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Title: **The Association between Age at First Calving and Survival of First Lactation Heifers within Dairy Herds**.

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Short Title: Survival of dairy heifers

Abstract:

The objective of this research was to evaluate the survival rate of primiparous heifers within a large sample of herds across the UK and specifically to assess the association between age at first calving (AFC) on their survival. Data from 437 herds was re-structured for analysis. Descriptive statistics were calculated, and a multilevel logistic regression model used to explore factors associated with the risk of first lactation culling. Potential explanatory variables included AFC, herd size, culling rate within the whole herd, calving season, herd mean 305d yield and herd mean calving interval. The mean within-herd culling rate for the primiparous heifers was 15.9%. The mean within-herd AFC was 29.6 months, with 35.9% of heifers having an AFC greater than 30 months of age. Multivariable analysis revealed a negative association between survival rate of primiparous heifers and increasing AFC, and also associations with herd culling rate in older cows and calving season. This study highlights the importance of AFC for survival of primiparous heifers, as well the need to address heifer wastage in herds with high culling rates.

Keywords: Age at first calving, heifers, longevity, culling

Implications:

This study has identified that culling rate of primiparous heifers during first lactation varies greatly between farms and that the age of first calving (AFC) has a significant association with this. The study highlights the importance of maintaining an AFC of 23 to 24 months of age because prolonged AFC leads to a greater wastage of primiparous heifers with associated financial losses.

Introduction:

Heifer rearing is a key financial component of most dairy farms, with the rearing of replacements accounting for 15-20% of total dairy production costs (Heinrichs 1993). The importance of replacement rate and the target number of replacements for each individual farm is dependent upon the culling rate of that particular farm. The annual culling rate within UK dairy herds has previously been reported to be between 22 and 25% (Esslemont & Kossaibati 1997; Bell *et al*. 2010; Whitaker *et al*. 2000). Culls have traditionally been classified as voluntary or involuntary; however another classification is “forced culls” and “economic culls”. Forced culls are those cows for which no possible productive future exists and economic culls are those cows for which a decision has been made that replacing them with another cow is a sensible economic option (Fetrow *et al*. 2006). Since the majority of the culls on farm are economic (Orpin & Esslemont 2010), this indicates that the incoming replacement animal needs to be a better financial option for the farm. Previous research highlights that the costs of rearing a replacement are not recovered until the second lactation (Archer *et al*. 2013), therefore it is imperative that replacement heifers survive to their second lactation.

A variety of studies have recently investigated the survival rates of primiparous heifers. A study in Spain reported that 8.4% of 7768 Holstein heifers born alive did

not finish the first lactation, with 31.5% (n=206) of the non-surviving heifers exiting within the first 50 days in milk (DIM) (Bach 2011). These heifers were all reared externally from the main dairies at one heifer rearing unit, under the same management system. In a study in the UK on 18 farms, which followed a cohort of 468 Holstein-Friesian heifers (Brickell & Wathes 2011), 19% (n=79) of heifers that calved for the first time (n=415) did not survive to the end of first lactation, equivalent to 28.2% (n= 132 heifers) of all heifers born (n=468 heifers). In terms of between herd variation, there was a range of 7 to 33% heifer loss during 1st lactation between farms. These findings were similar to those in 26 English herds in 1999, with a loss of 14% in the first lactation (Esslemont & Kossaibati 1997). Therefore survival of heifers through their first lactation is important, but there have only been a few large scale studies in the UK and worldwide to evaluate this.

Research has highlighted the impact of age of first calving (AFC) on production and health indices (Hoffman *et al*. 1996; Berry & Cromie 2009; Nilforooshan & Edriss 2004). Impact of AFC on survival has been extensively studied, with a number of trials finding that lower AFC was associated with increased survival (Lin *et al*. 1988; Archer *et al*. 2013; Brickell & Wathes 2011; Bach 2011), whilst a large number of other workers failed to demonstration such a link (Ducrocq 1994; Ojango *et al*. 2005). These studies were all either based on small numbers of farms, or were conducted in farming systems very different to those typical in the UK, making it difficult to put these findings into context of the performance of UK first lactation heifers. Therefore the objective of this study was to evaluate the survival rate of 1st lactation animals in a large sample of UK dairy herds and to evaluate the impact that age of first calving (AFC) had on survival.

Materials and Methods:

Data Collection and Organisation

Herd-management data were collected as part of a larger project (Hudson *et al*. 2012), with anonymized herd databases being requested from 20 veterinary surgeons across England and Wales, with an acknowledged interest in dairy herd health management and data analysis. Data came from a variety of sources, including on-farm recording software, veterinary practice bureau-recording services and records of national milk recording organisations. Although not a probabilistic sampling method, this convenience sample was used because high-quality data were essential for the analyses.

