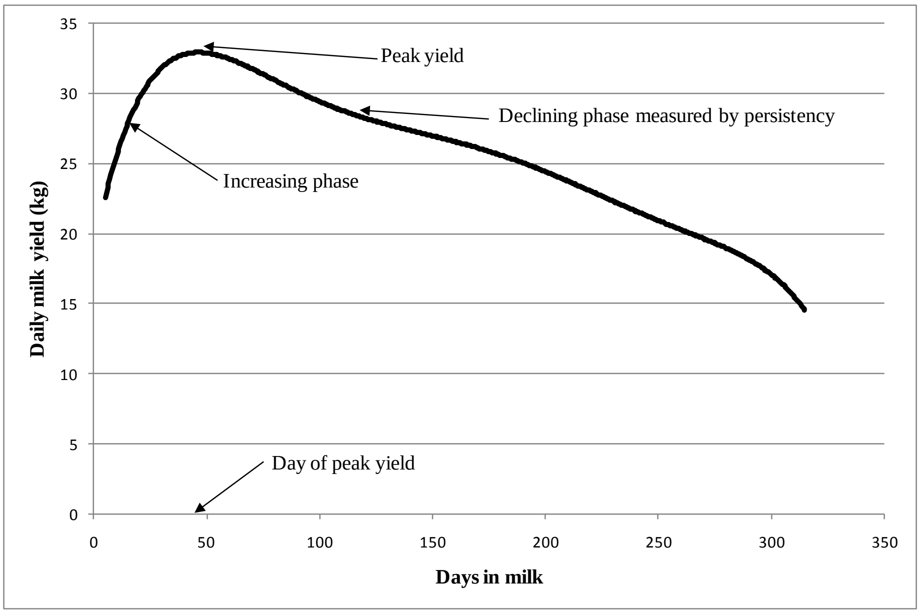

Figure 1.1. *A typical lactation curve (note the increased fall in milk yield from Day 200 onwards due to the developing pregnancy).*

Swedish experiment

A feature of extended lactation experiments is the small number of cows used on any given treatment; this makes significant differences between treatments difficult to achieve for some traits and so only ‘trends’ are often quoted. A number of reports exist describing work to extend the rebreeding period by a month or two but the first published results on the experimental use of extended lactations up to a calving interval of 18 months came from Swedish work (Bertilsson *et al*., 1997; Ratnayake *et al*., 1998; Rehn *et al*., 2000; Osterman and Bertilsson, 2003; Osterman *et al*., 2005). In this experiment 72 cows were divided between two treatments; 12 (12M) and 18-month (18M) calving intervals and 2 (2X) and 3-times-a-day milking. These papers report milk production, fertility and somatic cell count results from the system designed to compare the calving interval groups over a three-year cycle (i.e. three normal lactations compared to two extended lactations).

The twice-a-day milking groups had calving intervals of 358 and 545 days, equivalent to 11.8- and 17.9-month calving intervals. The longer lactation group obviously yielded more milk per lactation but on a ‘per day of calving interval’ basis this was significantly less ($P < 0.05$) for the 2X group at 21.3 v 22.7 kg/d. Interestingly in the 3X groups the situation was reversed with the shorter lactations resulting in lower production of 24.2 v 23.4 kg/d of CI. When the data were analysed over both milking management groups there was no difference between 12 and 18-month CI cows in milk yield per day of CI. In fact similar conclusions were reached for a number of traits i.e. overall there was no difference between 12 and 18-month groups; this applied to conception rate, pregnancy rate, number of inseminations per conception and somatic cell count. Small differences were observed between heifers and older cows in some traits.

The fat and protein % lactation curves showed a continuous rise after about week 10 of lactation; this is the expected situation in dairy cows (see for example Kolver *et al.*, 2007). Longer lactations result in a higher fat and protein percent overall. Similar patterns were also observed for somatic cell count such that later milking had a slightly raised value. This was thought to be due to the ‘normal’ effect of using milking machines damaging the udder to a slight extent, rather than an increase in mastitis.

Some positive effects of 18M were observed. Cows on the 18M regime required fewer interventions to overcome anoestrus and, within one herd, conception rate was higher for 18M cows. Other useful points found in this work included the fact that the higher persistency commonly observed in heifers allowed them to utilise the 18M regime better than older cows. Signs of heat were not found to diminish as cycle number increased past the 4th cycle, as is commonly expected by farmers. Increased milking frequency raised the whole lactation curve compared to 2X but both curves demonstrated the same pattern; i.e. peak was higher but persistency remained similar. The 3X treatment increased milk production with only a small increase in fat and protein production. Thus fat and protein percentage was reduced in 3X cows.

Scottish study

The work reported by Sorensen *et al*. (2008) took a different approach from the Swedish experiment. All 25 cows used in this research were managed for 18M calving intervals but a range of management options were studied, all aimed at improving milk yield and/or quality in extended lactations through improved persistency. The management options studied were milking frequency (2X v 3X applied to 2 different quarters each of the same cow at the same time), nutritional regime (additional 3 kg 18% CP concentrate v ‘normal’ ration) and calving season (spring v winter). The treatments that improved milk yield were 3X, high protein diet and winter calving. Persistency was negatively correlated with peak milk yield and was also improved by 3X and winter calving. Fat and protein proportion, and somatic cell count, showed an increase as lactation progressed, and were also increased by 3X and winter calving. This study also looked at casein content of the milk since this is a key aspect of manufacturing quality. This declined more in longer lactations but was again helped by 3X and protein supplementation. This study tended to confirm the conclusions reached in the Swedish study summarised above.

New Zealand research

The use of extended lactations in pasture-dominated systems raises a number of questions which differ from those found in largely-housed systems. These address the issue of nutrition throughout the extended lactation and the management of grazing under these conditions. Kolver *et al.* (2007) reported a trial using 2-year calving intervals with both North American (NAHF) and New Zealand Holstein-Friesians (NZHF; 30 cows per genotype). These animals were studied for 2 years and fed three levels of pelleted concentrate supplementation, 0, 3 and 6 kg DM/d. The 6 treatment groups were balanced for genetic merit, calving date, age and lactation number but, due to the genotype differences, the NZHF averaged 587 ± 70 kg bodyweight whilst the NAHF were 700 ± 98 kg. Performance parameters from the 2-year calving animals were annualised to allow comparison with a second group of animals maintained on 2 annual calvings.

Taking the results overall, this trial found a reduced level of milk production (18%), milk protein (13%) and milk solids (13%) from annualised two-year lactation results compared to the annual system. This pattern of results varied across the different feeding level/genotype combinations such that North American Holstein-Friesians fed on 3 and 6 kg of concentrates had similar levels of milk production in both systems. One interesting feature of these results was a second peak of milk yield which occurred during the second spring; this was more pronounced in the NAHF than the NZHF. Overall this report demonstrated that cows could maintain milk production over two years from grass-based systems but there was wide variation among individual cows in their ability to produce for more than 300 days; NAHF appeared to be better adapted to this system, particularly when fed concentrates to supplement the pasture. In particular, NZHF appeared to lay down too much body condition in the second year and arrived at the next lactation too fat. The authors concluded that ‘with appropriate cow genetics and feed management, reduced reproductive performance may be ameliorated in high-producing dairy cows without sacrificing milk solids production'.

Australian work
The use of extended lactations in a pasture-based system was reported by Audlist *et al.* (2007) from an experiment under Victorian (Australia) conditions. Cows were divided into equal groups to have lactation lengths of 10, 12, 16, 19 and 22 mo; 125 cows divided between 5 groups. A 56-day dry period was used in this work and milk production was the main measure of output, annualised to allow comparisons between treatments. The main conclusions were that treatments up to 16 mo (equivalent to 18-mo CI) did not adversely affect milk yield or milk solids production, but longer lactations (> 16 mo) led to a reduced milk and fat production per year. A rise in milk production was observed as lactations went into their second spring and the loss in milk production towards the end of long lactations was greater than the loss in milk solids. This was thought to be an advantage in industries which pay on milk solids rather than milk volume. These authors also monitored liveweight and condition score and noted that cows in longer lactations were in better condition at the end of lactation, probably due to being in positive energy balance for a greater part of the lactation.

American experience
A considerable amount of work in the United States of America has been undertaken looking at the effects of bovine somatotrophin on dairy performance. The use of BST increased milk yield and also the persistency of lactation (Bauman, 1992; Chalupa and Galligan, 1989; Chillard 1988; Peel and Bauman, 1987) compared to an untreated control. The extra milk was gained at the cost of extra feed for the additional milk produced but maintenance requirements were not altered (Bauman and Vernon, 1993). In addition Ferguson (1989) found that a delay in rebreeding until 150 to 200 days postpartum, in conjunction with BST use, resulted in improvement in a number of aspects of lactation including energy balance, fertility and health.

One of the effects of using BST is to raise both the level and persistency of lactation which has the potential to produce an extended lactation. Van Amburgh *et al*. (1997) looked at using BST as a way of creating an extended lactation. Twenty-four second lactation cows in each of 9 herds were allocated to one of four different treatments; 60-day rebreeding period, 150-day rebreeding period, a group not rebred and a group of heifers not rebred. The controls were contemporaries in the herds which were not part of the experiment. Cows on the trial were given BST as recommended by the manufacturer. Although this method is not available to UK producers it is worth noting that the greater persistency of the BST treated cows allowed the longer lactations to be more profitable due to the extra milk produced.

Short extensions to lactation

A number of authors have considered extensions to the 305-d lactation which resulted in calving intervals less than 18 months by design. Most of these studies were concerned with the 'problems' associated with an increased days open period on an annual calving herd and so were focussed more on fertility than overall production. Studies of this type were usually set in an economic framework rather that purely being about the animals' performance. They fall into three types of study; designed experiments, simulation studies and analyses of recorded herds.

In an Israeli study using cows in 19 commercial herds Arbel *et al.* (2001) compared two groups of cows, a control group with the 'normal' calving interval for these herds and a treatment group which had mating delayed by 2 months. Milk yield per day of CI was higher for the treatment group heifers but there was no difference between older cows. Several studies used a small number of treatments or relative short extensions to the days open period and consequently reported few differences between groups (Harrison *et al*,. 1974; Schneider *et al*., 1981).

Industry data
Dairy cow milk records used for genetic evaluation purposes are commonly taken monthly on all

milking animals in the herd. These records comprise daily milk yield, fat, protein and sometimes lactose % and somatic cell count, an indicator of mastitis in the cow. Many recording schemes also take data from other sources such as calving dates, service information and indicators of body characteristics in the form of 'type scores'. Given this wealth of information recorded on dairy herds one might expect a large number of reports providing information on lactation characteristics relating to extended lactations in commercial herds. This is not the case. To enable fair comparisons between animals, most genetic evaluations systems work on 305-day lactation lengths and information from longer lactations is not used. Many papers describe the phenotypic and genetic characteristics of dairy populations and the relationships between them but few authors report on extended lactations. Calving interval data is routinely available from many herds and persistency can be calculated from the monthly milk yield data but is rarely reported. Analyses of milk data from extended lactations tends to focus on finding a lactation curve model to adequately describe the course of milk yield (Vargs *et al*., 2000; Grossman and Koops, 2003; Dematawewa *et al*., 2007) but these studies yield little information about relationships between key variables. Even in our own studies modelling lactation to its conclusion we 'corrected' for lactation length in many analyses (Albarran-Portillo and Pollott, 2008).

Australian data

An analysis of Australian data on lactation length in Holstein Friesians gave a number of insights into the relationships between milk production after Day 305 of lactation and prior information (Haile-Mariam and Goddard, 2008). Herds which had a high number of cows with prolonged lactation were selected for these analyses. Data from first and second lactation cows were analysed for both genetic parameters and the phenotypic relationship between milk yield and somatic cell count traits. These data had the characteristic shape of first and second lactation cows, namely first lactation cows had a lower peak yield and were more persistent than second lactation cows. One result of this was that first lactation cows tended to have higher milk yields in later lactation than second lactation cows. Data on protein, fat and somatic cell count also showed differences between cows of the two ages with second lactation cows having poorer performance than first lactation cows.

