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Sustainable dairy production systems: Factors affecting heifer survival, lifetime productivity and replacement rate.

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Abstract

Global per capita consumption of dairy products is set to rise 12.5% by 2025. Heifers make significant contributions to farm profitability and increasing the efficiency of heifer rearing can lead to significant improvements in whole farm productivity. This study used historical data to evaluate the influence of morbidity in the rearing period on age (AFC) and live weight at first calving (LWFC) and the effects of these parameters on lifetime performance. Records of 1,188 Holstein heifers born between 2006 and 2017 on a UK dairy farm were analysed for morbidity, mortality, AFC, LWFC, milk yield in first lactation, longevity and lifetime productivity. Overall rearing period mortality rate was 18.8%, with greater neonatal mortality observed in winter. Heifers that received 5 or more clinical treatments for morbidity exhibited a significantly greater AFC than heifers that received none. Mean AFC was 759d and mean LWFC 571 kg; only 12.1% of animals met the target AFC and LWFC and only 4.9% the target AFC and mature weight. Reduced milk yields were seen in animals calving at <700 days and <550 kg, however above these weight and age categories, no significant increases in yield were observed. Analysis of AFC and LWFC in combination revealed LWFC was a greater predictor of first lactation milk production. Proportion of life spent productive and lifetime DIM were greatest in heifers calving for the first time at <759d and <500 kg, who spent on average 50% of their life in a productive state compared to just 33% in the highest weight category. In summary, optimum lifetime performance was achieved with an AFC of 701 to 759 days, a LWFC of 551 to 600 kg and a proportion of mature weight of 79 to 81%, with these heifers ensuring a balance between productive life and milk yield in first lactation.

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List of Abbreviations

ADG = Average daily gain

AFB = Age at first breeding

AFC = Age at first calving

AI = Artificial insemination

ANOVA = Analysis of variance

AMS = Automatic milking stations

BW = Body weight

BCS = Body condition score

BRD = Bovine respiratory disease

CI = Calving interval

CP = Crude protein

DIM = Days in milk

ECM = Energy corrected milk

FC = First calving

FPT = Failure of passive transfer

IGF-1 = Insulin-like growth factor 1

KPI = Key performance indicator

LW = Live weight

LWFC = Live weight at first calving

MP = Metabolisable protein

PMR = Partial mixed ration

TMR = Total mixed ration

T4C = Time for cows

1.0 Introduction

1.1 Background:

Global per capita consumption of dairy products is set to rise 12.5% by 2025, driven by a predicted population growth of 1.1 billion and rapid increases in demand in developing countries (OECD, 2016). However, this increased consumption can represent a challenge in terms of limited agricultural land mass, with 80% of land currently required to grow cereals and oilseeds for livestock, conflicting with the need to grow food directly for human consumption (Alexandratos and Bruinsma, 2012). In recent years, farmers have also been encouraged to meet targets for sustainable agriculture, with the aim of protecting the natural environment and resources (Van Passel et al., 2007).

Dairy farming can have a significant environmental impact, contributing 4% of total anthropogenic greenhouse gas emissions and 30% of nitrogen excretion by livestock (Garnsworthy, 2004), with one of the main drivers of environmental pollution being production efficiency. Consequently, there is an urgent need to improve industry efficiency to achieve increased productivity, whilst promoting greater economic stability and minimising environmental damage.

Heifer rearing represents a substantial proportion of a dairy farm's total production costs, in some cases as much as a quarter (Wathes et al., 2008), and places a significant burden on farm resources including feed, housing and labour (Akins, 2016). In addition, the rearing period is often termed 'non-productive', as farmers see no return on the investment made pre-calving until at least the end of the first lactation, and no profit until the middle to end of second lactation (Bach, 2011). This makes future lifetime productivity of heifers critical in determining farm efficiency and profitability (Brickell and Wathes, 2011). Exacerbating the expense of heifer rearing is poor fertility of the dairy herd, with increased genetic selection for high-yielding cows over time being accompanied by a downward trend in fertility, decreasing the number of lactations per cow and increasing culling rate, with failure to conceive accounting for nearly one third of all culls in the UK (Brickell et al., 2009b). This higher culling rate and shorter herd lifespan increases the need for replacement heifers, whilst the reduction in fertility limits the ability to produce more, all of which act to significantly increase rearing costs and negatively impact farm profitability (Wathes et al., 2008). Concerningly, figures also show that many heifers don't make it to first calving due to mortality, poor conception or abortion and of those that do calve, almost a third fail to make it to second lactation (Wathes et al. 2008).

Determining the exact cost of the rearing period can be difficult, due to estimation being based on biological factors and the time lag that exists between input and output. There is also significant variability between different farm systems and many heifers are fed wastage from the dairy herd in their later growth stages, meaning it can be hard to attribute costs to heifers alone (Boulton et al., 2017). The difficulty of estimating heifer rearing costs on-farm means that under-estimation appears to be a trait that is ubiquitous in dairy farming globally, with a study into rearing costs on Dutch dairy farms finding that although the average estimated cost of rearing by farmers was €1,030, actual values were closer to €1,790 (Mohd Nor et al., 2015), indicating a significant disparity. Estimated values for the UK have also ranged between £1,000 and £1,500 (Promar International, 2011). A study by Boulton et al. in 2017 attempted to address the absence of reliable UK data on heifer rearing costs through a survey of 102 UK dairy farms, with their findings indicating an average cost of rearing of £1819.01 (Table 1), or on average £2.31/day per heifer. As expected, costs also varied hugely with rearing period and calving system, with all-year-round calving significantly increasing rearing costs.

Table 1: Cost of heifer rearing in each development period on 102 UK farms

Period	No. of farms studied	Cost per heifer		
		Minimum (£)	Maximum (£)	Mean (£)
Birth to weaning	102	94.64	499.80	195.19
Weaning to conception	101	295.32	1745.85	745.94
Conception to calving	101	153.11	784.00	450.36
Rearing*	101	1073.36	3070.46	1819.01

*Including variable and fixed costs, interest on capital, opportunity cost and cost of mortality.
Source: Adapted from Boulton et al. (2015)

1.2 Age and Liveweight at First Calving

One possible approach to decreasing the cost of heifer rearing is to reduce the proportion of time a heifer spends non-productive, by lowering the age at first calving (AFC) (Ettema and Santos, 2004; Cooke and Wathes 2014). Not only does this reduce the cost of the rearing period, with studies showing a strong positive relationship between AFC and total cost of rearing (Boulton et al., 2017), but AFC has also been shown to have a significant impact on lifetime productivity, fertility and longevity in dairy cows; increasing survival, decreasing calving interval and increasing

lifetime milk production (Wathes et al, 2008; Bach, 2011; Archer et al., 2013; Cooke and Wathes, 2014). Calving below the age of 23 months is thought to compromise milk production, alter milk composition and detrimentally effect calving interval and conception rates to first service (Ettema and Santos 2004). However, above the age of 25 months, no associated improvements in milk yield or fertility have been observed and it is therefore widely accepted that the optimal AFC, which produces the highest economic returns, is 22 to 24 months.

Liveweight at calving (LWFC) and average daily gain are also important factors determining milk production, fertility and longevity in dairy cows (Van Amburgh et al., 1998; Bach, 2011) and are strongly correlated with age at first calving, meaning it can often be hard to separate the effects of each (Mord Nohr et al., 2013). In spite of the relationship between these factors, previous studies appear to focus on the effects of either liveweight or age at calving (Haworth et al., 2008; Berry and Cromie, 2009; Cooke and Wathes, 2014), with very few evaluating the relationship between the two as a means of determining heifer performance.

Current recommendations suggest that a live weight at calving of 85 to 90% mature weight is appropriate for an AFC of 22-24 months (Mourits et al., 2000, Gabler and Heinrichs, 2003; Margerison and Downey, 2005; Van Amburgh and Meyer, 2005), meaning heifers must obtain a breeding weight of 55 to 60% of mature weight at 13 to 15 months of age (Table 2), requiring an average daily gain (ADG) of roughly 0.8 to 0.9kg/day (Mclean and Freeman, 1996). However, if producers achieve the target AFC but not the correct liveweight due to inadequate ADG, there is the risk that these heifers will struggle to compete with mature cows when introduced into the herd. This could result in problems such as decreased intake, milk yield and even lameness (Grant and Albright, 2001). Likewise, if only the LW is considered and producers extend the length of the rearing period to reach the target of 55 to 60% of mature weight, without increasing ADG, then there is the possibility of an increased AFC, which in turn could negatively impact longevity and productivity (Cooke and Wathes, 2014).

Table 2: Target age, growth rate, weight and proportion of mature weight for a 24 month calving in Holstein heifers

Age (months)	Growth rate (kg/day)	Target weight (kg)	Mature live weight (%)
2	0.80	76	
4	0.90	127	20
6	0.90	180	30
12	0.86	340	50
15 (mating)	0.82	420	60
22	0.80	586	80
24 (pre-calving)	-	636	90
24 (post-calving)	-	568	85

Source: adapted from NRC (2001) and AHDB Dairy (2012)

In spite of these recommendations for AFC and LWFC having existed for a number of years, the practical reality is that many farms still aren't achieving them, with the UK averaging an AFC of 30 months (Hanks and Kossaibati, 2016) and global values ranging from 26 to 30 months (Haworth et al., 2008; Cole and Null, 2010). Many reasons have been hypothesised for this, however Duplessis et al (2015) proposed that the disparity between recommended targets and actual AFC and LWFC is mainly due to inadequate ADG, delayed age at first breeding (AFB) and underestimation of heifer weight at which breeding should take place. Particularly in all-year-round calving systems, where producers aren't tied to block calving, there is the temptation to increase the rearing period length for heifers that aren't considered big enough for breeding at 13 to 15 months, with producers holding them back until they reach what they consider to be an 'adequate' size (Dingwell et al., 2006). A number of producers also appear concerned about the increased initial costs of feeding to achieve higher ADGs (Wathes et al., 2014).

In addition to this, some researchers have questioned the validity of these recommendations, arguing that the advantages of a younger AFC can be outweighed by the possibility of decreased milk yield per lactation and lower feed efficiency achieved by heifers that are still growing in first lactation (Hoffman et al., 1996; Krpálková et al., 2014). There is also the argument that these recommendations, produced universally for the dairy industry may be inappropriate in relation to the management systems and capabilities on some farms, with each Dairy having a unique management strategy and environmental conditions (Wathes et al., 2014). With so much conflicting evidence regarding the effects of a reduced AFC on future

production, and the lack of implementation of these targets, there is an obvious need to provide farmers with data demonstrating the long term benefits and the possible economic advantages associated with optimisation of the rearing period.

2.0 Heifer Development

2.1 Early Nutrition and growth rate

2.1.1 Factors influencing growth rate

Many factors can influence growth rate in heifers and previous studies have highlighted the significant impact of growth on future age at puberty, AFC and first lactation milk yield (Bach and Ahedo, 2008; Soberon et al., 2012). As previously mentioned, the goal weight for AFC is considered to be 85 to 90% of mature weight (Margerison and Downey, 2005), which generally requires an ADG of 0.7 to 0.8kg/day, however this will vary depending on the stage of the rearing period (AHDB Dairy, 2012). One of the biggest factors impacting ADG is nutritional management, which can vary significantly between farms and accounts for nearly half of all costs associated with heifer rearing (Boulton et al., 2017). Nutritional management consists of many components which influence body composition, such as feed intake, feeding rate and diet composition (Davis Rincker et al., 2011). The level of effect of feeding also varies with age and can be categorised into stages of pre-weaning; weaning to conception; and conception to calving (Wathes et al., 2014). Along with nutrition, factors such as housing of young stock, season of birth, disease and genetics are important determinants of growth and development (Heinrichs et al, 2005; Wathes et al., 2008; Bach, 2011) and must also be considered when evaluating the efficacy of a heifer rearing programme.