The data were extracted for all animals calving between 1st January 2008 and 31st December 2008, from 468 dairy herds across the UK. Data quality was assessed at both an individual cow and herd level, with removal of animals lacking a date of birth (n=25,749) and those without a calving date (n=15). Herds which contained no 1st lactation animals (n=25 herds) and herds without any 305 day yield information (n= 5 herds) were removed. The resulting dataset was from 437 herds with a total of 73,227 animals, of which 18,406 were first lactation heifers. A binary indicator representing culling during first lactation was calculated for each cow, along with DIM at time of culling, calving interval and AFC. At herd level, mean 305d yield, herd size, calving index and culling rate was calculated for each herd. Data restructuring was carried out in Microsoft Excel 2010 and Microsoft Access 2010 (Microsoft Corporation, Redmond, WA).

Descriptive Analysis

Initial analysis was carried out to evaluate general herd features and performance of primiparous heifers within individual herds. In order to evaluate the patterns of times of removal of first lactation animals, conventional survival analysis was performed, using Kaplan-Meier curves (Kaplan & Meier 1958). The adult herd culling rate was defined as the number of cows equal to or above 2 lactations that exited the herd before their next calving. The primiparous heifer herd culling rate was defined as the number of animals that calved for the first time during 2008 and exited the herd before their next calving. The definition of exiting the herd before their next calving was either the animal exiting the herd before the next calving (n=17 404) or the animal having not re-calved for a minimum of 760 days at the end of the study period (n=139). The overall herd culling rate was defined as the number of animals, of all parities, that calved in 2008 and did not calve again. Descriptive statistics were calculated out in Minitab 17 Statistical Software (Minitab Inc. 2013).

Statistical Modelling

A multilevel logistic regression model was used to evaluate the association between the probability of a first lactation heifer exiting the herd prior to the second lactation (i.e. failing to calve for a second time) and a variety of potential explanatory variables. These included AFC, calving season, adult herd culling rate, herd size, herd mean 305d yield and herd mean calving interval. A 2-level hierarchical model was used to account for correlations between primiparous heifers within herds.

The model specification took the form:

$$\text{Exit Herd}_{ij} \sim \text{Bernoulli}\ (\pi_{ij})$$

$$(\text{logit}= \pi_{ij}) = \alpha + \beta_1 X_{ij} + \beta_2 X_j + u_j$$

$$[u_j] \sim N\ (0, \Omega_u)$$

where subscripts i and j denoted the ith primiparous heifer of the jth herd, respectively. π_{ij} was the probability of a heifer exiting before the start of her 2nd lactation for the ith heifer of the jth herd, α the intercept value and X_{ij} and X_j were explanatory covariates at heifer and herd levels respectively, with β_1 and β_2 being the corresponding coefficients for covariates X_{ij} and X_j respectively. u_j was the random effect to account for residual variation between herds (assumed to be normally distributed with mean = 0 and variance = σ^2_v)

Model building was carried out in MLwiN version 2.31 (Rabash, 2012). Initial model building was performed by forward selection and explanatory variables were retained in the model if deemed significant ($P<0.05$).

Results

Descriptive statistics

The number of animals that calved during 2008 in each herd varied between 25 and 848, with the mean number per herd being 168 (median: 144). The mean percentage of 1st lactation heifers calving in the herd was 24.3% (median: 23.9%), with an inter-quartile range of 18.5% to 30%. The distribution of the percentage of primiparous heifers by herd is illustrated in Figure 1. The mean herd mean calving interval was 412 days (median: 410 days) and the mean herd 305d milk yield was 7,204kg (median: 7,400kg).