High correlations between early and late lactation traits demonstrated that the characteristics of the cows found in early lactation carried on into late lactation. In common with many studies these authors found a high negative correlation between mean milk production and persistency. When the two traits were analysed with methods to negate this correlation, persistency was found to have a low heritability. Lactation length was found to have a very low heritability at ~0.02.

Analyses of days open

Funk *et al.* (1987) studied the effect of days open on milk yield from commercial dairy records in eastern USA; this included days open in both the current and previous lactations. Analyses of days open in the previous lactation is equivalent to looking at the effect of calving interval on the next lactation's milk yield whilst using days open in the current lactation is equivalent to looking at extended lactations, provided that cows are milked to within about 60 d of the next lactation. Milk yield in the current lactation increased by about 2 kg per extra day open in the previous lactation; this suggests an increase of 360 kg of milk just for using 18-mo lactations. The effect of extending the current lactation was not linear but increased rapidly up to about 100 days open and then had a more gradual increase above that. This is in effect a reflection of the trade off between more days in milk with the decreasing daily yield as lactation progresses.

Studies of Israeli data by Weller *et al.* (1985) and Weller and Folman (1990) also concluded that short days-open periods were less profitable than longer ones but neither study considered calving intervals as long as 18 mo. They did make one observation, which has been echoed by several authors, that the higher persistency in first lactation cows does make longer lactations more productive compared to cows in later lactations.

Modelling longer lactations

Lactation modelling has been an extensively studied subject. The ‘classic’ model is that described by Wood (1967) which is relatively simple to apply and widely studied. Many authors have shown the fit of this model to be lower than many other models and a variety of alternative empirical and mechanistic models have been proposed (see Masselin *et al.* (1987) for a review). More recently interest has centered on either suitable models for use in random regression analyses of the test-day model or models which describe the biology of the animals in more detail. Dematawewa *et al.* (2007) compared a number of models for describing extended lactations. One result of this work was to show that the biological model of Pollott (2000) fitted the data better than most other models. This model was used in the work described later in this project.

Economic modelling

A number of authors reported the results of economic simulations of extended lactations but these were very dependent on the particular country and prevailing economic conditions. The conclusions drawn from such studies also depended on how moving away from an annual calving pattern was viewed. If the production system was geared up to annual calving at a specific time of year then this imposed a much greater cost of an extended lactation than in an all-year-round calving system. Where economic comparisons between systems have been included, these studies have provided some general guidelines on key factors to investigate in such models.

Rotz *et al*. (2005) took an extreme view and modelled cows with ‘perennial’ lactations in the US. They demonstrated an improvement in profitability and improved environmental benefits from using such animals, mainly due to the increase in milking cow numbers that was possible in their system. Lactation yield, mostly influenced by persistency, was also shown to be critical in the US in a study comparing standard lactations with those from longer calving intervals (Holman *et al*., 1984). Profitability was shown to increase as lactations became longer but then the profitability peaked and started to decline once lactations were more than 13 months long.

Arbel *et al*. (2001) studied the economics of extended lactation in Israel. They too indicated that longer calving intervals appeared to be more profitable, up to an increase of 60 days. They also included production in the initial stages of the next lactation in their calculations and found an even better return for extended lactations compared to ‘normal’ ones.

The BST study of van Amburgh *et al.* (1997) also included an economic analysis of extended lactations. Extended lactations were shown to have a number of benefits including higher profitability, lower incidence of metabolic diseases, lower veterinary costs, fewer cullings and replacements, an improvement in herd life and animal well-being.

A number of other economic studies have been carried out in this area but with limited application to this project. Holman *et al*. (1984) modelled small changes in days open and found a positive benefit when increasing the calving interval from 12 mo to 13 mo but this changed to a negative value for up to 15-mo calving intervals. De Vries (2006) looked at the subject from a different perspective and calculated the value of pregnancy to a dairy herd. This value was found to be positive but was reduced by modelling more persistent cows. Interestingly it became negative for high producing first lactation animals which typically have a more persistent lactation. De Vries (2006) concluded that the optimum profitability for heifers was achieved by rebreeding at > 450 days and for older animals at about 200 days post calving. Dekkers *et al.* (1998) took a different view and studied the economics of persistency in the USA. Once again more persistent animals were shown to have several advantages over the ‘standard’ animal and longer lactations were more profitable.

Papers dealing with extended lactations, rather than poor fertility, tend to conclude that annualised milk yield from extended lactations is not detrimental and that such systems are equally as profitable as annual calving patterns. However this is very dependent of the persistency level of the lactations modelled. Three-times-a-day milking, and any other treatment designed to increase persistency, always proved more profitable than alternative systems.

Persistency

Persistency has already been found to be a key aspect of using extended lactations in the papers reviewed so far. The idea of persistency appears at first sight to be a simple one; a measure is required that describes the way lactation declines after peak yield. A wide range of measures have been used to describe persistency (see Gengler, 1995; Swalve and Gengler, 1998; Muir, 2004 for reviews). More recently we have published industry-wide estimates of genetic and phenotypic parameters of persistency based on a biological model of lactation (Albarran-Portillo and Pollott, 2008). Most studies conclude that there is both phenotypic and genetic variation in persistency, and the experimental results reviewed above highlight some management practices which can modify persistency. The heritability of persistency varied with method of calculation but was commonly in the 0.15 to 0.25 range. Persistency tended to be negatively correlated with both peak and total milk yield. However, van Amburgh *et al.* (1997) observed that higher yield was less important than greater persistency when discussing the factors affecting the profitability of extended lactations. As noted by several authors the higher level of heifer persistency often leads to better yields in extended lactations than older animals (Dekkers *et al.*, 1998; Arbel *et al.,* 2001)

Integrating reviewed information

The characteristics of extended lactations

The only characteristic of an extended lactation that is immutable is its length, by definition. All other characteristics are variable and depend on a range of factors. The milk yield of an extended lactation is determined by the same range of key measurements as any other lactation; peak yield, persistency and length (days in milk). The only different factor which may come into play is if the persistency is so poor that the lactation terminates before its desired length; a greater possibility the longer the lactation. Also pregnancy affects milk yield in a well defined way and the absolute reduction in milk yield will depend on the timing of the pregnancy in relation to day of lactation when successful conception occurred (Olori *et al.*, 1997). Pregnancies commencing later in lactation showed a smaller reduction in total milk yield compared to those starting earlier in lactation. However, it is not clear whether this is an effect due to level of milk production at the time of conception or a stage of lactation effect.

The results in Table 1.1 demonstrate some common relationships between lactation curve traits and were derived using a biological model of lactation (Pollott, 2000) in analyses ‘correcting’ for lactation length. Total milk yield is highly related to peak yield but little else, at the phenotypic level. Peak yield is also highly related to persistency such that lactations with a high peak yield have a lower persistency (NB low persistency is equivalent to a high loss in milk production between successive days). Persistency and the relative rate of cell loss are highly related but this latter trait is not highly related to peak yield. This may at first sight seem surprising but since peak yield occurs before the onset of cell apoptosis then the link between high peak yield and low persistency is likely to be due to an effect on milk secretion rate per cell, and/or the number of cells, rather than cell loss. These relationships are somewhat stronger at the genetic level. Also milk yield and peak yield are much more highly heritable than the other traits.

Table 1.1. *Heritabilities (on diagonal), genetic (above the diagonal) and phenotypic (below the diagonal) correlations between lactation curve traits (standard errors shown below in parentheses). From Albarran-Portillo and Pollott (2008).*

	PY	*DP*	*DR*	*PS*	*TMY*
Peak yield (PY)	**0.30**	-0.04	-0.12	0.54	0.96
		(0.004)	(0.053)	(0.034)	(0.004)
Day of peak yield (DP)	0.27	**0.03**	-0.69	-0.42	0.51
	(0.075)		(0.068)	(0.093)	(0.064)

Relative rate of decline in cell nos. (DR)	0.17 (0.004)	-0.39 (0.003)	**0.08**	0.84 (0.014)	-0.40 (0.045)
Persistency[1] (PS)	0.51 (0.003)	-0.10 (0.004)	0.88 (0.001)	**0.08**	0.31 (0.047)
Total milk yield (TMY)	0.82 (0.001)	0.14 (0.004)	-0.21 (0.004)	0.09 (0.004)	**0.34**

[1]Measured as the daily loss in milk yield mid-way between peak and end of lactation

Cows of different ages/lactation numbers have very different lactation characteristics. Heifers tend to have a lower peak than older cows and are more persistent. Second and 3rd lactation cows have increasingly higher peaks and lower persistency with each successive lactation. From the 4th to 6th lactation there is little to distinguish between lactations in peak or persistency. Not surprisingly total milk yield follows a similar pattern to the peak as lactation number progresses. Younger cows are therefore likely to have lactations which are more amenable to extension than older cows.

Although the pattern of milk component production reflects that of milk (Figure 1.1) when expressed as proportions of milk yield the pattern is inverted (Figure 1.2). This means that as lactation progresses fat and protein proportions increase and longer lactations will have a higher mean fat and protein proportion compared to shorter lactations. Figure 1.2 also shows another interesting feature of long lactations in New Zealand grass-based systems, the change in milk production during spring of the second year (~300 DIM). In their paper Kolver *et al*. (2007) highlight the increased milk yield and decreased fat proportion at this time. This is not so apparent in more intensively-fed Holstein animals, typical of British systems.

The change in (log) somatic cell count throughout lactation follows a similar pattern to that shown in Figure 1.2 for fat proportion; i.e. an initial fall followed by an ever increasing rise. This also means that cows with longer lactations will have higher somatic cell counts, although Osterman *et al*. (2005) suggest that this is not due to an increase in mastitis but the natural wear of the udder increasing with the longer lactation. Age also affects SCC with heifers having lower levels than older cows.

How to improve the milk yield for extended lactations
A number of researchers have demonstrated management practices which can be used to increase the milk output from extended lactations. The season of calving was shown to affect the ability to maintain a longer lactation, total milk yield and persistency (Sorensen *et al.*, 2008); winter-calved cows had higher values or better persistency than spring-calved cows.

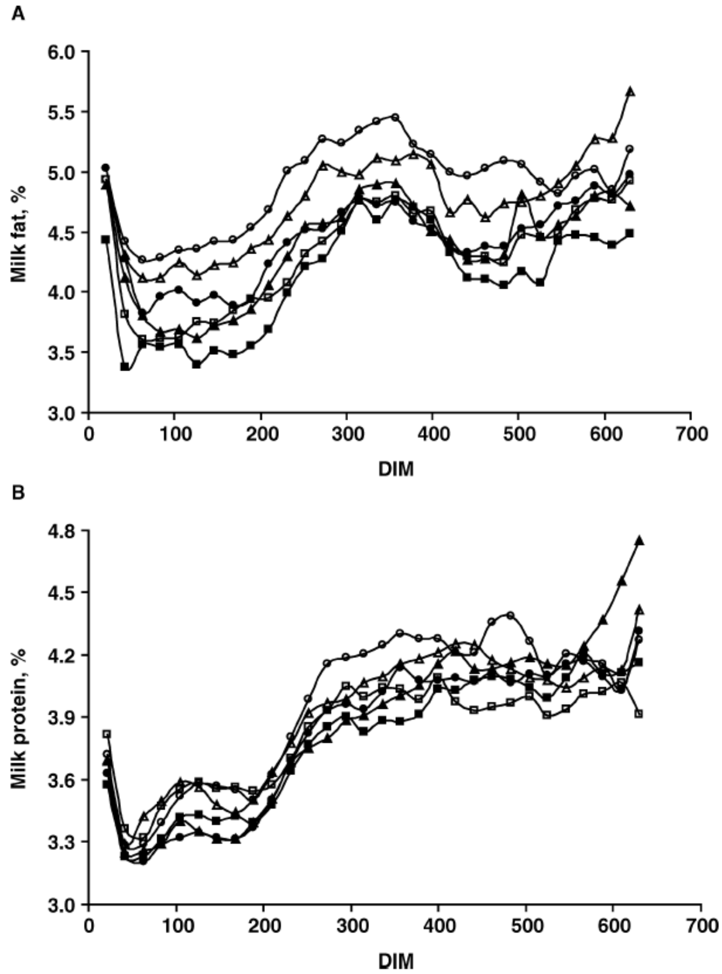

Figure 1.2. *Fat and protein percent throughout extended lactations for two genotypes fed three different protein quantities (Kolver et al., 2007). New Zealand (open symbols) and North American Holstein (filled symbols) fed on 0 (circles), 3 (triangles) and 6 (squares) kg/d concentrates.*

Feeding additional concentrate has been shown to affect yield from extended lactations with Sorensen *et al.* (2008) getting a higher milk yield from 3 kg/d extra rations, as did Kolver *et al.* (2007) from a comparison of 0, 3 and 6 kg/d. Neither study reported an increase in persistency with additional feed. In their comparison of North American (NAHF) and New Zealand Holstein (NZHF) cattle Kolver *et al.* (2007) were able to demonstrate a better use of the additional concentrate by the NAHF in extended lactations. This is illustrated in Figure 1.3 which shows a successively higher peak yield with increasing concentrate use but a similar persistency, within breed type.