2.1.2 Impact of nutrition on growth and development

2.1.2.1 Impact of nutrition pre-weaning

Average daily gain in the rearing period is controlled by “voluntary feed intake above maintenance” (Wathes et al., 2014) and as a key performance indicator for calves, must be carefully monitored throughout the rearing period to maximise economic efficiency.

A particularly key component in the pre-weaning stage - and a crucial determinant of future calf health - is colostrum management (Davis and Drackley, 1998), which has been the focus of a large-scale publicity drive in recent years to increase awareness of 'timing, quantity and quality' and the significant impact of this on future productivity (ADHB Dairy, 2012). Recommendations are for calves to be removed immediately after birth and receive 3l of colostrum within 2 hours and 4l within the first 12 hours (Chigerwe et al., 2008). It is essential to ensure that calves receive adequate colostrum within this timeframe, as there is no transfer of maternal antibodies from the dam to the calf and calves rely on the transfer of immunoglobulins in colostrum, the absorption of which decreases to half after 12 hours (Davis and Drackley, 1998). Insufficient intake or administration of poor quality colostrum, has been shown to significantly impact calf immunity, increasing the risk of perinatal mortality and disease (Blum and Hammon, 2000; Raboisson et al., 2016). Further to this, studies have also suggested a link between insufficient intake and reduced ADG in this critical pre-weaning period, as well as a possible reduction in first lactation milk production (DeNise et al., 1989; Van Amburgh et al., 1998).

Along with colostrum management, the liquid feeding strategies in place on each farm can also have a significant impact on ADG and calf morbidity and mortality (Soberon et al., 2012). Although traditional milk feeding programmes centred around restricted feeding, with calves fed at around 10% of their bodyweight to encourage starter intake as soon as possible (Lammers et al., 1999), research found that this had a negative impact on growth rate and weaning age and failed to reduce pre-weaning costs (Kertz et al. 1979; Anderson et al., 1987; Soberon et al. 2012). This resulted in the majority of farms instead choosing to implement moderate or intensive feeding programmes where calves are fed at 16 to 20% of their body weight (Akins, 2016). Although intensive rearing may increase pre-weaning costs, numerous studies have reported associated benefits, including higher ADG; increased weaning weights; earlier attainment of sexual maturity; and increased milk yields in first lactation (Drackley, 2008; Davis Rincker et al. 2011).

One particular study is that by Davis Rincker et al (2011), which evaluated the effects of a traditional versus intensive milk feeding programme on growth, age at breeding, calving age, milk yield and economic efficiency. Calves were placed on either a conventional diet with milk replacer containing 21.5% CP fed at a rate to obtain 0.45 kg ADG or an intensive diet consisting of 30.6% CP milk replacer fed at a rate to attain 0.68 kg ADG. They found that calves fed the intensive diet conceived 15 days younger and calved 14 days younger than those on the traditional programme and whilst pre-

weaning costs were higher, total costs in first lactation did not differ, suggesting that achieving a younger AFC is possible without affecting profitability.

These results supported previous findings from Raeth-Knight et al. (2009), where calves on an intensive high solid, high feeding milk replacer diet (28% CP, 18% fat) reached calving almost a month earlier than those on a conventional milk replacer diet (20% CP, 20% fat) (Raeth-Knight et al., 2009). However, in this study, calves on the intensive diet were fed a higher CP concentrate mix post-weaning than calves on the conventional diet, meaning it is hard to separate the effects of pre-weaning and post-weaning feeding on attainment of AFC. Furthermore, heifers in the study were reared in a contract operation and returned to their respective farms one month before calving and therefore it could be argued that environment, genetics, management and herd could have impacted on the results when assessing differences in long-term performance.

2.1.2.2 Impact of nutrition post-weaning

Better nutrition in the post-weaning period has been shown to increase the rate of reproductive development, and it is crucial that heifers are fed in relation to their target AFB and weight at first breeding (Cooke et al., 2013). Delayed growth during this period can increase the length of time until breeding and therefore the age at calving (Brickell et al., 2009b), both of which lead to an increase in the time spent non-productive, potentially increasing feeding costs (Boulton et al., 2017).

It is also important for producers to avoid excessive weight gain in the pre-breeding period, as this can increase the risk of calving difficulties and dystocia and lead to decreased conception rate (Wathes et al., 2008). Brickell et al. (2009b) found associations between excessive body weight at 6 months and 15 months and a reduction in fertility in 19 out of 450 dairy heifers. Insulin and glucose concentrations were measured at 1 and 15 months respectively and found to be higher in heifers with increased live weight and this was hypothesised to be due to insulin resistance (Brickell et al., 2009b). Furthermore, the risk of poor conception was greatly increased by excessive weight gain of over 1kg/day in the first 6 months of life. However, these findings were observed for a low number of heifers and only a tendency for heavier weights at 6 months was reported. These heifers were also investigated retrospectively after culling due to failure to conceive and the possible influence of farm and herd effects needs to be considered in the context of these results. Further

investigation on a larger scale and evaluation of possible genetic influences would therefore need to be performed to test the significance of this further.

Although the effects of pre- and post-weaning nutrition won't be directly assessed in this study, they are important determinants of AFC, LWFC and future performance and therefore must be evaluated in the context of this literature review. Efficiently measuring growth rate and ADG in heifers is essential to ensure they meet targets for AFB and AFC (Cooke et al., 2013), however very few farmers regularly weigh their animals. In addition to this, large variation can exist between heifers on the same farms, meaning that although some heifers may be achieving the target ADG, breed and genetic variance mean this may not be the case for all heifers (Akin, 2016; Sherwin et al., 2016).

2.1.3 Impact of mortality in the rearing period

Increased death rate pre-calving not only has economic consequences due to the lack of investment return, it can also lead to a reduction in genetic gain within the herd over time, as well as decreasing the number of replacement heifers available (Brickell et al., 2009a; Brickell and Wathes, 2011). In the UK, average rearing period mortality rates range from 0 to 29%, with an average of 11% of heifers born alive failing to reach first lactation (Brickell and Wathes, 2011). The estimated cost of mortality, according to a survey of 102 UK farms, was calculated to be £139.83 per surviving heifer, which was dependant on the individual farm's total mortality rate (Boulton et al., 2017). However, although determining the cost of mortality is crucial, the additional cost of disease in heifers that survive is potentially more significant. This extends far beyond veterinary and medicine costs, leading to longer-term economic impacts such as lower ADG, greater AFC and reduced milk production (Bach, 2011; Heinrichs and Heinrichs, 2011).

Mortality of calves and heifers also represents a problem from a welfare perspective, as well as an economic one, with mortality rates during rearing often used as an indicator of overall farm health and welfare (Ortiz-Pelaez, 2008). Accurately estimating mortality is essential to identify risk factors associated with the rearing period and to determine how these change during different stages of growth and development (Raboisson et al., 2013).

2.1.4 Impact of morbidity on growth and development

Previous studies investigating the impact of calf health in the first 3 months found that incidence of respiratory disease had a significant negative impact on survival (Bach, 2011), while heifers treated for scours were more than twice as likely to be culled before reaching first lactation (Waltner-Toews et al., 1986). Many calf diseases within the first few months of life have been linked with environmental factors such as: housing conditions, ventilation and season of birth, and have been shown to be especially crucial in influencing ADG, age and LW at first calving (Donovan et al., 1998; Place et al., 1998, Heinrichs et al., 2005).

One particular study by Heinrichs et al., (2005) investigated the effect of calf health pre-weaning on age at first calving on 18 farms. Their results indicated that factors including a difficult calving, health treatments, high humidity, high mean daily temperature and high ammonia levels all resulted in an increased AFC. Antimicrobial treatment of pre-weaned calves and elevated temperature within calf housing also resulted in reduced wither height. However, it could be argued that these may be interlinked, with increased temperature resulting in elevated levels of disease, due to proliferation of bacteria in warm, humid conditions, thereby resulting in calves requiring antimicrobial treatment. Differences in calf management and grouping strategy between farms could have also impacted on the results seen in this study, with ADG primarily influenced by calf housing, DMI and variation between farms (Heinrichs et al., 2005).

Bach (2011) reported that heifers that contracted BRD (bovine respiratory disease) once, twice or three times tended to have lower survival in first lactation, and heifers that contracted BRD ≥ four times prior to first calving were 1.87 ± 0.14 times more likely not to complete first lactation. Total DIM and lifetime productivity also decreased significantly with increasing incidence of BRD. However, as with the study by Raeth-Knight et al. (2009) mentioned previously, these heifers were reared in a contract operation and were returned to their respective farms of origin before calving. The effects of farm, herd, management and transition to another location therefore need to be considered in the context of these results when evaluating long-term performance of heifers.

2.1.5 Calf Housing

Adequate and appropriate calf housing is an essential element in preventing calf disease, with ventilation key in minimising the occurrence of pneumonia and BRD, which are some of the biggest causes of calf mortality (Blowey, 2005). Efficient ventilation should: prevent drafts and build-up of humidity; stagnant air and gases; maintain optimum temperature and humidity levels; decrease dust contamination; and reduce the level of airborne bacteria (Callan and McGarry, 2002; Earley et al., 2004).

Housing calves individually during the pre-weaning period, has been shown to reduce the incidence of respiratory disease and diarrhoea (Earley et al., 2004). A number of previous studies have reported a strong correlation between mortality and group-housing in pre-weaned calves in comparison to individual housing (Waltner Toews et al., 1986; Maatje et al, 1993; Svensson et al., 2003), with risk of disease greatest during the first 14 days after birth. Rearing calves outdoors in hutches is one method of individual rearing, with reported benefits such as lower morbidity and mortality (Mcknight, 1978; Waltner-Toews et al., 1986). However, there is the argument that adverse weather conditions and colder temperatures can compromise management of calves housed outdoors (McKnight, 1978), with extra energy required at a lower critical temperature of 10-15 ^{o}C in the first two weeks of life and 6-10 ^{o}C after this (Webster, 1984; Davis and Drackley, 1998).

Where calves are housed together, the optimum number of calves per group is in constant debate (Maatje, et al., 1993; Wells et al., 1996; Svensson et al., 2003). A study in Sweden assessing morbidity and growth rate of calves housed in groups of 6 to 9, versus 12 to 18 on 9 commercial dairy farms (Svensson and Liberg, 2006), found that calves kept in the smaller groups had lower incidence of BRD and grew at a faster rate than calves kept in the larger groups, which was thought to be due to decreased stocking density. However, assessment of morbidity could be defined as subjective, and as such, a blinded study would have been preferable when comparing the effects of small versus large group sizes, to remove the possibility of bias. Furthermore, calves were transferred in and out of groups depending on age and farm management, with the mixing of calves of different ages potentially impacting on levels of disease to a greater extent than group size. Indeed, Pedersen et al. (2009) found that groups where new calves of different ages were mixed exhibited more than twice the level of respiratory disease and diarrhoea and had significantly lower daily liveweight gains than calves housed in homogenous groups (810 ± 2.0 g/days vs. 870 ±2.5). This is a problem seen in many experimental studies investigating group

housing on commercial farms, where practical conditions limit the ability to control factors potentially influencing outcome. However, a number of studies have reached similar conclusions (Willard et al., 1996; Losinger and Heinrichs, 1997; Svensson et al., 2003) and together their results suggest that housing calves in groups of <10 is beneficial for reducing morbidity and mortality rates.