146 *Primiparous heifer performance.* Of the18,406 first lactation heifers within 437 herds,
147 15,296 animals calved for a second time (83.1%). The mean AFC was 29.6 months,
148 with a median of 28.0 months, indicating that 50.1% of heifers calved for the first time
149 at ≥28 months of age. 35.9% calved for the first time older than 30 months of age,
150 and 9.8% older than 36 months of age; the distribution of AFC is shown in Figure 2.
151
152 The mean calving interval of the 15,296 heifers that re-calved was 409 days (median
153 385 days), which was similar to a mean calving interval of 410 days (median 389
154 days) for animals in lactation 2 and above, shown in Figure 3. Ten percent of the
155 primiparous heifers had calving intervals <330 days and 53% of the heifers had
156 calving intervals >380 days. A third of primiparous heifers had a calving interval
157 greater than 420 days. Of the heifers calving in for the first time, the largest
158 proportion (33.6%) calved in autumn (September-November) and the smallest
159 proportion (18.0%) calved in spring (March-May). Twenty two percent calved in
160 winter (December-February) and 26.5% in summer (June-August).
161
162 A total of 16.9% of all of the primiparous heifers were culled prior to second lactation,
163 which was lower than the 36.0% of adult cows (lactation two and above) that were
164 culled. The overall herd cull rate across all of the herds was 31.5%, with 17,534
165 animals being culled prior to their next lactation. The primiparous heifer herd culling
166 rate was 15.7% on average (median 14.3%); the distribution is shown in Figure 4.
167
168 Survival analysis indicated that of those primiparous heifers culled, 31% were culled
169 before 100 DIM (n=955), which was 5% of all primiparous heifers. This cull rate

slowed to 14% (2% of all heifers) between 100 days to 400 days after calving as shown in Figure 5.

When stratified by AFC, primiparous heifer survival times were reduced as AFC increased (Figure 6). Heifers that calved between 23-24 months of age were most likely to calve for a 2nd time and those that calved >30 months were least likely to calve again. Also of note, there appeared to be a more rapid culling rate between 50 to 150 days after calving for heifers with an AFC >30 months.

Statistical Model

The results of the final model are shown in Table 1. The odds of a heifers calving for a second time was significantly associated with AFC, season of calving and adult herd culling rate as follows. The optimal AFC was 23-24 months of age and the risk of culling increased with increased AFC; the odds of being culled were 1.71 times greater for heifers calving over 30 months of age compared with those calving at 23-24 months ($P<0.05$). The risk of a primiparous heifer being culled increased with the adult herd culling rate, but decreased in summer, when compared to the other seasons (Table 1).

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Discussion

Although the mean culling rate for 1st lactation heifers was 16.9%, there was large variation between the 437 herds. For individual heifers, the likelihood of calving for a second time was associated with AFC, overall herd cull rate and calving season.

Increased AFC over 24 months of age was found to be significantly associated with an increased risk of being culled during the 1st lactation. The impact of AFC on survival of animals has been debated in the literature with significant associations being found in some studies, but not in others (Vukasinovic *et al*. 2001; Vukasinovic *et al*. 1997; Ojango *et al*. 2005; Ducrocq 1994; Lin *et al*. 1988). Studies that have shown an impact of AFC on survival have reported that the relative risk of culling heifers is higher in animals older at first calving (Pirlo *et al*. 2000; Chirinos *et al*. 2015; Berry & Cromie 2009). A decrease in AFC from 27 months to 24 months of age was associated with a 10% reduction in the odds of removal from the herd (Archer *et al*. 2013). This is echoed in a recent study, where heifers with an AFC of 23-25 months of age outperform later calving compatriots in terms of fertility, milk production and survival for first 5 years of life (Cooke *et al.* 2013). The main reason discussed for removal of first lactation heifers from a herd is due to poor fertility performance (Brickell & Wathes 2011; Evans *et al*. 2006), with a high AFC being connected with worse fertility performance in the first lactation (Zavadilova, 2013). This current study indicates that AFC does have an impact on the odds of being culled during the first lactation.

The average AFC was slightly higher in this study (29.6 months) than previously reported 27 months for the UK in 2011(Brickell & Wathes 2011). This previously

reported AFC of 27 months was taken from a relatively small sample of 18 farms in the south east of England which had a target herd AFC of 24 months. A study in Ireland reported a lower mean AFC of 25.8 months; this was taken from 14 spring-calving herds (Evans *et al*. 2006). An Italian study identified a mean AFC at 28.1 months of age (Pirlo *et al*. 2000) taken from a large heifer dataset, but this dataset excluded all heifers calving <20 months of age and >36 months of age and therefore excluded older heifers. Other studies have also reported different average AFCs across the world (Bach 2011; Wu *et al*. 2012; Ettema & Santos 2004) and these studies have been based on either single or a few farms, limiting the exposure to different management systems and geographical regions. The current study represents one of the largest to date, but it remains uncertain as to whether this truly reflects the UK situation, because a convenience sample was used to ensure data of sufficient quality. However these findings are in argeement with a review article, which described larger datasets reporting a wide range in AFC within in UK herds (Wathes et al. 2014)

The culling rate of first lactation heifers was 16.9% in this study, with the distribution of within herd culling having a right-sided skew and showing a large variation between herds. This variation in culling rate between herds had an inter-quartile range of 7.1% to 21.7%; this was similar to the Brickell study, which reported a range of 7.1% to 33.3%. Large between herd variation was also reported by Archer *et al* in 2013, in a large dataset of Irish heifers. The mean culling rate in this study was 2.1% lower than that reported by a previous UK study in 2011 (Brickell & Wathes 2011) and 0.7% lower than a study in California (Ettema & Santos 2004). It would be extremely beneficial to better understand the reasons for the large between herd

variation in culling rates of first lactation heifers; such variation is likely to result in major differences in financial performance and welfare outcomes between herds. This remains an important area for future research.