The lactation curves in Figure 1.3 also illustrate the advantage of using North American Holstein genes to aid extended lactations; so clearly breed type can have a dramatic effect on the efficacy of extended lactations.

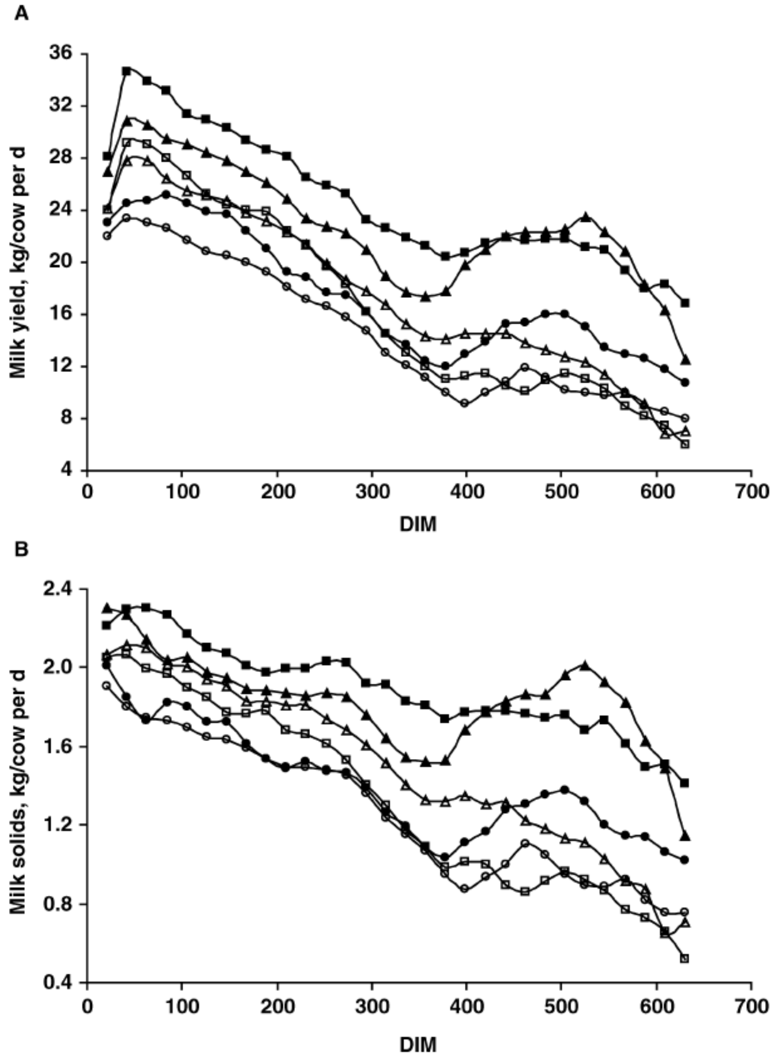

Figure 1.3. *Milk and milk solids production throughout extended lactations for two genotypes fed three different protein quantities (Kolver et al., 2007). New Zealand (open symbols) and North American Holstein (filled symbols) fed on 0 (circles), 3 (triangles) and 6 (squares) kg/d concentrates.*

A number of the factors affecting extended lactations have already discussed are part of what might be termed a 'system of production' e.g. time of calving, the use of concentrates etc. Both the Australian and New Zealand research used mainly-grazing systems in their research whereas Swedish, UK and USA work tended towards intensive systems with a greater emphasis on concentrate feeding. One advantage of the grazing systems was the second peak of lactation found in the second spring of extended lactations (Figure 1.3) but this could be viewed as compensating for the lower milk production of these systems when compared to intensive systems. Authors using both systems have described the conditions under which extended lactations are feasible for their particular production methods.

Several authors have demonstrated the effect of changing from twice-a-day to three-times-a-day milking frequency. The overall effect is to increase lactation yield brought about by both an increase in the level of the lactation curve (Ostermann and Bertilsson, 2003) and persistency (Sorensen *et al*., 2008). More frequent milking is expected to have such an impact in high-yielding dairy cows due to a reduction in the feedback inhibitor of lactation effect (FIL; Knight *et al*., 1994). A lower interval between milkings reduces the effect of FIL and hence allows more milk to be produced.

Fertility of extended lactations

Calving interval is commonly used a measure of fertility in dairy herds but relies on breeders aiming to get their cows back into calf as soon as possible after calving. In an extended lactation scenario this is not an objective and so other measures of fertility may be required. Most reports of designed experiments to investigate extended lactations have been too small to demonstrate differences in other measures of fertility such as the number of services per conception or abnormal luteal cycles. However, Ostermann *et al.* (2003) observed that there was no reduction in the signs of oestrus at the 7^{th} cycle. In his review of extended lactations Knight (2008) concludes that "there is no evidence that late rebreeding is 'easy' and it can be anticipated that problems may be different to those encountered in current practice." As yet no such problems have been suggested by the limited amount of published research.

Health, longevity and replacement rate with extended lactations
Once again the limited experimental evidence is unable to demonstrate any differences in health or longevity due to different lactation lengths. Knight (2008) suggests that because cows on extended lactations have fewer calvings, and calvings are seen as a high-risk and stressful event, then they should be healthier than conventional cows. Modelling work with BST in the USA with results expressed on a annualised basis (Allore and Erb, 2000) tends to confirm this view but such conclusions have not been tested in experimental conditions. One might expect cows on extended lactations to have a lower likelihood of culling at any given age. If this were the case then the annual replacement rate would be reduced and the number of followers required would be lower. However this remains as speculation at the present time.

Conclusions
A summary of the relevant literature on extended lactations has been reviewed. The information from these papers will be used as the basis for the analysis and modelling work subsequently reported in this project.

Objective 2.

Determine the relationships between peak yield, total lactation yield, persistency and calving index in the UK dairy herd.

Introduction
Genetic selection for milk yield has led to a deterioration in fertility in British dairy cows during the last two or three decades. One of the earliest reports was by Wood and Wilson (1983). They analysed the lactations of a group of the highest yielding Friesian-Holstein cows in the UK at that time and showed that the calving intervals of these cows were 9 days longer than the average cow. High yields were explained by the use of high genetic merit sires and the improvement of herd management practices. They also found a negative effect of high milk production on the incidence of diseases. Since then, an increasing number of reports from several countries have been published showing the decline in fertility due to selection for milk production (Dhaliwal *et al.*, 1996; Pryce *et al.*, 1997; Pryce *et al.*, 1999; Fulkerson et al., 2001; Lucy, 2001). Clearly longer calving intervals are related to longer lactations since the average dry period has remained at about 62 days for the last 10 years (Coffey, M,; Personal Communication). Calving interval is a widely used measure of fertility since calving dates are widely available in milk recording schemes. From these CI can be estimated and analysed in order to assess fertility of all cows from commercial dairy farms in the UK.

Calving intervals reported in the literature range from 368 d (Evans *et al.*, 2006) to 398 d (Haile-Mariam *et al.*, 2003) but recent work from the SAC Langhill Herd found CI to be 403 days (Pollott and Coffey, 2008). There is general agreement that calving intervals have been unfavourably affected by the increase of the genetic potential of dairy cows for milk production (Pryce *et al.*, 2000; Olori *et al.*, 2002; Kadarmideen *et al.*, 2003 and Banos *et al.*, 2005). Reproductive parameters that reflect the reproductive status of dairy cows, such as days to first observed oestrus and start of luteal activity, have been found to be delayed in high genetic merit cows by 21 and 11 days, respectively. These resulted in a longer days open period (99 d) than that of low genetic merit cows (91 d) (Fulkerson *et al.*, 2001). Lucy (2001) estimated that for every 100 kg increase in milk yield there was an increment of 1 day from calving to conception (open days), a trait closely related to CI. The high proportion of milk produced in the first third of lactation has been associated with a reduced rate of pregnancy to first service (Buckley *et al.*, 2003).

Genetic selection for increased milk yield has directly (due to selection) or indirectly (due to energy balance) affected some characteristics of the lactation curve and milk composition. It has been established that selection for higher milk yields and its components (fat, protein and lactose) has negatively affected the proportions of these components (Kelm *et al.*, 2000).

Lactation curve parameters such as day of peak yield, peak yield and persistency have been affected by selection for higher milk yield. For instance, the day of peak yield the level of persistency of lactation, the later the day of peak the better the persistency (Muir *et al.*, 2004). The level of peak yield determines total milk yield (Batra *et al.*, 1987; Buckley *et al.*, 2003), the higher the peak yield the higher the total milk yield.

Pollott (2000) proposed a biological model to study the lactation curve. This model was an alternative to empirical lactation curve models which were based on mathematical equations that fit the shape of the lactation curve but have no biological basis. The biological model describes parameters of the curve in terms of secretory cell differentiation in early lactation, cell death rate after parturition and changes to secretion rate during lactation. Therefore, the output parameters from this model have a biological basis that explain the lactation in terms of the number of differentiated cells during lactation, the numbers of cells dying throughout lactation, plus the secretion rate per active cell. The dynamics and characteristics of the mammary cell population have been reported by Knight and Wilde (1987), Wilde and Knight, (1988), Wilde and Knight (1989) Wilde *et al.*, (1997), Knight and Wilde (1993) and Knight *et al.*, (1998).

The parameters from Pollott's (2000) model cover those described by Wood (1967), as well as some newly proposed parameters such as maximum secretion potential (MS), which is a function of the total number of parenchyma secretory cells and the maximum secretion rate (kg/cell per day), and is closely related to peak yield; the relative growth rate in cell numbers (GR) from parturition to peak yield and the relative death rate in cell numbers (DR) from the start of lactation to the end of lactation, which gives, as a result, the persistency of lactation. Pollott and Gootwine (2001) used the biological model to estimate the genetic characteristics of the complete lactations of Awassi sheep. They found a negative genetic correlation of 0.66 between DR and total milk yield (TMY) and a correlation of 0.99 between MS and peak yield (PY). These genetic correlations show the usefulness of the model to describe the parameters of the lactation curve. In dairy cows, the model has been used to describe curve parameters and milk components of a small data set from a single farm (Pollott, 2000) and from a multiple ovulation and embryo transfer (MOET) herd (Pollott, 2004 and 2009). Additionally, the model was used to determine the genetics of the lactation curve parameters from a large dataset of commercial dairy cow records (Albarran-Portillo and Pollott, 2008).