3.0 Influence of rearing period on future productivity:

3.1. Fertility

Although many aspects of dairy herd performance, such as calf growth rate and milk yield per cow, have improved greatly in recent years (Lammers et al., 1999; Tsuruta et al., 2005), poor fertility remains a significant problem facing the dairy industry globally (Wathes et al., 2014). The consequences of this can be far-reaching and include: loss of milk production due to excessive dry periods; fewer total lifetime DIM; disruption to calving patterns and milk production predictions; premature culling; fewer heifer replacements; additional AI costs; and loss of genetic gain over time (Cooke et al., 2013; Wathes et al., 2014). All of these in turn impact farm profitability, with estimates proposing that the total cost of the above is roughly £25,000, or 3.5p/litre (Esslemont and Kossaibati, 2002). In seasonal calving herds, any deviation from the target calving date has a huge effect on the ability to coincide calving, peak milk yield and feed requirement with seasonal grass availability, detrimentally effecting feed and milk production costs and the system efficiency as a whole (Brickell et al., 2009b).

The age at first calving has been shown to have a significant effect on future fertility of dairy heifers (Wathes et al., 2008; Brickell et al., 2009b) and one of the most common measures of fertility is calving interval (CI). The UK average, although down from 428 days in 2009/10 is 413 days, which is still significantly higher than recommendations (Hanks and Kossaibati, 2016).

The appropriateness of a 365-d CI target has been debated in previous studies, with some researchers arguing that due to greater milk yields seen on UK farms, it is unrealistic to expect cows to calve every 365 days (Knight, 2004; Sorenson et al., 2008). Knight (2004) proposed that instead, shifting to calving every 15 to 18 months would reduce veterinary costs and minimise problems such as drying-off cows that are still yielding >20 litres/day. However, there is very little evidence to support this theory at present and studies have reported conflicting results when comparing 12 vs 15 month intervals (Bertilsson et al., 1997; Knight, 2004). The financial implications of

shifting to a 15 or 18 month calving interval could also be significant, with lower annual milk yields and reduced numbers of calves, and it would also conflict with milk production patterns, whereby producers aim to calve cows to ensure higher yields in the most profitable months (IGERS, 2005).

Ettema and Santos (2004) compared three AFC groups of <23, 23 to 24.5 and >24.5 months, and found the CI was shortest and number of inseminations per conception were fewest for heifers with an AFC between 23 to 24.5 months of age. This is similar to other studies that found the shortest interval in heifers first calving at 23 to 25 months (Eastham 2012) and 25 to 26 months (Hoffman et al., 1996). Calving heifers at older ages, heavier weights and higher BCS (≥3), increased the incidence of dystocia and led to subsequent poor fertility, mainly due to BCS and total body fat content (Hoffman et al., 1996), while calving heifers at younger ages, <23 months, resulted in heifers requiring more inseminations per conception and having longer CIs (Ettema and Santos (2004).

Another important consideration with AFC is the size at which heifers are calving. If heifers are calved at a young age to meet recommendations but are not of adequate size, or are calved younger than 22 months, this can mean that they are still growing, with more nutrients partitioned for growth than fertility (Wathes et al., 2008). Heifers that are smaller and have a lower live weight at FC struggle to compete for food with the older cows in the herd (Grant and Ablright, 2001; Hayirli et al., 2002), possibly resulting in greater body weight and BCS losses. Excessive loss of condition during the first lactation impacts energy balance and can delay resumption of oestrus, impacting on fertility and subsequent calving interval (Ettema and Santos, 2004). However, if heifers are calved at greater than 25 months, it is likely they will have a higher body weight and condition score that could also increase mobilisation of fat and negative energy balance in early lactation, resulting in decreased fertility (Brickell et al, 2009b).

3.2 Milk Production

3.2.1 Effect of nutrition and growth rate

Soberon et al. (2012) compared heifers at the Cornell Dairy herd and a commercial farm in an attempt to investigate the effect of increased milk replacer feeding rate on milk yield in first lactation. Significant correlations between pre-weaning ADG and milk yield in first lactation were seen in both herds, with an average 850kg more milk

produced for every 1kg of ADG pre-weaning. However, it could be argued that it is difficult to separate the influence of pre-weaning and post-weaning growth rate on milk production in this study, as heifers also received a higher nutrient intake post-weaning on both farms. Comparison with a conventional diet was also not performed and further development of this work could therefore involve analysis of increased feeding rate pre-weaning with conventional feeding post-weaning and vice versa. Similar results have been observed in other studies however, with calves fed more milk ad libitum demonstrating increased ECM yields in the first lactation and dietary supplementation with 2% CP increasing total LW and ECM yields (Shamay et al., 2005).

In a New Zealand-based study, Macdonald et al. (2005) assessed the effect of both pre- and post-weaning feeding rates and the impact of this on future milk production potential. Experiments were carried out on Holstein Friesian and Jersey heifers in a 3 x 2 factorial design, with heifers fed to achieve differing ADGs. Heifers on the higher feed level pre- and post-weaning had higher liveweight, height and heart girth circumference which continued until the study concluded in third lactation. Higher feeding levels pre-puberty had no effect on milk yield in 1st and 2nd lactation. However, milk yield in the 3rd lactation was reduced, which contradicts previous findings (Van Amburgh et al., 1998; Soberon et al., 2012). This was suggested to be due to the higher live-weight at calving disguising the possible negative effect of accelerated growth on mammary development, as lower LW-corrected milk yields were seen in heifers on the higher feeding level pre-puberty. However, there is conflicting evidence regarding whether increased growth rate impairs mammary development. Some researchers have argued that excessive average daily gain during rearing results in increased fat deposition, compromising mammary development and reducing milk yields (Mourits et al., 2000; Serjsen, 2005), while Daniels et al. (2009) found little evidence of an increased plane of nutrition on the histological development of mammary glands.

3.2.2 Influence of age and live weight at calving

The influence of AFC alone on future production can be hard to quantify, given that live weight, ADG and AFC are highly correlated. Calving below 23 months is thought to result in compromised milk production due to insufficient development of the mammary gland (Serjsen, 2005), however studies have produced conflicting results. Eastham (2012), reported significantly lower milk yields up to 4th lactation in heifers

calving below 23 months and Mohd Nor et al., (2013) found heifers calving at 23 months compared to 24 months produced 143kg less milk per 305-day productive period. In contrast, more recent studies such as that by Cooke and Wathes (2014), found no significant difference in first lactation milk yield between heifers in different AFC groups and when looking over a 5 year productive period, found heifers in the youngest calving groups, <23 months and 23 to 25 months, had the highest overall milk production. However, these studies, although thorough in their approach to AFC analysis, did not evaluate live weight at calving, or average daily gain beyond the early rearing period.

Live weight at calving has been shown to be key in influencing first lactation yields (Hoffman, 1997; Ettema and Santos, 2004), with previous research suggesting weight is at least twice as important as age in influencing production (Clark and Touchberry, 1962; Dobos et al., 2001). Dobos et al., (2001) investigated the effect of AFC and LWFC on milk, protein and fat yield and found that although AFC independently influenced milk yield, live weight was between 2 and 3 times more important in determining production. Given the conflicting results seen with regards to calving below 23 months (Sejrsen, 2005; Eastham, 2012; Cooke and Wathes, 2014) it could be argued that the differences in milk yield were more likely due to variation in heifer weight at calving than age, with the lower yields perhaps due to heifers being under target for weight. A more detailed analysis of the combined effects of AFC and LWFC on first lactation milk yields and overall lifetime productivity therefore needs to be performed and this will be addressed in the present study.

3.3 Lifetime productivity and longevity

3.3.1 Lifetime production

Although a number of studies have shown the benefits of an earlier AFC on milk yields in the first and second lactation (Ettema and Santos, 2004; Haworth et al., 2008; Cooke et al., 2013; Cooke and Wathes, 2014), it is important to consider the significant impact AFC can have on total lifetime productivity and therefore the economic returns that can be achieved from an animal over its milk productive lifetime. Whereas previously farmers may have delayed first calving to achieve a higher body weight or greater milk yield in first lactation, more recent research has provided evidence of the benefits of an earlier AFC for greater lifetime production, through a shorter CI to second lactation, reduced non-productive period and a greater number of total lactations (Richardson, 2011; Cooke et al., 2013; Cooke and Wathes, 2014).

Considering that farmers see no return on the investment made pre-calving until at least the end of the first lactation (Akins, 2016), it is essential that farmers maximise the lifetime productivity of dairy cows to ensure adequate return on investment.

Days in milk is an efficient way of measuring lifetime productivity and Cooke et al. (2013) found that 23 to 25 months was the optimum calving age for the greatest number of DIM over 5 years, with these animals spending nearly half their lives in milk production compared to just a third for heifers with an AFC greater than 25 months. In a study evaluating 170,000 heifers, the benefits of the 23 to 25 month AFC were also demonstrated by Richardson (2011), who found that peak lifetime production was present in the group with an AFC of 23 to 25 months, with milk production tailing off in heifers with an AFC greater than 25 months.

Perhaps one aspect of a lower AFC that has deterred farmers is the possibility of a lower milk yield in first lactation, due to a lighter bodyweight at FC. However, Carson et al., (2002) found that although milk yields may be reduced in heifers with lower body condition scores at calving, CI was shorter and thus total milk yield over two lactations was similar to animals with a greater AFC and LWFC. However, in order to fully maximise the benefits of an early AFC, farmers must ensure their heifers have a sufficient growth rate and LWFC to support first lactation production, which is especially important given that studies have demonstrated the positive relationship between milk yields in first lactation and lifetime milk yield (Stassen et al., 1991; Haworth et al., 2008).

3.3.2 Age at first calving and survival through first lactation

Ensuring heifers complete first lactation and enter second lactation has been found to be crucial in ensuring dairy farm margins, as dairy heifers need to complete first lactation to repay rearing costs and no return on investment into heifer rearing can be gained until the second lactation cycle (Bach, 2011; Archer et al., 2013; Sherwin et al., 2016). The number of replacement heifers needed - and therefore the importance of replacement rate - varies with cow culling rate on farm, which depends on a number of factors including management and fertility (Archer et al., 2013). In a study by Brickell and Wathes (2011), 19% of first lactation heifers did not complete first lactation, with varying rates between farms of 7% to 33%, which was similar to previous findings of 14% (Esslemont and Kossaibati, 2002).

A number of published papers have investigated the link between AFC and first lactation survival, with many finding that a lower AFC increases survivability of heifers (Lin et al., 1988; Bach, 2011; Archer et al., 2013), while other papers have produced conflicting results (Ducrocq et al., 1988; Ojango et al., 2005). However, a number of previous studies have only been conducted on a small scale in systems which vary considerably to those seen on UK farms. Sherwin et al. (2016) investigated survival rates of heifers on 437 UK farms, with results indicating that, within herd, the mean number of heifers culled in first lactation was 15.9%. A negative correlation was found between survival rate and increasing AFC, with a third of heifers calving at over 30 months. Bach (2011) also assessed the association between AFC and survival and found that heifers completing first lactation had a lower average AFC (724.3 d) than the AFC (737.4 d) of heifers culled before the end of first lactation. But interestingly, the AFC could be as low as 662 d without adverse effects on survival.

3.3.3 Heifer rearing and longevity of dairy cattle

Short lifespan of dairy cattle presents economic, environmental and welfare issues. Early culling, and poor longevity, result in the loss of genetic merit over time, limiting animals available for selective breeding and increasing the number of replacement heifers required (Wathes et al., 2008). They also compromise farm feed and economic efficiency and increase the financial risk to the farm business (Brickell and Wathes, 2011). The annual culling rate in the UK is currently 27%, with 59% of animals culled before they reach 4th lactation (Hanks and Kossaibati, 2016). These culling rates are similar to other countries, with a particularly high rate in the US, where very few cows survive beyond fifth lactation, shifting the herd demographic towards younger ages (De Vries et al., 2010).