The overall estimated herd culling rate was associated with the risk of a heifer being culled during the first lactation, with the risk increasing as the herd's overall culling rate increased. This association suggests there may be reasons within an individual farm's system for a generally increased culling rate across all lactations and that this affects primiparous heifers as well as older cows. Further studies to examine these reasons and relationships are warranted.

Another significant finding in this study was the association between season of calving and survival, with heifers calving in summer having higher odds (0.82) of re-calving. This differs to other studies (Bach 2011; Archer *et al*. 2013) that reported improved survival in different calving seasons. The reasons why calving season influences heifer survival differently in different studies are unclear and may warrant further investigation, however a possible reason could be related to differences in climate.

This study has highlighted the variation in culling rate of first lactation heifers across 437 herds in the UK. There was an association between decreasing survival of first lactation heifers and both an increasing AFC and an increasing culling rate of animals which were parity two and above. The results suggest that closer monitoring of heifer rearing practices is important, as well as the potential need to address reasons for high culling rates across all parities within UK herds.

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373 milk production traits in Czech Holsteins. Czech J. Anim. Sci., 58, 2013 (12): 554–565

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378 Tables:

379 Table 1 Parameter estimates from the final multilevel logistic regression model with
380 the binary outcome variable being a primiparous dairy heifer culled (yes or no) during
381 their first lactation. N/S = non-significant, AFC = age of first calving, Season = season
382 of the first calving date for the heifers, Herd Cull Rate = the estimated overall herd
383 cull rate.

Model Term	**Number**	**Odds Ratio**	**95% Confidence interval**	**P value**
AFC <23 months	626	1.12	0.87-1.28	N/S
AFC 23-24 months	2812		Reference	
AFC 25-26 months	3558	1.19	1.04-1.40	<0.05
AFC 27-28 months	2883	1.36	1.17-1.57	<0.05
AFC 29-30 months	2506	1.37	1.18-1.60	<0.05
AFC >30 months	6021	1.71	1.55-1.94	<0.05
Season: March-May	3305		Reference	
Season: June-August	4871	0.85	0.76-0.96	<0.05
Season: September-November	6178	0.94	0.84-1.19	N/S
Season: December-February	4052	0.96	0.85-1.08	N/S
Herd Cull Rate <15%	1274 (59 herds)		Reference	
Herd Cull Rate 16-18%	913 (54 herds)	1.46	1.13-1.91	<0.05

Herd Cull Rate 19-20%	1462 (39 herds)	1.13	0.89-1.44	N/S
Herd Cull Rate 21-22%	1405 (53 herds)	1.50	1.13-1.90	<0.05
Herd Cull Rate 23-24%	1838 (55 herds)	1.81	1.12-2.26	<0.05
Herd Cull Rate 25-26%	2218 (41 herds)	1.51	1.21-1.88	<0.05
Herd Cull Rate 27-30%	3709 (62 herds)	1.94	1.58-2.37	<0.05
Herd Cull Rate >30%	5580 (72 herds)	2.67	2.20-3.24	<0.05

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387 List of Figure Captions:

388 Figure 1: Histogram of the percentage of primiparous dairy heifers within the 437
389 herds

390 Figure 2: Distribution of the age of first calving (AFC) for primiparous dairy heifers
391 (n=18,406)

392 Figure 1: Herd average calving intervals for Lactation 1 animals versus Lactation 2
393 and above animals.

394 Figure 4: Histogram of the percentage of primiparous dairy heifers culled per herd

395 Figure 5: Kaplan-Meier survival plot for overall survival of primiparous dairy heifers

396 Figure 6: Kaplan-Meier Survival Plot of primiparous dairy heifers exiting the herd in
397 terms of age at first calving (AFC). AFC <23 months (n=626), AFC 23+24 months
398 (n=2812), AFC 25+26 months (n=3558), AFC 27 + 28 months (n=2883), AFC 29+30
399 months (n=2506), AFC >30months (n=6021).