The objective of this study was to determine the relationship between calving interval with key lactation characteristics such as the yield traits (milk, fat, protein, lactose, total solids and water) and parameters of the lactation curve. A full description of the research carried out is given in Appendix 2. Only the key results are shown here

Discussion

Correlations between calving interval and lactation curve traits

The genetic correlations between calving interval and lactation curve traits were all unfavourable in the sense that increases in production, or a decrease in persistency, were associated with increased calving interval. The only exception was DR (the decline in cell numbers from parturition to the end of lactation independently from the peak yield) which had a low negative correlation with CI. This favourable correlation implies a lower rate of active cells dying as calving interval increased, resulting in a better persistency of lactation. This was confirmed in the phenotypic correlation of CI with DR and DM (-0.18 and -0.09, respectively).

The genetic correlations between CI and milk yields were also unfavourable, ranging from modest 0.48 (protein) to high 0.73 (fat). The correlations of CI with milk and protein were within the range reported by Campos *et al.*, (1994) Haile-Mariam *et al.*, (2003), Kadarmideen *et al.*, (2003) and Muir *et al.*, (2004). However, none of these studies reported a higher correlation than the one found in this study of 0.73 between CI and fat production.

Appendix 2, Table 2.5. *Genetic and phenotypic correlations between calving interval and lactation curve traits (standard errors are shown below each correlation)*

Correlations	*MS*	*GM*	*DP*	*PY*	*DR*	*DM*	*CTMY*	*TMY*
Genetic	0.59	0.46	0.20	0.59	-0.12	0.36	0.63	0.62
	0.064	0.084	0.022	0.063	0.089	0.092	0.050	0.051
Phenotypic	0.03	-0.08	0.06	0.04	-0.18	-0.09	0.54	0.54
	0.004	0.004	0.004	0.004	0.004	0.004	0.002	0.002

The genetic correlation between milk yield and calving interval confirmed that selection for production has led to a genetic decline in fertility, considering CI as a suitable estimator of fertility (Pryce *et al.,* 1999 and Pryce *et al.,* 2000).

Appendix 2, Table 2.6. *Genetic and phenotypic correlations between calving interval and milk component traits (standard error shown below correlations)*

	Milk	*Fat*	*Protein*	*Lactose*	*Total solids*	*Water*
Genetic	0.51	0.73	0.48	0.57	0.57	0.50
	0.130	0.147	0.128	0.125	0.129	0.132
Phenotypic	0.02	0.03	0.010	0.018	0.016	0.019
	0.005	0.007	0.005	0.005	0.005	0.005

Phenotypically, CI and milk components were poorly correlated, in particular the correlations of CI with milk and fat, were close to zero (0.02 and 0.03). Pryce *et al.*, (2002) reported a negative phenotypic correlation between CI and milk (-0.03). Other than that, phenotypic correlations between CI, milk, fat and protein were within the ranges reported in the literature.

Levels of milk protein have been related to reproductive performance. Fulkerson *et al.*, (2001) associated low levels of protein (< 2.89%) with a negative energy balance, resulting in a poor reproductive performance. Regarding fat results, De Vries *et al.,* (2000) suggest that changes in fat percentage are a very good indicator of energy balance and concluded that weekly changes of fat percentages (from week 2 to week 15) were highly correlated with energy balance. Because of this, changes of fat percentages in early lactation are good indicators of energy balance, making it possible to use them in order to assess energy balance of cows at risk of poor reproductive performance.

Heritability of lactation curve traits

Peak yield was the trait with the highest h^2 estimated (0.36). This h^2 was higher than the 0.27 from a similar dataset in Albarran-Portillo and Pollott (2008), and higher than 0.30 estimated by

Pollott (2009) for the same trait.

Maximum secretion potential (MS) is a theoretical estimator of the maximum productive potential of the animal that accounts for the relative number of secretory cells in the udder and the secretion rate per active cell. As in both Albarran-Portillo and Pollott (2008) and Pollott (2009), the h^2 of MS was close to the h^2 of PY (0.36), which was the highest among the curve traits. The heritability of PY was high compared to the h^2 reported by (Farhangfar, 2002; Pollott, 2009) and was within the range reported by Zwald *et al.*, (2003).

The heritability of GM was 0.13. This relates to the same trait as parameter "b" in Wood's model, and was higher than the estimates by Shanks *et al.*, (1981), and Farhangfar (2002), but was lower than Varona *et al.*, (1998) who reported a h^2 of 0.17.

Day of peak (DP) is a trait usually reported with low h^2. Heritability estimates in this study was 0.03 and was lower than 0.09, 0.09, 0.10 and 0.06 reported by Shanks *et al.*, (1981), Muir *et al.*, (2004), Farhangfar (2002) and Pollott (2009), respectively.

Persistency was found to have an h^2 of 0.10 and was low compared to other reports in the literature (Shanks *et al.*, 1981; Batra *et al.*, 1987; Jamrozik *et al.*, 1998; Zwald *et al.*, 2003; Muir *et al.*, 2004 and Pollott, 2009). However, Farhangfar (2002) also found a low value of 0.08. Heritability estimates of CTMY and TMY were 0.26 and 0.27 and ranged within the values reported in the literature (Shanks *et al.*, 1981; Batra *et al.*, 1987; Zwald *et al.*, 2003; Muir *et al.*, 2004; Ben Gara et. al., 2005; Silvestre *et al.*, 2005).

Heritability of calving interval

There are several reports regarding the h^2 of calving interval. All of these reports concluded that CI has a low heritability. The h^2 of calving interval reported here was 0.03 and was lower than 0.10 (Campos *et al.*, 1994), 0.09 (Pryce *et al.*, 1999), 0.04 (Olori *et al.*, 2002) and, 0.07 (Muir *et al.*, 2004). However, the h^2 in this study was slightly higher than 0.02 (Pryce *et al.*, 2000), 0.01 (Pryce *et al.*, 2001), 0.02 (Pryce *et al.*, 2002), 0.03 (Haile *et al.*, 2003), 0.02 (Kadarmideen *et al.*, 2003), 0.03 (Wall *et al.*, 2003) and, 0.03 (Banos *et al.*, 2005).

Extended lactations

These results are not directly about extended lactations but calving interval is very closely related to lactation length. These analyses indicate that there is a link between calving interval and milk production. It has commonly been assumed that this is due to higher milk yields causing low-energy-balance anoestrus and hence the number of days open increasing. In the context of extended lactations this may also be due to longer lactations having a higher number of productive days and hence greater total lactation yields. The correlations reported here imply that selection for increased milk yield will inevitably lead to longer calving intervals, higher peak yields and reduced persistency. However, the use of suitably weighted selection indexes, or the use of independent culling/selection levels, can break such correlations and lead to a more desirable type of animal. Thus selection for a more persistent animal without increasing peak yield would be possible. This could increase total milk yield without the negative effects of a high peak yield being a factor in poorer fertility. In the context of extended lactations a longer lactation with a higher persistency is achievable and may be desirable.

Objective 3.

Establish the extent to which extended lactations occur by default in UK dairy herds, and reasons for its occurrence.

Introduction

For many years developed dairy industries have been focussed on an annual calving pattern and genetic testing has been based around 305-day milk yields. Consequently very little work has been published on lactation length in the UK. Calving interval has been widely studied since it is a relatively easy measure of fertility, and lactation length is a major component of calving interval. However, if extended lactations are the result of positive management decisions, rather than a by-product of reduced fertility, then calving interval no longer becomes a measure of fertility. The objective of this part of the project was to investigate the occurrence of extended lactations in the UK over recent years.

Materials and methods

Data from milk recorded herds was extracted from the NMR database, held by EGENES as part of the National Genetic Evaluations for the UK. Natural lactation length was taken to be the day of the last lactation record in this database as opposed to a 305-d lactation length, hence the data reported here is an underestimate by ~15d on average, since milk recording occurs once per month. Records were collected from all completed lactations commencing since 1990. In these analyses the year of lactation is taken as the year the lactation started. All lactations from the fifth lactation onwards were grouped into one lactation number class.

The distribution of the lactation length data was found to be highly positively skewed and the mean herd/year lactation length and its SD were related. Since a key output from this research was to be the relationship between mean and standard deviation of herd lactation length it was necessary to transform the data to a normal distribution to avoid bias in the results. A Box-Cox transformation was used to normalise the data and achieve a dataset with a skewness of 0. The transformation took the form:

$$LL_{trans} = (LL_i^{\lambda} - 1) / \lambda$$

where LLtrans and LL_i were the transformed and original lactation length respectively and λ the transformation parameter. The transformed value was scaled to give an apparently similar range of values to the original dataset. The transformation parameter (λ) was calculated using the original data, appropriate calculations for the skewness and the solver in Microsoft Excel to set the skewness of the dataset to zero given the Box-Cox transformation.

Lactation length data were analysed by maximum likelihood evaluation in ASReml (Gilmour et al., 2009) using the following model:

$$Y_{ijklm} = \mu + h_i + y_j + l_k + e_{ijkl}$$

where was lactation length in the h_i^{th} herd, in the y_j^{th} year and from a cow in its l_k^{th} lactation with e_{ijklm}, the random error term.

Results

A total of over 6 million lactations occurring between 1990 and 2008 were used in these analyses and had a mean and standard deviation lactation length of 373.6 ± 62.42 d. Figure 3.1 shows the highly skewed nature of the distribution of lactation length in this population.

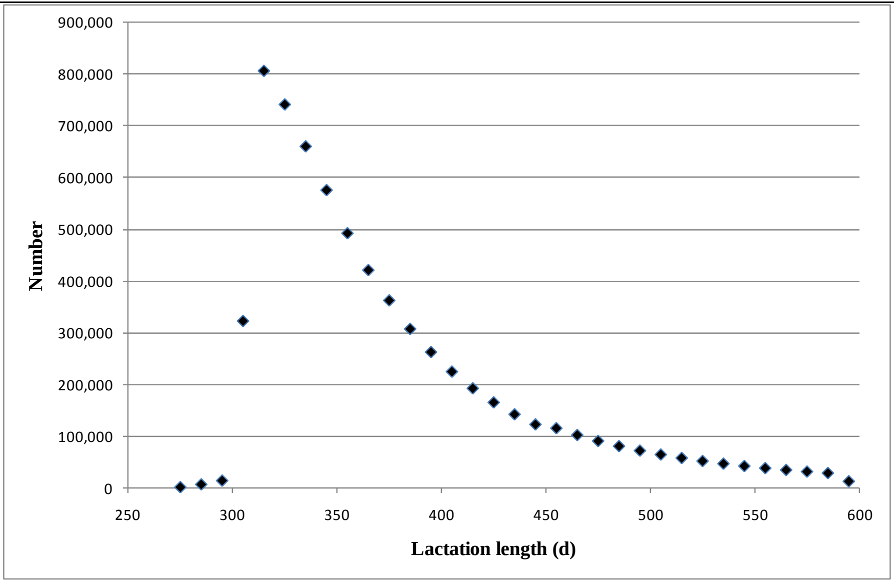

Figure 3.1. *The distribution of lactation lengths in 10-d group categories.*

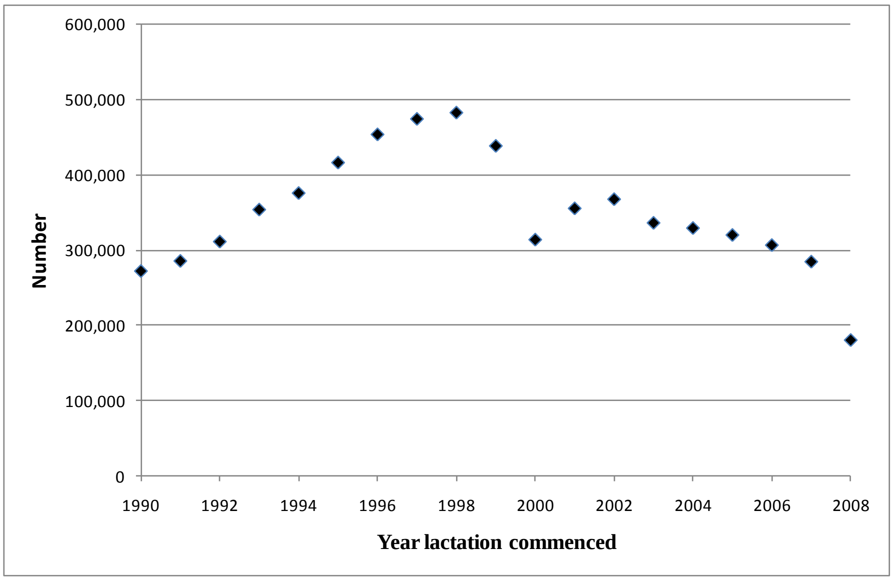

Figure 3.2. *The distribution of lactations by year of commencement.*

The number of lactations by start year (Figure 3.2) reflects the ‘popularity’ of milk recording. From 1990 to 1998 the number of lactations rose from ~270,000 to 483,000. From 1999 to 2001 lactation numbers reduced dramatically reflecting the influence of the foot-and-mouth outbreak in 2001. Since then the steady decline in dairy herds has resulted in fewer recorded animals. The low number in 2008 is the result of many cows starting their lactation in 2008 having not completed it by the time this dataset was constructed. Records from 2008 will be disregarded in subsequent analyses.