An older AFC only serves to exacerbate this problem, increasing rearing and housing costs and extending the non-productive period, with many farms rearing double the number of replacements required to account for losses and poor fertility (Akins, 2016). Not only does this have an economic impact in terms of feed and labour, it can also have a significant environmental impact, increasing total herd methane and ammonia emissions (Garnsworthy, 2004). Studies have shown that for an AFC of 27 months, the number of heifers is increased by 12%, but replacement heifers can increase methane emissions by as much as 30%, because of their larger size, and increase emissions from the whole herd by 6% (Garnsworthy, 2004). Thus, increasing herd lifespan and longevity through a younger AFC and consequently shorter calving

interval, reduces the number of replacements needed and the total number of cows on farm, so reducing whole herd methane emissions (Wathes et al., 2014).

Studies have shown that first lactation heifers are often given many more chances to conceive than older cows (Tsuruta et al., 2005; Brickell et al., 2009b), with Brickell et al. (2009b) finding heifers in first lactation had on average 322 days compared to only 280 days in second lactation cows and older. This was hypothesised to be due to high mortality in the heifer rearing period forcing farmers to keep first lactation heifers with poor fertility due to the lack of replacements coming in (Brickell et al., 2009b). If survival can be predicted based on factors of heifer development such as ADG, AFC and reproductive performance, it could help to maximise the success rate of culling decisions by increasing the expected longevity of replacement heifers (Cooke et al., 2013).

4.0 Aims

This project therefore aims to assess the influence of morbidity in the rearing period on attainment of age and live weight at first calving and the effect of these parameters on subsequent lifetime production, fertility and longevity in an all-year-round calving herd. This will build on previous research, focusing on overall lifetime productivity, as opposed to simply first lactation performance and will evaluate the combined effects of weight and age. The hypotheses of this study are that: lower levels of morbidity in the rearing period will be associated with decreased age at calving and increased weight at calving; milk yield in first lactation will be greatest in heifers calving for the first time at 23 to 24 months; and that an age at calving of 23 to 24 months will be optimum in terms of total lifetime productivity and longevity, with heifers calving at this age spending a greater total proportion of their life productive.

5.0 Materials and methods

5.1 Animals and location

Ethical approval was obtained from the University of Nottingham Animal Welfare and Ethical Review Board prior to commencement of the study and all work with animals was conducted in accordance with the UK Animal (Scientific Procedures) Act 1986. This study was completed using data obtained from 1188 Holstein-Friesian heifers born on a UK dairy farm between 2006 and 2017. The herd follows an all-year-round calving pattern.

5.2 Rearing period management

5.2.1 Nutrition

The newly born calves were separated from their dam following birth and given 3 L of unpasteurised colostrum, followed by 2 L of colostrum for four subsequent feeds over the first 24 h of life. Following this, calves received 2 L of milk replacer (Milkivit Activator SMP, Trouw Nutrition, Ashbourne, Derbyshire; CP: 23%; crude oils and fats: 20%, crude fibre: 0.03%, crude ash: 7.5%) offered twice daily, reconstituted at concentrations according to manufacturer recommendations at 37°C for the first 10 days. At 10 days of age, the volume of milk replacer offered to the calves was increased to 2.75 L before milk feeding amount peaked at 3.5 L, offered twice daily, at 40 d of age. This was offered via 'Lely Calm' automatic feeders (Lely UK Ltd., St Neots, UK), with calves progressively weaned up to 80 days of age. A cereal based starter feed (PrimeCalf and Nustart pellets, Bibby Agriculture, Carmarthen;18% CP, 12.5MJ ME/kg, 4.25% crude oils and fats, 8.5% crude fibre, 8% crude ash, as fed), wheat straw and fresh clean water was provided ad libitum from the first week of age up to four weeks post-weaning. At weaning until three weeks pre-partum, heifers were offered a TMR consisting of maize, whole crop and grass silage (18% CP; 12.0 MJME/kg).

5.2.2 Calf housing

Calves were housed in indoor deep litter straw pens from 2006 to 2012 in small groups of 4 to 6 until 1 month of age, at which point they were moved to larger groups of up to 16. Calf hutches were introduced in 2012 and from this point onwards, calves were kept in individual hutches outdoors from birth to 3 weeks, after which they were moved

into indoor deep litter straw pens and maintained in groups of 16 calves. Heifers remained in these groups up until 12 months of age, when they were moved to a bulling shed with free stall cubicles and rubber mats covered with sand. At 3 weeks pre-partum heifers were moved into dry cow yards with deep litter straw beds up until calving and offered a specialised transition diet, consisting of a TMR containing grass and maize silage, straw and dry cow transition minerals (16% CP, 10.5MJ ME/kg). Pregnant heifers were intermittently grazed over the 10-year period depending on grass availability and were turned out during early pregnancy for 4 to 6 months.

5.2.3 Breeding management

Heifers were served by a commercial company using artificial insemination (AI), with heat detection via tail paint and visual observation of bulling behaviour. Selection criteria for AI were age and visual estimation of size/weight, with a target age at conception of 14 months between 2007 and 2012, to achieve an AFC of 23 months. This changed to 17 months from 2012 onwards, as a result of a management decision to aim to calve heifers at 26 months. Bulls were selected for low somatic cell count, good legs and feet and wide rear teat placement. During the breeding period, heifers were housed in a ‘bulling’ shed with free stall cubicles.

5.2.4 Health

Calves scouring were isolated in individual pens and received Volac AsGold (3%CP, 1% oils) in milk replacer twice a day for 7 days. Pneumonia was diagnosed by visual signs in the first instance, including droopy ears, quietness, drop in intake (milk replacer only measurement), coughing and rapid respiratory rate. A rectal temperature was then taken and recorded. Treatment for Pneumonia was via Draxin and Metacam, followed 48 hours later by a repeated treatment of Metacam. Calf jackets were introduced in 2009 and were routinely used in cold weather after this time. The farm experienced an outbreak of cryptosporidium between 2012 and 2014 and calf diptheria has also been observed previously throughout the 10 year period.

5.3 Post-partum management

5.3.1 Adult dairy cattle

Lactating dairy cattle were housed all-year-round under commercial conditions in cubicles and were milked individually via automatic (robotic) milking stations (AMS), using Fullwood Merlin milking stations (Fullwood Merlin; Fullwood Ltd., Ellesmere, UK) from 2006 to 2011, and Lely Astronauts (Lely Astronaut A3; Lely UK Ltd., St Neots, UK) between 2011 and 2017. Cows and primiparous heifers were housed together in the same groups, with a maximum of 60 cows per robot. The average annual milk yield per cow was 10,000l. All animals had unrestricted access to PMR, consisting of a nutrient concentration sufficient to support maintenance plus 32 L of milk production, an example of which is shown in Table 3. They also received pelleted compound feed, (ME:12.5 MJ, CP: 21.9%, NDF: 33.2%, total starch and sugars: 17.8 %, Ash: 6.1%, Oil:3.4 % as fed), at a rate of 0.4 kg/L for each additional kg of milk produced above 32 L/hd/d, during milking to a maximum of 12 kg DM/hd/d. All cows and heifers on farm were bred by artificial insemination, with semen provided by Genus Plc and bulls were selected for low somatic cell count, good legs and feet and wide rear teat placement. Target dry period length was 60 days, with dry cows housed in yards with deep litter straw beds up until calving and offered a specialised transition diet, consisting of a TMR containing grass and maize silage, straw and dry cow transition minerals (16% CP, 10.5MJ ME/kg).

Table 3: Example diet components and nutritional composition of partial mixed ration offered to dairy cattle

Partial mixed ration	g/kg of DM
Ingredient	
Grass silage	226
Maize silage	253
Whole-crop wheat silage	215
Soybean meal	80
Rapeseed meal	80
DDGS	24
Soybean hulls	24
Sugar beet pulp	24
Beet molasses	40
Fat Supplement	13
Minerals and vitamins	22
Analysis	
DM (g/kg)	463
ME (MJ/kg of DM)	12.0
CP (g/kg of DM)	175
NDF (g/kg of DM)	367
Starch (g/kg of DM)	163
Sugars (g/kg of DM)	67
Crude fat (g/kg of DM0	37
Forage DM (% of total DM)	69

Minerals and vitamins; calcium, 18%; phosphorus, 10%; magnesium, 5%; salt, 17%; copper, 2,000 mg/kg; manganese, 5,000 mg/kg; cobalt, 100 mg/kg; zinc, 6,000 mg/kg; iodine, 500 mg/kg; selenium, 25 mg/kg; vitamin A, 400,000 IU/kg; vitamin D_3, 80,000 IU/kg; and vitamin E, 1,000 mg/kg (ABN Ltd., Peterborough, UK)

Source: Adapted from Garnsworthy et al. (2012)

5.4 Data collection

Data was extracted from a number of farm databases including Uniform-Agri Professional UK (Taunton, Somerset TA1 1SW), Lely T4C (Lely UK Ltd., St Neots, UK), vet/farm records and interviews with farm staff. Only heifers that entered the herd prior to first calving were included in the analysis. Data was originally extracted from 2005, however, due to a system changeover in 2007, it was found that prior to 2007 there were a number of animals that had their age at calving entered into the system incorrectly and were entered as first calving heifers when they were second or third lactation animals. Data from 2005 was therefore excluded from the analysis and

young stock mortality data was obtained for 2006, but animals born in this year were not included in any post-partum lactation data analysis.

5.5 Determination of sample size

Using the report writer function on Uniform-agri, a report was generated containing animal ear tag, date of birth, age at first calving, first calving date, the total number of lactations completed, culling date and culling reason. The report included young stock and mature cows, both present and historic, generating a total of 1188 animals from 05/01/2005 to 16/02/2017. As previously mentioned, the data from 2005 was excluded from the analysis and only data on calf mortality was used from 2006. This gave a dataset of 1142 animals and of these, 125 were sold prior to first calving and so were excluded from the analysis, leaving a dataset of 1017 animals (Table 4). The accuracy of this data was ensured by manual evaluation of data quality and any animals with missing or incomplete records were excluded (n=11) according to the following criteria:

1. Animals that were sold to other farms during their lifetime as their longevity would appear to be shorter than it actually was.
2. Animals that had an AFC of greater than 1075, or less than 550 as these may not have been a heifer when the age at first calving was recorded, or may have aborted and been brought into milk early.
3. Animals that did not calve for the first time in the herd as lifetime data would have been incomplete.
4. Animals that had missing data in first lactation.

Table 4: Total number of heifers included in the study between 2006 and 2017, rearing period mortality rate and the total number of lactations completed each year

Birth year	Heifers born alive	Heifers sold	Heifer total (born-sold)	Rearing period mortality		Total number of lactations							
	(n=1142)	(n=125)	(n=1017)	(n=192)	%	1	2	3	4	5	6	7	8
2006	64	0	64	4	6.2	60	51	43	24	16	7	2	1
2007	60	1	59	4	6.8	55	45	33	22	14	4	2	1
2008	81	17	64	20	31.3	44	33	23	14	9	3	0	0
2009	99	6	93	19	20.4	74	69	56	42	21	8	1	-
2010	86	9	77	19	24.7	58	47	37	20	11	1	-	-
2011	86	11	75	15	20.0	60	52	46	29	9	-	-	-
2012	132	29	103	29	28.2	74	66	40	5	-	-	-	-
2013	108	17	91	24	26.4	67	42	1	-	-	-	-	-
2014	133	33	100	30	30.0	63	3	-	-	-	-	-	-
2015 [1]	139	1	138	18	13.0	5	-	-	-	-	-	-	-
2016 [1]	129	1	128	10	7.8	-	-	-	-	-	-	-	-
2017 [1]	25	0	0	0	0.0	-	-	-	-	-	-	-	-
Total	1142	125	1017	192		560	408	279	156	80	23	5	2

[1] Incomplete data set due to some animals yet to reach parturition

5.6 Rearing period data

5.6.1 Mortality

Data on mortality during from birth to first calving was collected from 2006 to 2016 using the report writer function on Uniform Agri and collated according to date of birth, culling reason and age at death. Age at culling was categorised into perinatal (0 to 48 hour), neonatal (3d to 30 d), 1 to 6 months, 6 to 12 months and 12 months to calving. A category for conception to calving could not be calculated due to the wide variation in age at calving and therefore age at conception.