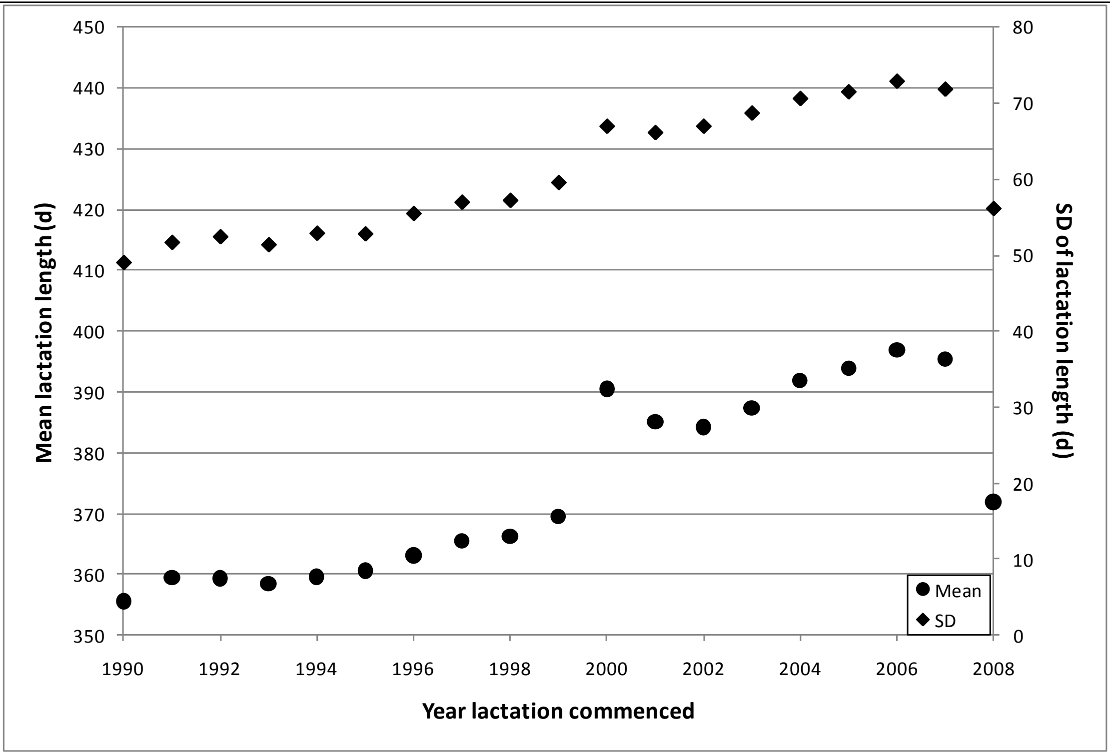

Figure 3.3. M*ean and standard deviation of lactation length by year (1990 – 2008).*

Mean annual lactation length has risen since about 1994 from 360 d to 395 d in 2007 (Figure 3.3). At the same time the variability has increased as shown by the increasing standard deviation of the data.

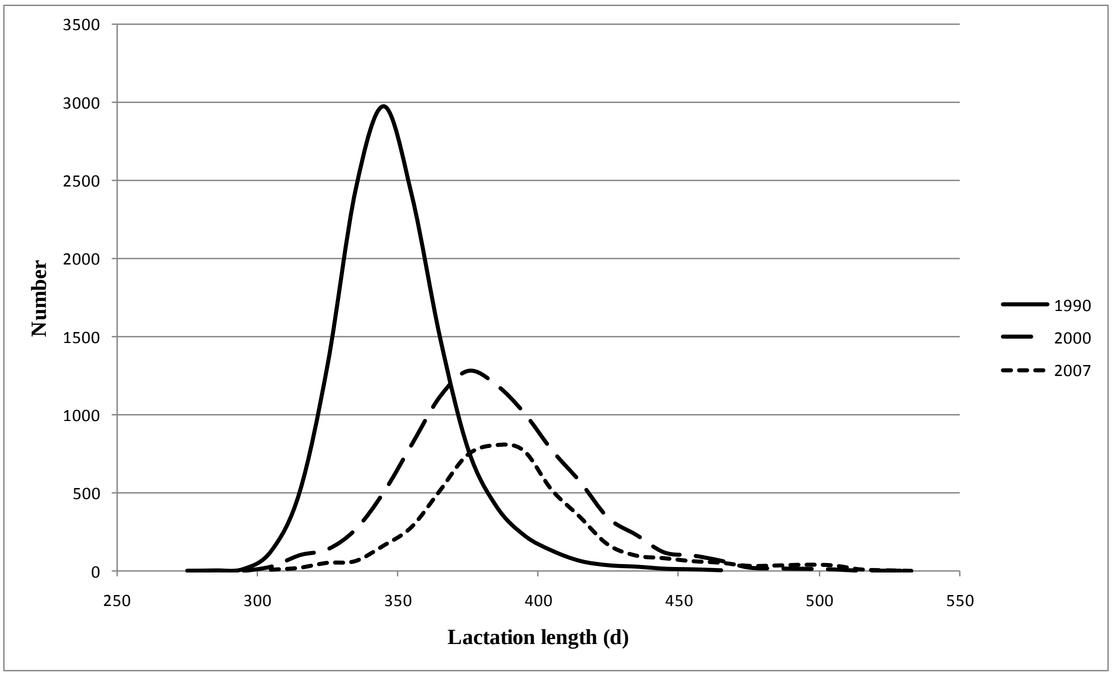

Figure 3.4. *The distribution of lactation length for each of the years 1990, 2000 and 2007.*

All three aspects of the change in the distribution of lactation length over time are illustrated in Figure 3.4. Data from 1990 were characterised by larger numbers, lower mean lactation length and a narrower distribution. As time progressed the number of recorded cows reduced, mean lactation length increased and the distribution was more widely dispersed.

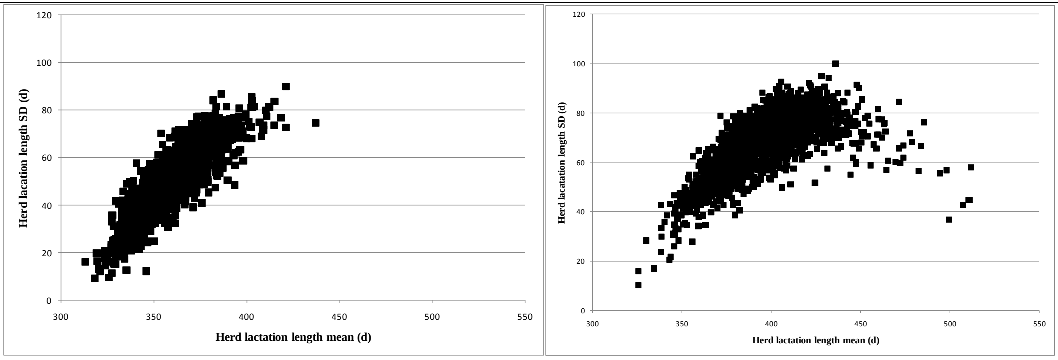

Figure 3.5. *The plots of herd/year mean lactation length against SD (d) for 1990 (left figure) and 2007 (right figure).*

Plots of herd mean (minimum herd size = 40 cows/year) against herd SD for lactation length for both 1990 and 2007 are shown in Figure 3.5, on the same scale. Several notable features of the dataset are illustrated by these plots. Firstly the increased mean and SD noted in the overall data is reflected in the two yearly datasets for individual herds. Secondly there is a strong correlation (0.49) between mean and SD in these data suggesting, along with the overall distribution of lactation length in Figure 3.1, that a transformation was necessary in order to analyse the data using ANOVA-style methods. Such methods require the mean and variance to be independent.

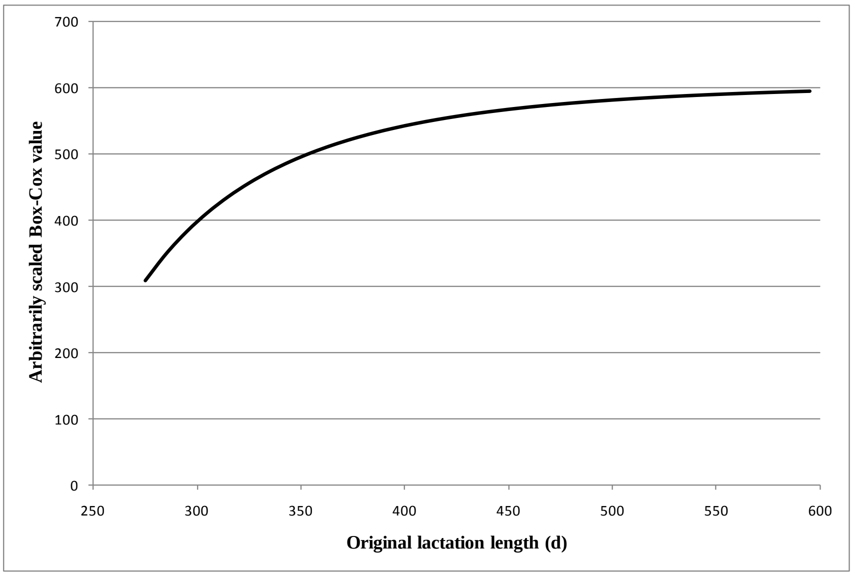

Figure 3.6. *A plot of the transformed scaled lactation length data against the original values.*

A Box-Cox transformation parameter of -4.06444 was used to reduce the skewness of the lactation length distribution to zero. The transformed data were scaled to give a similar range of data points as the original data and so care should be taken when using these ‘arbitrary units’. The conversion of original to transformed data is shown in Figure 3.6 and the distribution of transformed data plotted in Figure 3.7. In the transformed dataset the correlation between herd/year mean and SD was -0.01; thus showing how successful the transformation had been.

Figure 3.7. *The distribution of the transformed lactation length data (Arbitrary units).*

The plots of herd mean (minimum herd size = 40 cows) against herd standard deviation for 1990 and 2007 using transformed lactation lengths are shown in Figure 3.8. These two plots show little correlation between mean and SD confirming that the transformed data was more suitable to use in subsequent analyses.