5.6.2 *Morbidity*

Data on health treatments were obtained from vet records for the period 03/10/14 to 08/10/16. Health data for young stock was not routinely entered into the Uniform database on farm, meaning morbidity and treatment data could not be obtained for the entire study period. Bull calves were reared on farm during this period and any treatments administered to them were removed from the analysis. These calves were shot or recorded as died directly following birth and as such care was taken to remove these from the calculation of mortality rate.

Microsoft Access was used to merge the treatment data with existing records to obtain date of birth, culling date, age and live weight at first calving for all animals treated for ill health. There were a total of 275 treated animals and, of these, only 99 were old enough to have calved for the first time at conclusion of this study, resulting in age and live weight at calving only being obtained for this number. All treatments were categorised according to age at treatment: 0 to 48 hours, 3d to 30d, 1 to 6 months, 6 to 12 months and 12 months to calving; season of treatment: Spring (March to May), Summer (June to August), Autumn (September to November) and Winter (December to February) and treatment reason: ‘pneumonia’, ‘diarrhoea’, ‘temperature’ and ‘other’. The number of treatments each calf received was also determined and categorised according to none, one, two, three, four and five or more.

5.7 Post-partum data

5.7.1 First lactation

A small number of animals (n=2) were excluded from analysis of AFC, LWFC and production data as they were culled at the very start of lactation and therefore had insufficient data to be included in this study. A number of animals had not calved for the first time at commencement of the study and were, therefore, not included in post-partum data analysis. This left a dataset of 487 heifers for which data was available from first lactation onwards, excluding animals born in 2006.

Age at first calving was extracted from the Uniform database using the report writer function, with instructions to obtain age at first calving and first calving date for animals both present and historic from 2007 onwards.

The data regarding productivity was obtained via the Lely T4C database, linked to the Lely automatic milking machines, which allows the user to obtain information on a number of key performance indicators (KPIs). The Lely T4C software shows only the animals currently in the herd and as such data from heifers milked historically was collected from the Microsoft SQL Server Management Studio database linked to Lely T4C. The first lactation data was extracted using a code that was written for each birth year and included instructions that obtained the mean daily; live weight, milk production and production date for each animal's freeze brand over a specified period of time (Figure 1).

The length of lactation (d) for each individual animal was determined and cross-checked with data from the Uniform database and any days that were deemed to be outside the scope of first lactation were excluded from the spreadsheet. As Lely T4C used the freeze brand number as an individual animal identification, Microsoft Access was used to combine ear tag and freeze brand identification to create one large spreadsheet for every year containing all the relevant information from each individual animal.

```
SELECT        dbo.HemAnimal.AniUserNumber,
dbo.PrmMilkDayProduction.MdpProductionDate,
dbo.PrmMilkDayProduction.MdpDayProduction,
                         dbo.HemAnimal.AniResponderNumber,
dbo.PrmMilkDayProduction.MdpAverageWeight, dbo.HemAnimal.AniBirthday,
dbo.PrmMilkDayProduction.MdpAniId,
                         dbo.PrmMilkDayProduction.MdpDayProductionMAvg
FROM            dbo.HemAnimal INNER JOIN
                         dbo.PrmMilkDayProduction ON dbo.HemAnimal.AniId =
dbo.PrmMilkDayProduction.MdpAniId
WHERE        (dbo.HemAnimal.AniUserNumber IN (129, 541, 135, 2217, 122, 20, 145,
123, 121, 124, 132, 18, 147, 26, 141, 2, 125, 136, 143, 148, 6)) AND
(dbo.HemAnimal.AniBirthday > '2009-12-31 00:00:00.000') AND
(dbo.HemAnimal.AniBirthday < '2011-12-31 00:00:00.000') AND
(dbo.PrmMilkDayProduction.MdpProductionDate < '2014-05-01 00:00:00.000')
```

Figure 1: SQL code to extract 2010 first lactation daily production data

The live weight of each animal was recorded every milking in the Lely milking robot (Lely Astronaut A3; Lely UK Ltd., St Neots, UK) via load cells and automated computer recording. The live weight of animals was recorded from first calving throughout lactation and the calculated mean weight over the first 7 days of lactation was used as post-partum live weight. Recommendations are for a live weight of 85 to 90% of mature weight post calving (Margerison and Downey, 2005). In order to determine whether animals met this target, mature weights were calculated as the mean weight 7 days post-partum of cows in third lactation or greater for each year that heifers calved, with a code similar to the above, specifying instructions for mean daily weight. Percent mature weight was then calculated as:

$$\frac{\text{Live weight at calving of heifer}}{\text{Average mature weight for each year}} \times 100$$

Ideally, the mature weight of each individual dam would be used to evaluate their daughter, however extraction of data from SQL was restricted to freeze brand number and lactation number could not be specified. As a consequence, to calculate the proportion of MW for each individual animal, the dam would have to be identified and her weight calculated from her third lactation calving date, which within the timeframe available was not possible.

The daily milk production date and daily milk yield were used to calculate days in milk (DIM), 305-day yield and average daily milk yield in first lactation for each individual

animal. These were then cross-checked with the Uniform-Agri database against drying off dates. The animals that were dried off/culled before 305 days had their total milk yield recorded as their 305-day yield, to standardise the milk yield data. Likewise, for heifers that exceeded 305 days before being dried off, their total yield was taken as their yield up to and including 305 days. The mean daily yield was calculated as total yield/305 days. This was then repeated for each year for all animals born from 2007 to 2015, as 2015 was the last year in which animals were born and had completed their first lactation at conclusion of the study.

5.7.2 Lifetime data

The calving interval between first and second lactation was calculated via extraction of calving dates for first and second lactation for each individual animal from the Lely T4C database. The dry period length was calculated as the period (d) between the end of the first and commencement of the second lactation, which could be calculated as calving interval minus days in milk in first lactation.

```
SELECT        dbo.HemAnimal.AniUserNumber, dbo.HemAnimal.AniResponderNumber,
dbo.HemAnimal.AniBirthday, dbo.RemLactation.LacCalvingDate,
                         dbo.RemLactation.LacDryOffDate,
dbo.RemLactation.LacNumber, dbo.RemLactation.LacAniId, dbo.HemAnimal.AniId
FROM            dbo.HemAnimal INNER JOIN
                         dbo.RemLactation ON dbo.HemAnimal.AniId =
dbo.RemLactation.LacAniId
WHERE        (dbo.HemAnimal.AniUserNumber IN (253, 256, 16, 259, 243, 266, 273,
249, 242, 316, 278, 318, 305, 295, 232, 306, 296, 294, 299, 308, 310, 354, 345))
AND (dbo.HemAnimal.AniBirthday > '2010-12-31 00:00:00.000') AND
(dbo.HemAnimal.AniBirthday < '2012-12-31 00:00:00.000')
ORDER BY dbo.HemAnimal.AniBirthday
```

Figure 2: SQL code to extract data on total lifetime days in milk

The total lifetime days in milk was calculated as the difference between the calving date and drying off date for each completed lactation for each animal and this was calculated as a total for all completed lactations, using a code (Figure 2) to extract the data from the SQL database. The removal date in last lactation in the herd was used to calculate days in milk for the final lactation if no drying off date was recorded. This calculation could only be applied to the animals that had left the herd, which gave a total dataset of 276 animals.

The lifespan (days) of each animal was calculated as the difference between the date of birth and the date the animal was removed from the herd. The longevity index was subsequently calculated as the lifetime DIM/lifespan and was used to present the proportion of an animal's lifetime that was spent producing milk. The first lactation and lifetime production data were then merged with the original dataset from Uniform, using Microsoft Access, to create one large dataset containing data for all available post-first calving animals.

5.7.3 Culling in first lactation

The heifers that were culled during first lactation were identified from culling date and days in milk. Culling reasons were categorised into infertility, injury, lameness, died, mastitis, downer cow, calving difficulty, udder conformation, milk production and other. A number of heifers were recorded simply as 'died', with no further information available for these. Culls were then further broken down into stage of lactation: 0 to 10, 10 to 50, 50 to 100, 100 to 200, 200 to 300 and >300 d of lactation.

5.8 Statistical analysis

5.8.1 Rearing period mortality and morbidity

Survival analysis (Kaplan and Meier, 1958) was completed using Genstat 17th Edition statistical package (VSN International, Hemel Hempstead, UK) to evaluate the pattern of animals leaving the herd before first calving. The survival probability was calculated using the Kaplan-Meier estimator, from birth to 30 d of age. Animals were then split by season of birth: spring (March to May), summer (June to August), autumn (September to November) and winter (December to February) with survival data to 30d analysed using Kaplan-Meier survival analysis. This was then followed by a log rank test for further comparison between seasons of birth.

The relationship between the number of treatments an animal received for illness and age and live weight at first calving was assessed using GLM ANOVA in Minitab 17.2.1 (Minitab Ltd., Coventry, UK). Traits at $P<0.05$ were further evaluated using Tukey's post hoc test with a confidence interval of 0.95.

5.8.2 Age and live weight at first calving

The relationship between age and live weight at calving and age and proportion of mature weight was evaluated using simple linear regression in Minitab 17.2.1 (Minitab Ltd., Coventry, UK).

5.8.3 First lactation production

To investigate the effect of age at first calving on first lactation production parameters, the population was split into four groups according to their age at first calving in days, based on similar categorisation in previous studies to enable easy comparison of results (Brickell et al, 2007). The groups were: Early; <700 d (n=104), Target; 701 to 759 d (n=155), Late; 760 to 879 d (n=191) and Very late; >880 d (n=36). The data was presented in days rather than months due to this being the most common reporting format in previous studies (Haworth et al., 2008; Brickell et al., 2007; Krpálková et al., 2014). Data was first checked for normality and homogeneity of variance using Levene's test in Minitab 17.2.1 (Minitab Ltd., Coventry, UK). The four AFC groups were compared via GLM ANOVA with regards to mean AFC, LWFC, % mature weight, 305 d yield, mean daily yield, days in milk and calving interval, using AFC group as a fixed effect and individual animal as a random effect. Traits at $P<0.05$ were further evaluated using Tukey's post hoc test with a confidence interval of 0.95. Data for dry period length was not normally distributed, even after transformation was performed and this data was therefore analysed using non-parametric Kruskal Wallis and multiple comparisons, with results presented as a median.

Sixty-one heifers were culled during first lactation, resulting in data on 305 d yield and mean daily yield being considerably lower for these animals. If these animals were included in the analysis, it would have made mean total yields appear lower than they actually were for each age category. Therefore, the four AFC groups for animals with incomplete lactations were compared separately via GLM ANOVA with regards to age, live weight, mature weight, yields and days in milk. An overview of all animals was then completed with regards to age, weight and mature weight.

The assessment of the effect of live weight at calving on first lactation production parameters, was achieved by using post calving live weight to divide the animals into 5 categories: <500 kg, 501 to 550 kg, 551 to 600 kg, 601 to 650 kg and >651 kg. LWFC groups were then compared with regards to AFC, % mature weight, 305 d

yield, mean daily yield, days in milk, calving interval and dry period length via GLM ANOVA, using LWFC group as a fixed effect. Traits at $P<0.05$ were further evaluated using Tukey's post hoc test with a confidence interval of 0.95. Data for dry period length was again assessed via non-parametric Kruskal Wallis and multiple comparisons, with results presented as a median. As with AFC group analysis, the animals were split according to whether or not they completed first lactation.

A multiple linear regression analysis was then performed to predict 305-d yield in first lactation based on the combined effects of age and liveweight at first calving, with 305d yield as response and AFC and LWFC as continuous predictors.

5.8.4 Survival through first lactation

To identify patterns in culling in first lactation, days in milk at exit was evaluated using Kaplan-Meier survival analysis. The primiparous herd culling rate was calculated as the number of animals that calved for the first time and exited the herd before their next calving. Mean AFC, LWFC and % mature weight were compared for animals that completed and did not complete first lactation using GLM ANOVA.

5.8.5 Longevity

To assess the effects of AFC and LWFC on longevity, AFC groups and LWFC groups were compared with regards to lifespan (days), parities per lifetime, lifetime DIM and DIM/lifespan (longevity index). The data did not follow a normal distribution and were analysed using non-parametric Kruskall Wallis followed by multiple comparisons. Kaplan-Meier survival analysis of total DIM for each live weight group was then performed, with log rank test for further comparison. Finally, the relative importance of age at calving, live weight at calving and 305-d yield combined on total lifetime productivity (DIM/lifespan) was assessed using multiple linear regression, with DIM/Lifespan as response and AFC, LWFC and 305-d yield in lactation 1 as continuous predictors.

6.0 Results

6.1 Rearing period survival, mortality and culling

A total of 1017 dairy heifer calves were born alive between 2006 and 2017 and, of those, 192 died and/or were culled prior to first calving. Rearing period mortality was greatest between 2012 and 2014 (Figure 3), with mortality rates of 28% in 2012, 26% in 2013 and 30% in 2014, as a percentage of total heifers born alive each year. Perinatal and neonatal (birth to 1 month) mortality were also high during that time, ranging from 16 to 21%.

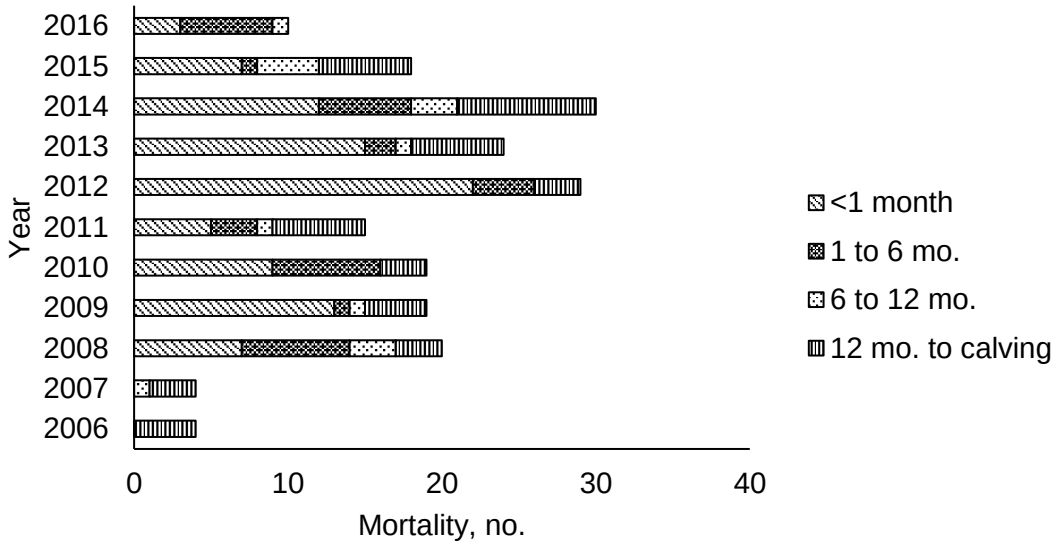

Figure 3: Rearing period mortality of heifers born alive between birth and first calving from 2006 to 2016

During the perinatal and neonatal periods (birth to 1 month), reasons for mortality were largely unexplained, with 62.4 % of mortality due to 'death', followed by 13 % as a result of enteric disease and 10.8% due to pneumonia (Table 5). The highest overall level of mortality, 86.2%, occurred in the neonatal stage of development, from 3 to 30 d of age. During the early growth period, from 1 to 6 months, mortality rate was 42.9% and the most frequently recorded reason for this mortality was; 'died', followed by pneumonia, enteric disease and emergency slaughter, which encompassed 'shot', 'broken leg' and 'injury'. Overall mortality increased between 1 year and calving, during which heifers reached breeding age, with 67% of all deaths due to infertility.

Table 5: Rearing period mortality rate and rationale for heifers born alive between 2006 and 2017, categorised according to age

	Age					
	0 to 48h (n=8)	3 to 30 d (n=85)	1 to 6 mo. (n=35)	6 to 12 mo. (n=15)	12 mo. to calving (n=49)	%
Reasons						
Died	5	53	15	1	3	40.1
Barren	0	0	0	0	33	17.2
Emergency	3	6	2	9	8	14.6
Pneumonia	0	10	10	2	2	12.5
Enteric disease	0	12	2	0	0	7.3
Bloat	0	1	1	2	0	2.1
Freemartin	0	2	1	1	0	2.1
Other	0	1	4	0	0	2.6
Lame	0	0	0	0	3	1.6

Survival analysis (Figure 4) indicated that the majority, 48%, of the total mortality occurred within the first month of life and that substantial numbers of heifers were culled prior to first calving (Table 5) and did not enter the dairy herd. The survival probability estimate was 0.91 at 30 days of age and overall culling rate was 18.8% over the whole rearing period up to calving.

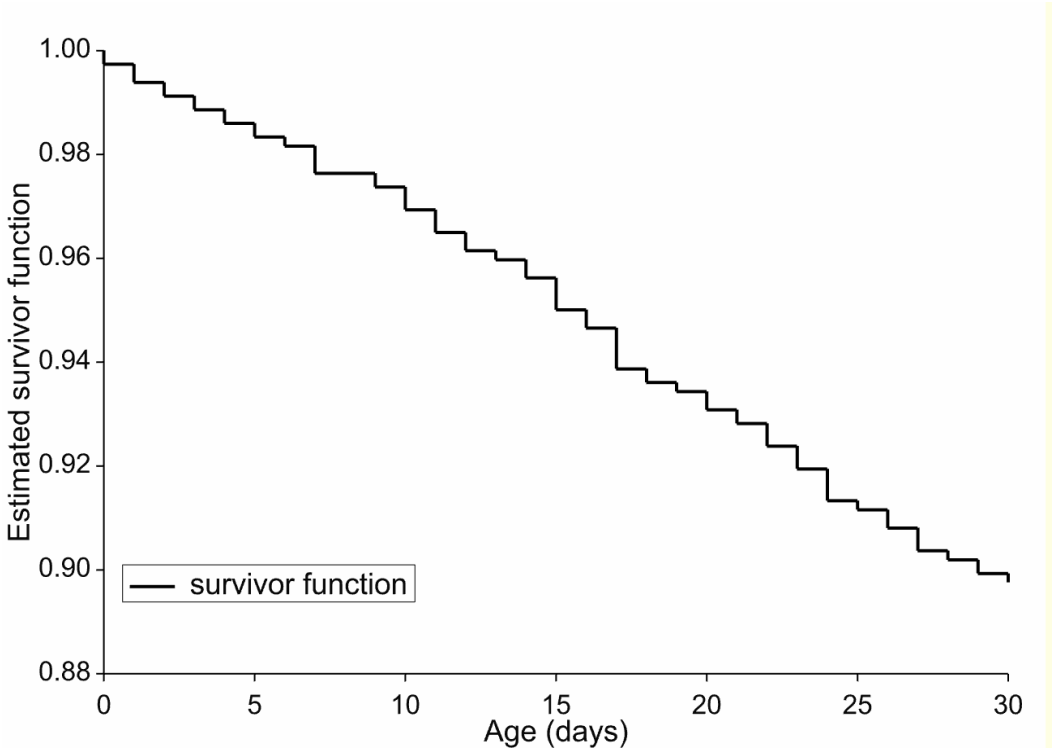

Figure 4: Kaplan-meier curve of heifer mortality up to 30d of age

The Kaplan-Meier survival probability estimates differed between season of birth, according to the seasonal categorisation log rank test (P<0.001). The probability of survival, at 30 d of age was lowest for calves born during winter at 0.86 for December to February, followed by 0.9 for September to November, 0.91 for March to May and 0.92 for June to August (Figure 5).

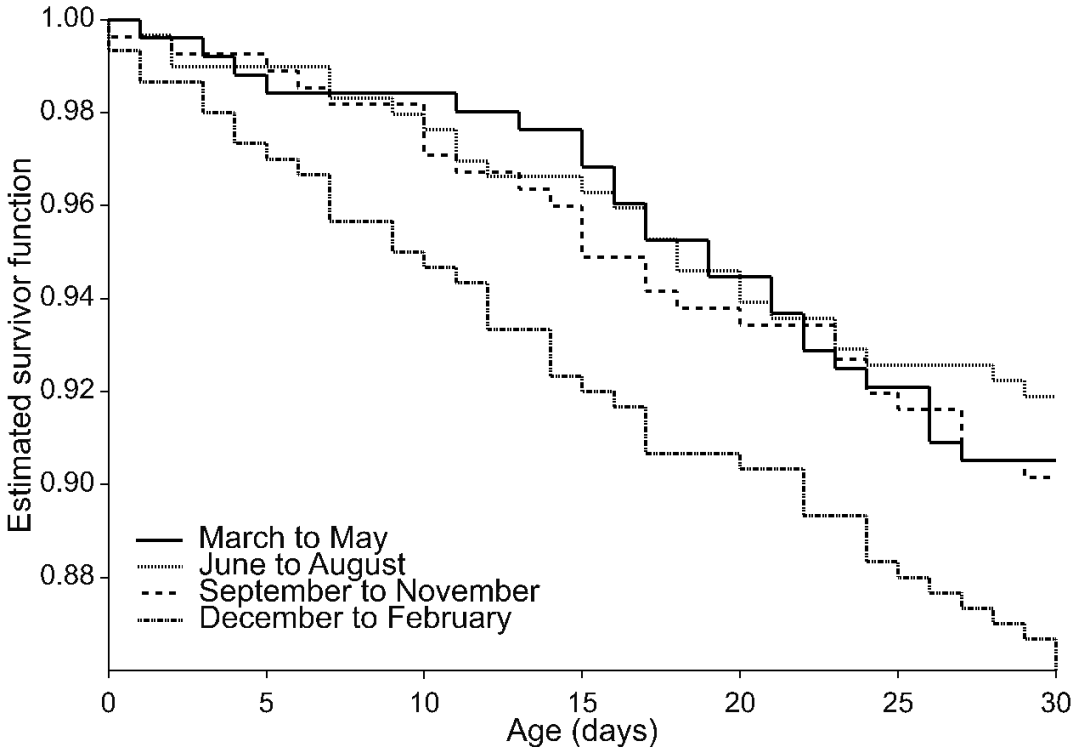

Figure 5: Kaplan-meier curve of heifer mortality up to 30d categorised by season of birth

6.2 Morbidity and treatment of ill health

There was a total of 767 treatments administered to heifers born alive between 31st October 2013 and 29th November 2016, from birth up to calving. During the neonatal period, between 3 and 30 d of age the majority, 67% (n=139), of treatments were due to the diagnosis of diarrhoea, while 25% (n=52) of treatments were administered due to clinical symptoms of pneumonia (Table 6). During the period between 1 and 6 months, pneumonia was the main cause of morbidity, responsible for 94.6% (n=453), of heifer treatments and fewer heifers were treated for diarrhoea. Overall, the total number of treatments was lower once calves were over 6 months of age and very few treatments were administered between one year and calving. The 'other' reasons for which heifers received treatment included; swollen legs, cuts and ear infections.