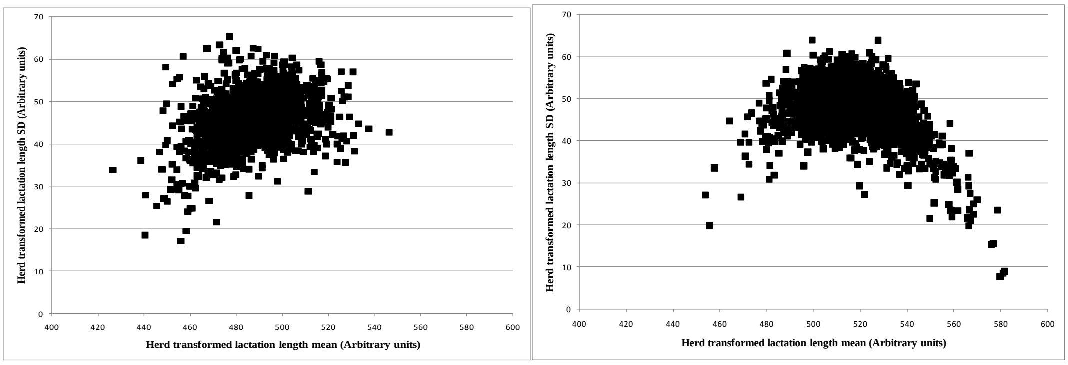

Figure 3.8. *The plots of herd mean against herd/year SD using the transformed lactation length data (Arbitrary units); 1990 (left figure) and 2007 (right figure).*

A comparison of the plots shown in Figure 3.4 illustrates the considerable increase in longer lactations that has occurred in British dairy herds in recent years. The within-herd/year SD of lactation length (Figure 3.8) highlights the fact that a number of herds with a high mean lactation length also have a below average SD. This indicates that many herd owners are already dealing with extended lactations and are likely to have adapted their herd management to cope with this change.

An analysis of variance was carried out on lactation length and the results summarised in Table 3.1. The large number of records available for these analyses meant that most mean comparisons were significantly different. With an RSD of 48.09 units, then for a group size of 350,000 (a typical number of records per year) then a difference in means of only 0.11 units would be significant.

Table 3.1. *ANOVA summary for the main factors affecting transformed lactation length (arbitrary units).*

Source of variation	*Df*	*MS*	*F*
Herd	18,304	58,656	25.36***
Year	18	48,148,552	20,817***
Lactation number	4	9,075,428	3,923***
Residual	6,651,927	2,312.9	

The effect of lactation number on lactation length is shown in Table 3.2 as the mean and SD of lactation length by lactation number.

Table 3.2. *The effect of lactation number on lactation length.*

Lactation number	*Number of records*	*Mean all years (d)*	*SD (d)*	*Transformed data (arbitrary units)*	*2007 data (d)*
1	2,331,749	378.7	67.07	505.1	399.1
2	1,695,634	371.8	61.62	499.7	394.1
3	1,219,029	370.3	59.56	498.5	393.8
4	852,208	370.3	57.90	498.9	393.0
5+	571,634	370.5	55.87	500.1	394.3

First lactation cows had longer lactations than all others, 2nd lactation cows had longer lactations than 3rd lactations but no other differences were significant.

One inevitable consequence of the change from an annual calving pattern to one involving longer lactations was the change in distribution of calvings throughout the year. A summary showing the distribution of month of calving in both 1990 and 2007 is in Figure 3.9. In 1990 there was a marked peak of calvings in September which declined steadily until May. From June onwards calvings picked up again until the next September peak. By 2007 this pattern of calving had changed; there was still a peak in September but this was considerably lower than in 1990 and the monthly proportion of calvings from December through to April were similar with a slight drop in May. The pattern of calving seen in 2007 was likely to be a consequence of many farms abandoning an annuals calving pattern and using longer lactations than previously was the norm.

Discussion

These data show a steady increase in lactation length of about 50 days between 1990 and 2007, as measured by the day of the last test day. This probably underestimated lactation length by about 15 days. Apart from heifers, which have a longer lactation by a week, all other ages of cow had similar lactation lengths. There was considerable

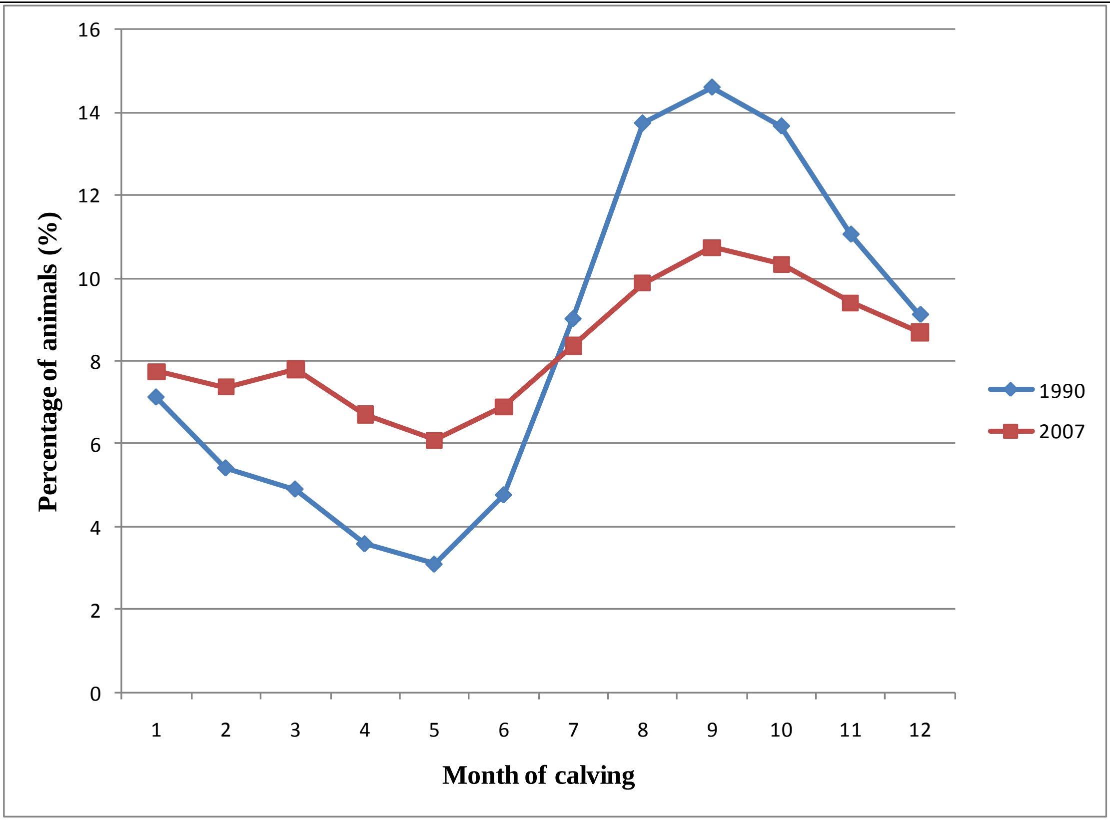

Figure 3.9. *The proportion of annual calvings in 1990 and 2007 by month of calving.*

between-herd variation in mean lactation length with herd ranging from just over 300 days to over 500 days. There was also a range in the SD of lactation length of herd/year groups. A large group of herds was found to have a high mean lactation length but a moderate to low level of within-herd SD. This implies that a number of farmers are managing their herds for long lactations. The increase in lactation length inevitably led to a changed pattern of calvings throughout the year.

Objectives 4 and 5.

Determine whether or not the current output of milk in the UK could be sustained through the adoption of extended lactations in the national dairy herd, and if so what size of milking cow and herd replacement population would result, if the current levels of dairy cow fertility and longevity are maintained.

Determine the potential impact on greenhouse gas emissions from the dairy sector of the adoption by dairy farmers of extended lactations.

The approach taken in this section was to firstly to analyse data from UK dairy herds to define the characteristics of the current production scenario. These results were then used to model new scenarios based on the use of extended lactations and the GHGE calculated for each scenario. This was then translated into results at the national level using the national inventory.

The research carried out as part of this project to define the lactation curve characteristics of UK dairy herds is shown in Appendix 3. The datasets used in the modelling work derived in this way are shown in Appendix Tables A1 to A4.

Modelling Greenhouse Gas Emissions from Alternative Lactation Lengths

Introduction
Livestock systems play an important role in food production, as well as in the provision of public good objectives including biodiversity and landscape value, which are jointly produced with conventional outputs. However, agriculture also generates external costs or negative public goods; specifically, diffuse pollution to air and water. Mitigating greenhouse gas emissions from livestock is increasingly recognised as a necessary part of the UK's overall climate change obligations. Under its Climate Change Act of 2008, the UK Government is committed to ambitious targets for reducing national emissions by 80% of 1990 levels by 2050

There are many possible technical mitigation options for livestock systems. These could be delivered through improved livestock and livestock system efficiency - converting more energy into product output, thereby reducing GHGE per unit product. The aim of this part of the project is to examine the impact of extended lactations on system greenhouse gas emissions.

There are many models which aim to calculate greenhouse gases for agriculture. These include simple animal emissions factors (e.g., Tier I techniques in IPCC guidelines), national inventory techniques (e.g., Choudrie *et al.*, 2010), carbon footprinting tools and lifecycle analysis (e.g., Williams *et al.*, 2006). However, most models differ in the way they calculate the emissions; what output data it provides and their level of detail and accuracy.

Currently, the national inventory of GHGE uses a simplified Tier II (IPCC, 1997) to calculate CH_4 emissions from the dairy herd. This involves calculating CH_4 emissions factors, due to enteric fermentation and manure, for a milking dairy animal based on UK production parameters (see description later). This one figure is then multiplied by the total number of animals in the dairy breeding herd. This method does not account for variation between animals and systems, including differences in the length of the lactation. To overcome this, a more detailed methodology was applied to the calculation of GHGE from a dairy herd, including considering the N_2O emissions and CO_2 equivalent emissions due to animal diets.

Methodology
IPCC (2006) formulae were used as the basis for developing the greenhouse gas models. UK-specific energy coefficients and other parameters where available were put into the model moving it from Tier I (the lowest) methodology toward the higher Tier II and III. Only emissions that related directly to the stock were included. Emissions from capital, fuel, power etc. were assumed to remain constant regardless of changes in lactation length and were not included in this investigation as they were assumed to be insignificant. The carbon cost of the feed was based on data from the Cranfield LCA model (Williams *et al.*, 2006). In addition, the net annual carbon dioxide emissions from livestock were assumed to be zero in accordance with IPCC (2006).

The herd

The basic biological and herd parameters are given in Appendix Tables A5 and A6, most of which are based on the study of Stott *et al*. (2005), which involved a level of specialist and industry validation of the assumptions. These figures were chosen to provide a consistent set of figures thought representative of UK dairy farming practice.

The model parameters used by Stott et al (2005) and IPCC Tier II/III methodologies (IPCC, 2006) were used to model the CH_4 (enteric fermentation and manure management) and N_2O (manure management) emissions from the whole farm system (young stock and milking herd). Under IPCC framework N_2O emissions due to nitrogen excretion when cows are grazing should be reported in the agricultural soils of the inventory framework. This study, however, will include these emissions as it accounts for a large proportion of the total nitrogen excreted by the dairy system and therefore GHGE.

When examining the impact of alternative lactation lengths on overall system GHGE it was assumed that the overall annual herd yield would remain constant and that numbers of cows (and followers) would increase/decrease to maintain this overall yield. The following herd was described in terms of annual steps (i.e., 0 – 1 year old, 1 – 2 year old pregnant/non-pregnant). Results were then represented on an annualised scale. The model assumed that farmers wished to keep total annual herd output constant, rather than individual cow lactation output. Although total lactation output may be higher with longer lactations it may not always hold that annual outputs of alternative lactation lengths are constant.

It was assumed that dairy cattle spent half the year indoors (Appendix Table A6). Therefore it was assumed that their maintenance energy requirements did not have to increase to account for the cold winter temperatures. Dairy cattle were assumed to be exposed to 'Cool' annual average temperatures (10-14 ºC) for the purposes of quantifying the manure management coefficient. This meant that manure management coefficient for dairy cows at grass was 1.5%. For cattle which had their slurry managed from indoor housing this coefficient was averaged at 17% to represent the average values for the range of slurry management systems on dairy farms (see manure management section).