Table 6: Number of treatments for clinical symptoms of ill health according to age of heifers born between 31/10/13 and 29/11/16

	Age, d					
	0 to 48 h (n=2)	3 to 30 d (n=206)	1 to 6 mo. (n=479)	6 to 12 mo. (n=76)	12 mo. to calving (n=4)	%
Reasons						
Pneumonia	1	52	453	74	3	76.1
Diarrhoea	1	139	11	2	1	20.0
Temperature	0	14	4	0	0	2.3
Other	0	1	11	0	0	1.6

The majority of heifers, 33.1%, received no treatment for clinical symptoms of ill health between birth and calving, while 24.9% were treated once, 13.8% were treated twice and 28.1% were treated three or more times for varying types of clinical symptom of ill health (Figure 6).

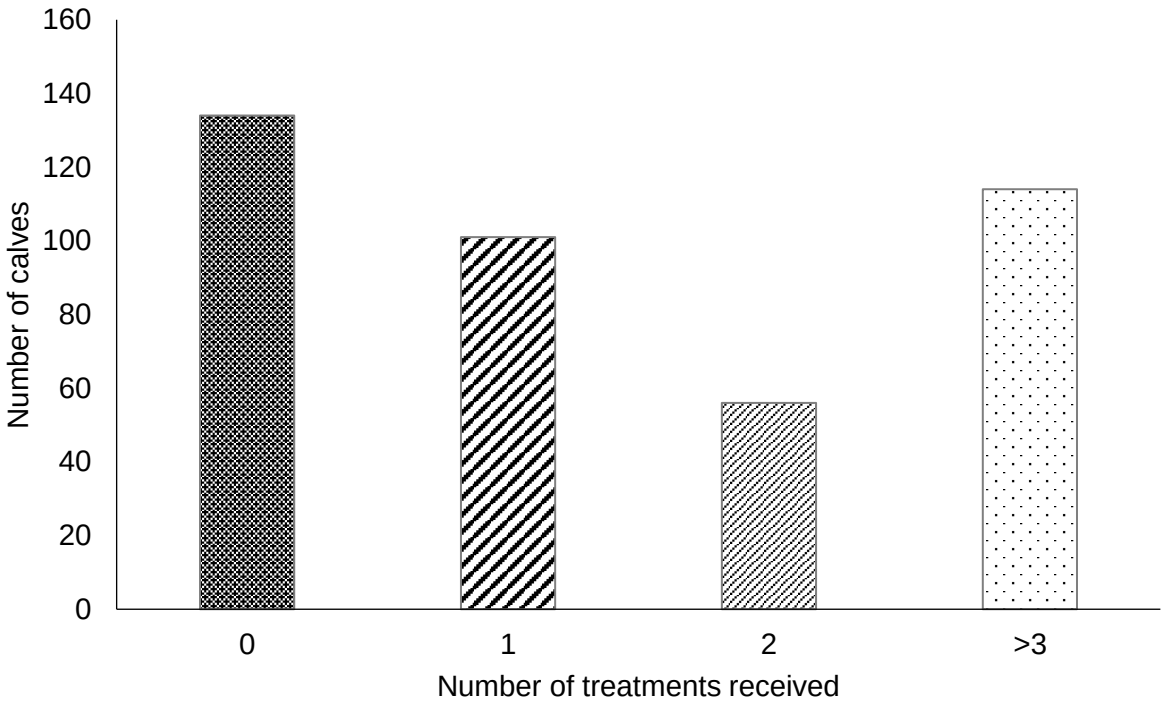

Figure 6: Number of heifers that received zero, one, two, three or more treatments between 2014 and 2016

The treatment of clinical ill health was mainly administered, 50% (n=381), during winter and 202 more treatments were administered during this time compared with the autumn (Figure 7). The main cause in all seasons was pneumonia, with the number of treatments for clinical symptoms peaking in autumn and winter, followed by diarrhoea. Summer had the lowest number of animals treated for clinical symptoms of pneumonia.

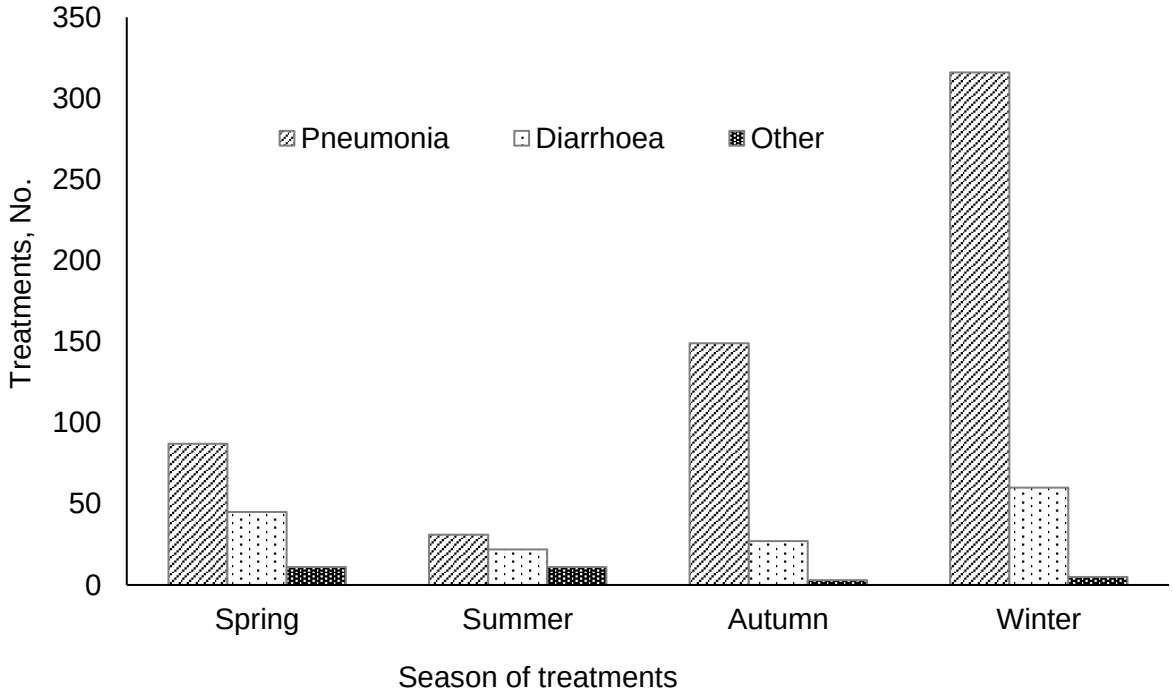

Figure 7: Seasonal distribution of morbidity and treatment of ill health of dairy heifers born between 31/10/13 and 29/11/16

During this study, 99 of the calves for whom data for the treatment of ill health was recorded were old enough to have calved for the first time. This data showed that the AFC was 49 d greater for animals that received 5 or more treatments compared with animals that received none (Table 7), with animals that received the most treatments having the highest mean AFC ($P<0.05$). The live weight of heifers at FC was 41 kg more in those that received no treatment compared with those that received 5 or more, but this did not differ ($P=0.294$) significantly.

Table 7: Mean (±SE) age and live weight at first calving of 99 primiparous heifers according to the number of treatments received, 0 to 5, between 03/10/14 and 08/10/16

	Treatments administered, No.						
	0 (n=20)	1 (n=18)	2 (n=14)	3 (n=12)	4 (n=14)	≥5 (n=21)	P Value
First calving							
Age, days	771 (12.4) [b]	769 (12.4) [b]	780 (14.0) [a,b,]	794 (15.2) [a,b]	788 (14.0) [a,b]	820 (11.5) [a]	0.033
Live weight, kg	630 (12.7)	608 (13.3)	620 (15.1)	622 (16.3)	609 (15.1)	589 (12.3)	0.294

[a, b,] Means followed by differing superscript letters differ significantly

6.3 Age and live weight at calving

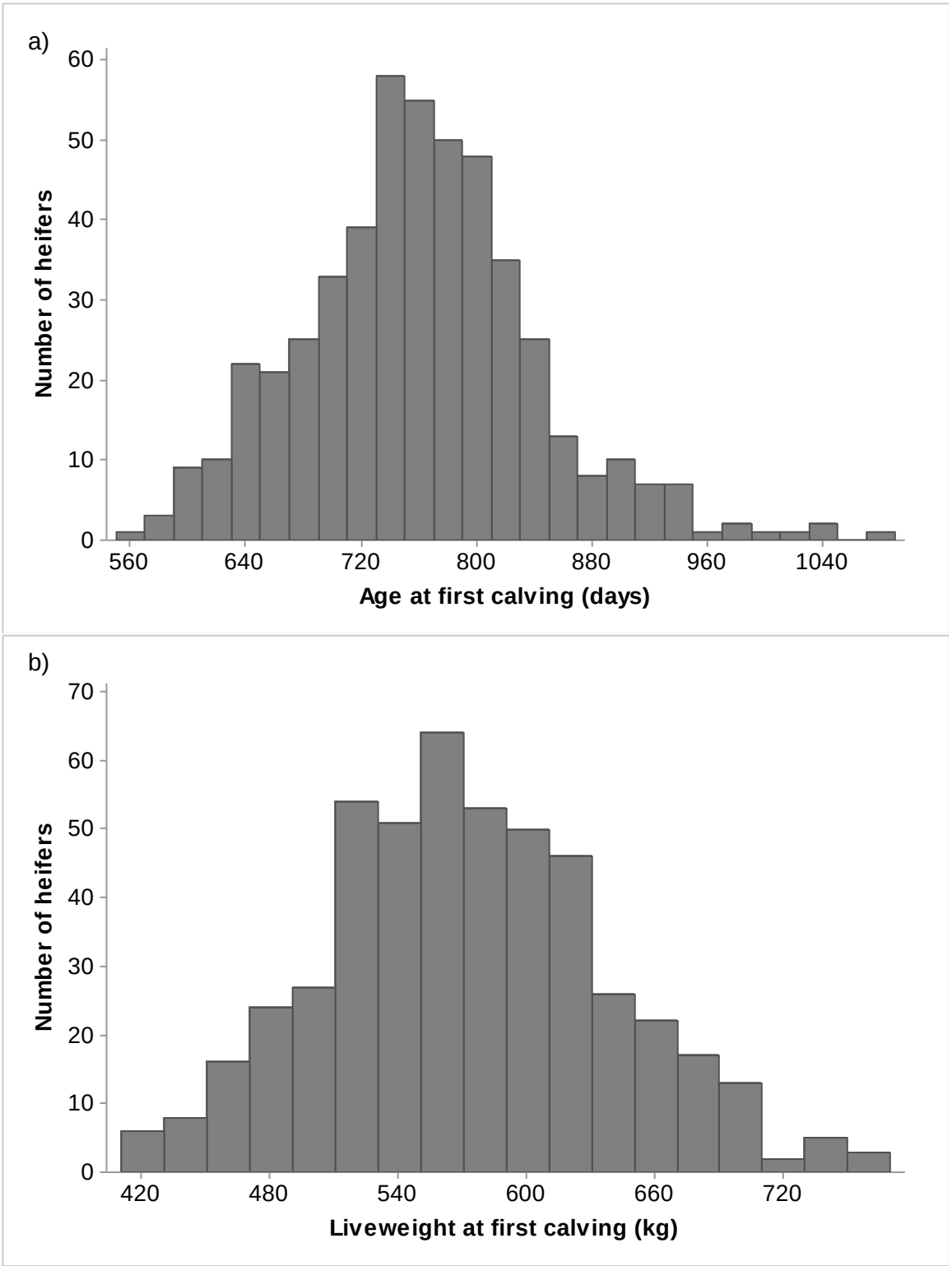

Figure 8: Frequency distribution of a) age at first calving from 2007 to 2017 and b) live weight post-first calving from 2007 to 2017

AFC ranged from 557 to 1071 d with mean and median values of 759 and 754 d respectively (Figure 8a). Live weight at first calving ranged from 410 to 769 kg, with mean and median values of 571 and 567kg respectively (Figure 8b).