Management

Feed digestibility (a measure of feed quality) is an influential factor in determining the productivity and efficiency of farming ruminants (Russell *et al.*, 1971). It can also have a significant bearing on methane emissions (IPCC, 2006). For example a 10% error in estimating feed digestibility can cause a 12-20% error in methane emissions (IPCC, 2006). The digestibility values for dairy cattle on concentrates and on pasture were therefore set in the models as the upper limits of the IPCC (2006) recommendations. Concentrate feed and lowland pasture digestibilities were set to 85% and 75% respectively.

It was assumed that the dairy cows were grazed for approximately half the year on lowland pastures. Cows were maintained indoors on a mixed diet of grass silage and concentrates for the remainder of the year. The followers were assumed to follow a similar management system. The average crude protein percentage in the annual diet was 18%. The annual average for pasture quality was 18.45 MJGE/kg DM following recommendations by IPCC (2006) that the feed energy value was 'relatively constant' (at 18.45 MJGE/kg DM) across a wide range of forage and grain-based feeds commonly consumed by livestock'. The impact of the different diets, in terms of GHGE, was taken from the LCA study of Williams *et al*. (2006). Production data were based on the results derived previously in this study and are shown in Appendix Tables A1 to A4.

Emissions from manure storage and production at grass were estimated based on the days at grass and indoors of the model and assumptions on manure output and storage from IPCC and Prevention of Environmental Pollution from Agricultural Activity (PEPFAA, 2005). Greenhouse gases from manure were calculated based on volume produced from each of the livestock categories kept on the farm (e.g., dairy cows and followers).

Results

Results from the analysis of lactations of different lengths from national data were used to parameterise the model of dairy system GHGE. The main differences between the base scenario (as described in Appendix Table A6) and the alternative lactation lengths are given in Table 4.1.

Table 4.1. *Differences in the model assumptions for alternative lactation lengths.*

			Lactation length		
Model parameter	*Units*	*Base*	*305*	*370*	*440*
1st lact yld	kgs	7,750	7,300	8,650	10,250
2nd lact yld	kgs	8,605	8,400	9,700	11,500
3rd+ lact yld	kgs	8,973	8,760	10,100	12,000

Fat percent	%	3.8	3.77	3.77	3.8
Replacement rate	%	25.8	25	22	20
Calving interval	days	370	370	430	500
Days in milk	days	307	310	370	440

Running the model to produce the current level of milk output resulted in different herd structures for the four scenarios studied (Table 4.2). As lactation length increased all categories of animals decreased.

Table 4.2. *Herd structure results from the model assuming a replacement rate of 25.8%*

	Base (PLI)	*305-d*	*370-d*	*440-d*
Milking herd size	125	129	129	127
Non-pregnant followers	17	17	15	12
Pregnant followers	39	40	34	29
Female calves	56	58	49	42

Table 4.3. *Output from the GHG model of overall system emissions for alternative lactation lengths, assuming a replacement rate of 25.8%, quantifying the total volume of GHGE from alternative sources, expressed in t of CO_2e.*

	Base (PLI assumpt^{ns})		*305-d*		*370-d*		*440-d*	
	Grass	*Indoors*	*Grass*	*Indoors*	*Grass*	*Indoors*	*Grass*	*Indoors*
Enteric CH_4 young stock	70.00	50.73	72.39	52.46	61.47	44.54	51.79	37.53
Enteric CH_4 milking herd	250.65	196.57	252.97	198.05	248.89	247.65	243.62	302.93
Manure CH_4 young stock	1.89	16.06	1.96	16.61	1.66	14.10	1.40	11.88
Manure CH_4 milking herd	9.04	82.88	9.12	83.50	8.97	104.41	8.78	127.72
N_2O young stock	14.61	3.64	15.11	3.76	12.83	3.19	10.81	2.69
N_2O milking herd	61.90	15.41	64.02	15.94	64.03	15.94	62.74	15.62
CO_2e feed young stock	42.30	46.92	43.75	48.53	37.15	41.21	31.30	34.72
CO_2e feed milking herd	151.48	181.84	152.88	183.21	150.41	229.09	147.23	280.23
TOTAL/yr t CO_2e		1,195.90		1,214.25		1,285.54		1,371.02

Results in Table 4.3 show that as lactation length increases the overall annual GHGE increase. Although there is a reduction in the number of follower animals when a dairy herd has a longer lactation length, given the data from the national herd, the overall milking herd numbers need to increase to maintain overall yield. Figure 4.5 shows that as lactation length increases the proportion of the total herd emissions that comes from the follower animals decreases. About 10% of total system emissions come from enteric fermentation from the followers in the herd in the base scenario. This decreases to 6.5% when average lactation length is 440 days. However, as lactation length increases the proportion of GHGE from milking herd enteric fermentation increases from 37.4% in the base scenario to 39.9% when lactation length is 440 days.

Table 4.4 shows that overall system GHGE for the differing lactation lengths with different replacement rates. This shows that as the replacement rate increases the overall system emissions increases. This is as a result of requiring more replacement animals to meet the requirements for new cows entering the milking herd. However, the overall increase in emissions with increasing replacement rates is relatively small, increasing approximately 0.5% when replacement rate changes from 20% to 25%

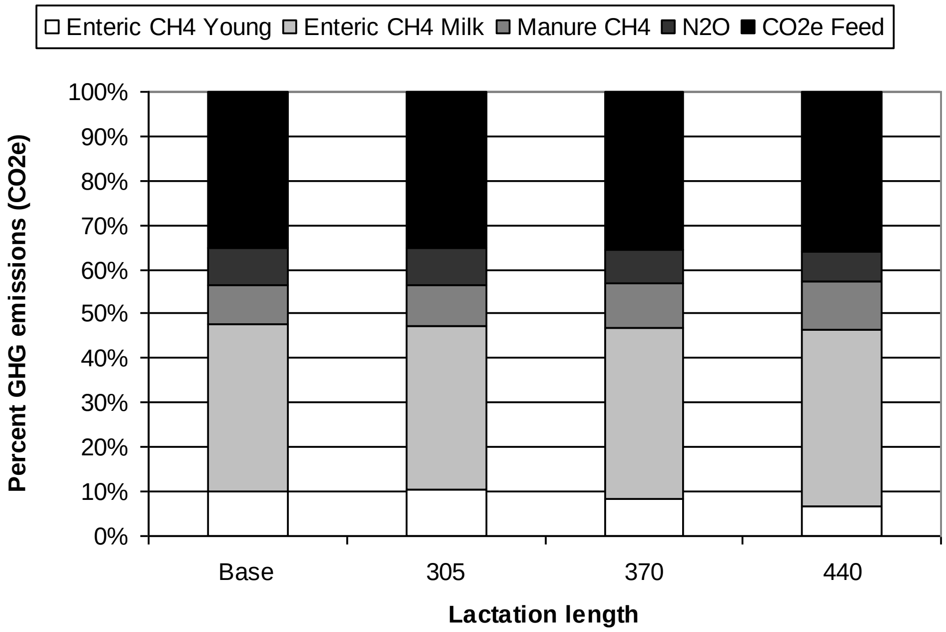

Figure 4.1. *Distribution of GHGE from dairy systems with different average lactation lengths, expressed as a proportion of the total emissions in CO_2e.*

Table 4.4. *Overall system GHGE for herds with different lactation lengths (base, 305d, 370d and 440d) and different replacement rates (Base, 20%, 22% and 25%) expressed in t of CO_2e.*

	£PLI (25.8%)	*20*	*22*	*25*
Base	1195.90	1188.59	1191.05	1194.88
305	1214.25	1211.96	1211.96	1211.96
370	1285.54	1294.66	1297.44	1301.76
440	1371.02	1380.74	1383.68	1388.26

Sensitivity analysis

Further to the examination of the mean results for the alternative lactations and interaction with replacement rates an additional study of the sensitivity to the results to differing assumptions within lactation length class was explored.

Firstly, the impact of lactation persistency was investigated by altering the persistency level of the representative lactation curve for each lactation class, as detailed above and shown in Appendix Tables A1 to A4. The results show (Table 4.5) that altering the persistency of the lactation curve has a minor impact on the overall GHGE from a dairy system producing a fixed annual yield. Improving the persistency of lactation by 10% reduced the GHGE from the dairy system by 1% for cows with lactation length of 440 days and by 3% for cows with lactation lengths of 305 and 370 days. Increasing persistency by 20% decreased the GHGE by approximately 3.3% for cows with lactation length of 440 days and 4.5% for cows with lactation lengths 305 and 370 days. Reducing the persistency of the lactation curve by 10% resulted in a small increase in overall system emissions of less than 1% for cows with lactation length 305 and 370 days. However, decreasing the persistency of a cow lactating for 440 days increased system emissions by 3.8%

Table 4.5. *Total herd GHGE from alternative lactation lengths with better/worse persistency levels, expressed in t of CO_2e/year.*

	Change in persistency			
	From Table 4.3	*-10%*	*+10%*	*+20%*
305	1214.25	1220.82	1181.83	1163.61
370	1285.54	1301.20	1252.38	1229.91
440	1371.02	1436.09	1369.05	1338.79

There was also variation in the total lactation yield within each of the lactation lengths. The second sensitivity study examined the impact of this variation of total lactation yield on the predicted system emissions. This was done by modelling the overall system emissions, at fixed annual milk volume output, of the top and bottom 10% yield cows in each of the lactation length categories. Table 4.6 shows that the 10^{th} and 90^{th} percentile for overall lactation yield, within lactation length, was wide. However, the fat % for higher yielding cows was always lower in the top yielding lactations compared to the lower yielding lactations, averaging at 4.18% for lower yields and 3.71% for higher yields. This would suggest that, although herd milk volume could be maintained with far fewer cows for the higher yields that overall milk solids, as represented by fat %, would be reduced.

Table 4.6. *Total herd GHGE (t of CO_2e/year) and number of cows in the milking herd from the top and bottom 10% yields for alternative lactation lengths*

	Bottom 10%				*Top 10%*			
Lact^n length	*Lact^n milk yld*	*Fat%*	*t CO_2e/yr*	*Cow No.*	*Lact^n milk yld*	*Fat%*	*t CO_2e/yr*	*Cow No*
305	6,044	4.17	1,512.18	177	13,673	3.58	912.69	78
370	6,586	4.23	1,660.98	189	14,070	3.73	1,037.98	89
440	8,652	4.14	1,642.68	167	14,867	3.83	1,196.00	97

The results show that for lower yields the GHGE from the system in a year increases significantly (compared to Table 4.3). For the lower yields within lactation class it is expected that overall emissions would increase by between 19% (440 days) and 29% (370 days). This is largely as a result of the increase in milking cow numbers, and the subsequent followers, required to maintain overall herd output. For the higher yields within lactation lengths it is expected that overall system emissions would decrease by between 14% (440 days) and 25% (305 days). This is also due to the change, in this case decrease, in the size of the milking herd to maintain the total annual milk output. It should be noted that the percentiles examined here are the extremes of the yield distributions within lactation length and that they are the exception rather than the norm. To achieve yields such as these would take a number of generations of genetic selection. Other options to achieve such yield improvements, via nutritional or management interventions, would not only have financial implications but also likely to have an emissions cost in their own right.

Impact in terms of national emissions

The national reporting of GHGE from dairy cattle is based on guidelines and equations set out by IPCC (1997). The reporting mechanism means that there is limited scope to separate out the CH_4 and N_2O emissions and fully attributed them to dairy cattle production. For example, all young dairy cattle stock are grouped with beef cattle stock. For the purposes of clear comparisons, this section will focus on the methane due to enteric fermentation and manure in milking dairy cows only.

Emissions are calculated from animal population data (Table 4.7) collected in the June Agricultural Census and published in Defra (2009) and the appropriate emission factors (Table 4.8). The dairy cattle emission factors are estimated following the IPCC Tier 2 procedure (IPCC, 1997) and vary from year to year. The base data and emission factors for cattle for 2003-2008 are given in Table 4.8.

Table 4.7. *Livestock population data and methane emissions factors for 2008 by animal type as used in the National GHG Inventory reporting*

Animal type	*Number*	*Enteric methane kg CH_4/head/year*	*Methane from manures kg CH_4/head/year*
Dairy Breeding Herd	1,908,945	108.9	26.8
Beef and others >1 year old [1]	5,361,344	48	6
Other cattle < 1yr	2,836,696	32.8	2.96

[1] Beef and others >1 year old include dairy heifers, beef heifers, others>2 and others 1-2 years old.

Table 4.8. *Dairy cattle methane emission factors*

Year	*Average Weight of cow (kg)*	*Average Rate of Milk Production (litre/d)*	*Average Fat Content (%)*	*Enteric Emission Factor (kg CH_4/head/y*	*Manure Emission Factor (kg CH_4/head/y)*
2003	467	18.3	3.96	94.8	23.3
2004	495	18.2	4.00	96.5	23.7
2005	714	18.8	4.02	111.6	27.4
2006	641	18.7	4.04	107.2	26.3
2007	652	19.1	4.06	109.5	26.9
2008	644	19.3	4.06	108.9	26.8

NOTES: 46% of animals graze on good quality pasture, rest confined
Gestation period 281 days; Digestible energy 74%; Methane conversion rate 6%;
Ash content of manure 8%; Methane producing capacity of manure 0.24 m^3/kg VS

Table 4.9 shows that the methane emissions factor (enteric fermentation and manure) does vary when recalculated for cows with different lactation lengths. The emissions factors in all scenarios studied are higher than those currently used in the UK inventory. This does not reflect a real difference in the emissions from these dairy cows but rather highlights how the different calculations and presentation methods could result in different messages in the overall GHGE from a dairy system.

The methane emissions factors for the alternative lactation lengths could be applied to the national reporting framework if the total numbers of cows in each class of the lactation length (and/or replacement rate) was know. This highlights how inventory reporting mechanisms could be easily updated to consider a wider range of animals if more details were used, as opposed to total census numbers only.

Table 4.9. *Derived dairy cattle methane emission factors for cows with different lactation lengths.*

Lact^n length	*Weight of cow at 1st calving (kg)*	*Average Rate of Milk Production (litre/d)*	*Average Fat Content (%)*	*Enteric Emission Factor (kg CH_4/head/y*	*Manure Emission Factor (kg CH_4/head/y)*
Base	540	Lact 1 = 25.2	3.8	143.1	29.4

		Lact 2 = 28.0 Lact 3+ = 29.2			
305	540	Lact 1 = 23.5 Lact 2 = 27.1 Lact 3+ = 28.3	3.77	139.9	28.7
370	540	Lact 1 = 23.4 Lact 2 = 26.2 Lact 3+ = 27.3	3.77	154	35.2
440	540	Lact 1 = 23.3 Lact 2 = 26.1 Lact 3+ = 27.3	3.8	172.1	43

Table 4.10 describes the proportion of milk recorded cows that could be assigned to the 3 different lactation lengths based on the number of milk recorded cows. To allow for a fair comparison the total volume of methane produced under a methodology akin to the current inventory was calculated based on the emissions factors estimated from the base scenario in this study, as opposed to values currently used in the national inventory reporting. Assuming the base scenario, when cows were not subdivided into different lactation lengths the overall methane emissions from the milking (breeding) dairy herd was 329 Gt CH_4 per annum. The proportions of the cows in each lactation class were based on the numbers of milk recorded cows in each lactation length class. Assuming that the proportion of milk recorded cows in each lactation length is representative of the entire milking herd then the methane emissions attributable to the milking herd would be estimated to be 365 Gt CH_4 per annum, 11% higher than the estimate when cows are not subdivided by lactation length. The impact of increasing the proportion of cows in shorter/longer lactations was also shown to affect the estimation of GHGE. Such an approach could help to highlight how inventory methodologies could be adapted to present estimates of emissions on a finer, and more accurate, level.

Table 4.10. Derived dairy cattle methane emission factors for cows with different lactation lengths.

	Number of cows	*Enteric ferment^n (Gt CH_4/y)*	*Manure (Gt CH_4/y)*
Base (no lactation length information)	1,908,945	273.17	56.12
2008 (cows split into lactation lengths*)	305d = 645,274	90.27	18.52
	370d = 613,385	94.46	21.59
	440d = 650,286	<u>111.91</u>	<u>27.96</u>
		296.65	68.07
Increasing proportion in shorter lactations by 10%	305d = 1,095,925	153.32	31.45
	370d = 441,468	67.99	15.54
	440d = 371,552	<u>63.94</u>	<u>15.98</u>
		285.25	62.97
Increasing proportion in longer lactations by 10%	305d = 202303	28.30	5.81
	370d = 1294944	199.42	45.58
	440d = 411697	<u>70.85</u>	<u>17.70</u>
		298.58	69.09

305d = less then 345d; 370d = 346d – 405d; 440 = greater than 406d

Objective 6.

Examine research and industry data into extended lactations to identify any negative impacts that they might have on other aspects of milk production e.g. seasonality payments, lower milk price due to higher somatic cell counts.

A number of aspects of extended lactations which could be viewed as having negative impacts have been mentioned by several authors. These are discussed here.

Milk composition
There was a link found between lower daily milk yields and higher fat and protein content. This was not a new piece of information since the pattern of fat and protein proportion during lactation has been known for a long time. This relationship was illustrated in Figure 1.2 showing an initial fall followed by a continual rise as lactation progressed. Our analysis of test-day yields showed that there was a linear relationship between milk yield and fat % (F% = 4.925 – 0.0372 MY) and this is reflected in Figure 1.2 (from Kolver *et al.*, 2007) when falling milk yield was halted at turnout and fat% dropped for a while. The extended –lactation period (> 12 mo into lactation) was characterised by falling milk production, the rate depending on persistency of the lactation, and so was also characterised by increasing fat and protein %. In situations where payment for milk was based on one or both of these measures then there may be a negative effect on profitability depending on the particular penalties imposed. However, the overall effect of using extended lactations on fat% was small, as shown in Table 4.1.

Somatic cell count
Log somatic cell count values show a very similar pattern throughout lactation to that of fat and protein %. Appendix 3, Figure 4.7 demonstrated an initial fall followed by a rise from about day 60 of lactation. This rise continued until the end of lactation. Once again payments based on somatic cell count may have an effect on the profitability of milk production but the overall effect is likely to be small, since the rise in SCC in late lactation is not a major contributor over the total length of the lactation. Bertilsson *et al.* (1997) suggested that this rise was not due to an increase in mastitis but the normal erosion of mammary cells as lactation progressed.

Casein content
Sorensen *et al.* (2008) commented on the reduced casein content of late-lactation milk from cows with lower milk yields. A higher casein content is required for successful processing of the milk into cheese, fermented products, heat-treated products and cream liqueurs. This effect was not found from more persistent lactations and so was not associated with higher-yielding animals.

Saltier taste
The Swedish work reviewed earlier suggested that there was a slightly saltier taste associated with milk produced from very low daily yields. This is unlikely to become a major negative factor since dilution of this milk by that from all other parts of the lactation in the bulk tank will make it undetectable.

Gaps in knowledge
Although this research project has used a considerable amount of information associated with extended lactations very little of it has come from commercial UK herds managed to achieve 18-month calving intervals. In this sense there are huge knowledge gaps on the use of extended lactations. However, persistency is a key feature of extended lactations and all animals evaluated as part of the national genetic evaluations could have a persistency EBV. Critical features of extended lactations that need more research include fertility and longevity of cows involved in extended lactations, particularly if the move towards higher milk yields is seen as the way to

reduce GHGE from the dairy sector. The combination of higher yields and longer lactations will highlight conception rate as a more critical fertility trait, rather than calving interval. By removing the imperative to get cows back into calf as soon as possible after calving then culling for poor fertility may be reduced and so longevity may increase.

An economic assessment of extended lactations based on real UK data is also required so that producers have some idea of the real costs of moving to extended lactations. This assessment will need to take into account the effects of different levels of milk yield and persistency.

Final discussion and conclusions

The objective of this research was to see if the use of extended lactations in the UK dairy industry would lead to a reduction in greenhouse gas emissions and also have any negative effects which may need to be considered. The approach to this project was to use a model of the 'average' UK dairy farm and to investigate the GHGE changes likely under a range of extended lactation scenarios, the inputs to the model being based on a review of the literature and an analysis of records from UK dairy farms. This is the first time that extended lactations have been investigated as a means of reducing GHGE.

The starting point to discuss the results is Table 4.2 which compares the GHGE from the current 'PLI' base herd and herds having 305-d, 370-d and 440-d lactations, all having lactations characteristics based on results from analysing performance recorded herds. This comparison suggested that a herd based on extended lactations (440-d lactation length) would have increased GHGE compared to the other 3 scenarios, some 14% more than the base scenario. These comparisons were made on the basis that the current annual milk yield, fertility and longevity within the herd were maintained. The extended lactation scenario resulted in a larger dairy herd and fewer followers but the reduced emissions from the followers were far outweighed by the increase in emissions from the milking herd. The increase in cow numbers was due to the constraint that milk output should remain the same. Since milk yield in the last 6 months of the extended lactation was relatively low, compared to the first 12 months, then more cows are required to maintain annual output. These extra cows contribute to the increased GHGE and the milk produced during the last 6 months of an extended lactation is the least efficient production, in terms of GHGE.

Alternative scenarios were investigated to see how GHGE changed with a change in lactation persistency or a shift in the lactation curve. Improving persistency by 10 or 20% resulted in reduced GHGE but this reduction was not enough to bring the extended lactation emissions back to the base scenario levels (Table 4.4). If herds using extended lactations reached the level of performance in the top 10% of herds then their GHGE would be the same as the current base herd scenario. The level of milk yield in such herds was 14,867 kg per lactation and cow numbers were reduced from 127 to 97 in such a scenario.

Several authors suggested that the use of extended lactations may lead to greater longevity in dairy cows. Greater longevity would be reflected in lower replacement rates so alternative scenarios were modelled looking at a range of replacement rates (Table 4.3). Reduced replacement rates resulted in lower levels of GHGE but the change was relatively small and herds using extended lactations would still have higher levels of GHGE than the current base scenario.

The current research has found that a change from the current lactation length to an extended lactation of ~450 days is unlikely to lead to a reduction in GHGE. Both improved persistency and longevity do have an effect to reduce GHGE in longer lactations but their ability to make substantial inroads into GHGE is small. The modelling work carried out in this study indicates that increased milk yield is the most likely method by which GHGE can be reduced for any given level of output from the UK dairy herd. Substantial increases in yield have been achieved over recent years and this has been linked to reduced fertility and longer lactations. Recent studies have shown that continuing reduced fertility as milk yield increase is not inevitable and UK, Ireland and USA have all demonstrated a halt to declining fertility in recent years, by positive selection for increased fertility. Selection for higher yields will result in reduced persistency unless a positive move to select for increased persistency is incorporated in selection programmes. This may be achieved using the parameters already calculated as part of the national genetic evaluation process or by using parameters such as the relative rate of cell death which arise from applying a biological model to lactation analysis. Increased yields could also be achieved by moving to three-times-per-day milking.

Although the prime objective of this project was to estimate the effect of moving to extended lactations on GHGE from the UK dairy herd there are a number of other interesting side-effects from extended lactations. These include the possibility of using a more welfare-friendly system having improved animal health, less culling from health and fertility related problems and hence greater longevity, and the possibility of no loss in economic returns. Of course all these aspects require more research but they may prove to be useful incentives for future research on extended lactations.

All the project objectives have been met.

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