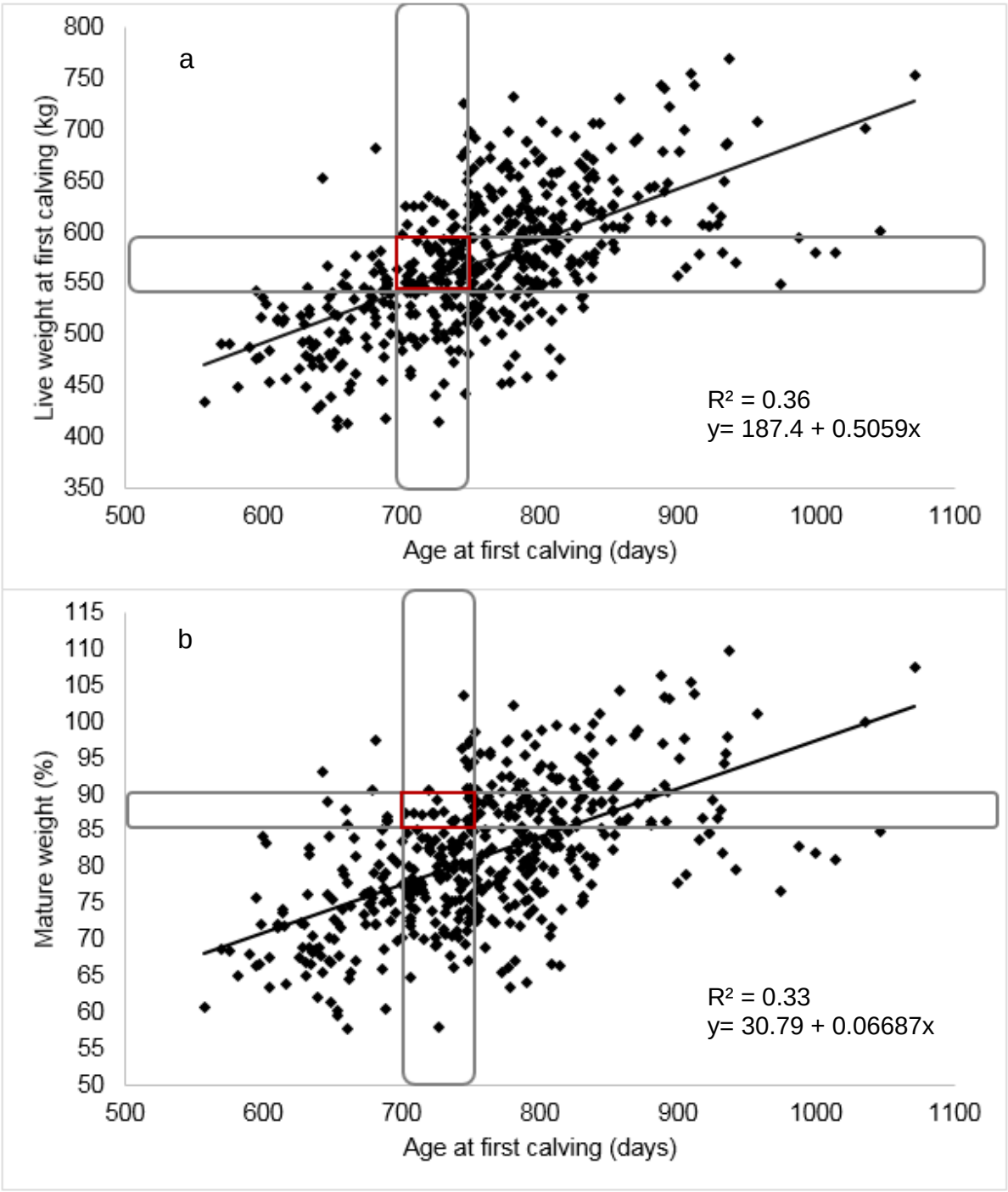

Figure 9: Relationship between a) age and live weight at calving and b) age and mature weight at calving in 487 primiparous heifers. Red boxes represent proportion of animals that met a) age and live weight targets (701 to 759 d and 550 to 650kg) and b) age and mature weight targets (701 to 759 d and 85 to 90%).

The target AFC of 701 to 759 d, was achieved by 155 animals in total, which was equivalent to 31.8% of the population. The estimated target live weight at FC, of 550 to 600 kg according to breed recommendations, was achieved by 133 animals, which was equivalent to 28.3%. Overall, 59 animals achieved both the target age and live weight at FC, which was equivalent to 12.1% of animals (Figure 9a). A weak but positive relationship (r^2=0.36) existed between age and live weight at FC, indicating that as AFC increased, live weight at calving increased and 36% of the variation in live weight was accounted for by age. The target mature weight of 85% to 90% was achieved by 87 animals, equivalent to 17.8% of heifers. Finally, 24 (4.9%) animals in total met the combined age and mature weight targets and there was a weak, but positive, relationship (r^2=0.33) between age and mature weight at FC (Figure 9b), with 33% of the variation in mature weight explained by age alone.

6.4 Age at first calving and primiparous performance of first lactation heifers

6.4.1 All animals

The greatest number of animals, 39.2% (n=191) calved in the late category group at an AFC between 760 and 879 d, followed by 31.8% (n=155) in the target AFC group between 701 to 759 d, 21.4% (n=104) in the early AFC category < 700 d and the least number, 7.6% (n=37), calved in the very late AFC category > 800 d (Table 8). Mean live weight and mature weight was lowest in animals that had an early AFC < 700 d of age, followed by animals that calved at the target AFC between 701 and 759 d, animals that had a late AFC between 760 and 879 d and finally animals that calved very late at an AFC > 880 d of age.

6.4.2 Incomplete first lactation

There were 61 animals that did not complete a whole first lactation due to culling or death. The majority, 44.3% (n=27), of these animals calved late for the first time between 760 and 879 d of age, followed by 29.5% (n=18) at target AFC, 19.7% (n=12) at an early AFC of < 700 d and least, 6.6% (n=4) at a very late AFC of > 880 d of age (Table 8). The live weight at calving was lower for animals that calved early at an AFC < 700 d compared with animals that calved at the target AFC and late AFC, but was not significantly different compared with the very late AFC group. There was no

difference between the four AFC groups with respect to mature weight, daily yield or days in milk in first lactation.

Table 8: Number of heifers, mean (±SE): age, live weight and mature weight (%), milk yield and days in milk of heifers that calved between 2007 and 2017 at: an early age, < 700 d; target age, 701 to 759 d; late age, 760 to 879 d and a very late age, >880 d of age at first calving

	Age at first calving, d				
	Early; <700	Target; 701 to 759	Late; 760 to 879	Very late; >880	P value
Animals, No.	104	155	191	37	-
Age at first calving, d	652 (2.8) [d]	734 (2.3) [c]	804 (2.1) [b]	931 (4.8) [a]	<0.001
Weight at first calving, kg	509 (4.4) [d]	562 (4.4) [c]	597 (3.9) [b]	647 (9.1) [a]	<0.001
Mature weight, %	73.7 (0.78) [d]	80.1 (0.64) [c]	85.1 (0.57) [b]	91.5 (1.32) [a]	<0.001
Incomplete first lactations					
Animals, No.	12	18	27	4	-
Age at first calving, d	663 (7.2) [d]	737 (5.8) [c]	804 (4.8) [b]	927 (12.5) [a]	<0.001
Weight at first calving, kg	523 (16.0) [b]	591 (13.1) [a]	601 (10.7) [a]	591 (27.7) [a, b]	<0.001
Mature weight, %	79.0 (2.40)	83.0 (1.94)	85.0 (1.60)	84.0 (4.12)	0.190
Milk yield, L/d	16.9 (3.80)	25.4 (3.06)	19.9 (2.50)	20.7 (6.50)	0.304
Days in milk, d	204 (49.8)	264 (39.6)	233 (32.6)	274 (86.3)	0.775

[a, b, c, d] Means followed by differing superscript letters differ significantly

Table 9: Number of heifers, age, live weight and mature weight (%), milk yield, days in milk, calving interval and length of dry period of heifers that completed first lactation and calved between 2007 and 2017 at: an early age, < 700 d; target age, 701 to 759 d; late age, 760 to 879 d and a very late age, >880 d of age at first calving

	Age at first calving, d				
	Early; <700	Target; 701 to 759	Late; 760 to 879	Very late; >880	P value
Animals, No.	104	155	191	37	-
Mean age at first calving, d [1]	652 (2.8) [d]	734 (2.3) [c]	804 (2.1) [b]	931 (4.8) [a]	<0.001
Mean weight at first calving, kg [1]	509 (4.4) [d]	562 (4.4) [c]	597 (3.9) [b]	647 (9.1) [a]	<0.001
Mean mature weight, % [1]	73.7 (0.78) [d]	80.1 (0.64) [c]	85.1 (0.57) [b]	91.5 (1.32) [a]	<0.001
Complete first lactations					
Animals, No.	89	115	123	20	-
Mean age at first calving, d [1]	650 (3.1) [d]	732 (2.7) [c]	803 (2.6) [b]	939 (6.5) [a]	<0.001
Mean weight at first calving, kg [1]	502 (5.4) [d]	555 (4.8) [c]	592 (4.6) [b]	652 (11.4) [a]	<0.001
Mean mature weight, % [1]	72.4 (0.79) [d]	79.1 (0.70) [c]	84.3 (0.67) [b]	92.1 (1.67) [a]	<0.001
Mean milk yield, L/d [1]	30.0 (0.58) [b]	32.0 (0.51) [a]	33.3 (0.50) [a]	35.3 (1.3) [a]	<0.001
Mean 305 d milk yield, L [1]	9154 (178.0) [b]	9773 (156.1) [a]	10164 (151.0) [a]	10768 (381.1) [a]	<0.001
Mean days in milk, d [1]	335 (7.7)	347 (6.8)	337 (6.6)0	353 (16.3)	0.494
Mean calving Interval, d [1]	380 (8.0)	400 (7.0)	389 (6.8)	411 (16.8)	0.161
Median dry period, d [2]	43 (33.0 – 52.0) [a]	47 (35.8 - 58.5) [b]	47 (37.0 – 57.0) [b]	54 (43.8 – 59.0) [b]	0.012

[a, b, c, d] Means and medians followed by differing superscript letters differ significantly

[1] Mean (±SE) from GLM ANOVA [2] Median (Interquartile range) from non-parametric Kruskall Wallis and multiple comparisons tests

6.4.3 Complete first lactation

Complete lactations were observed in 347 animals, with 79 yet to finish first lactation at conclusion of the study (Table 9). The live weight of heifers resulted in a mature weight at FC that differed between each of the AFC groups and was lowest for heifers that calved early below target AFC, followed by those calving at target AFC, late AFC and very late AFC >880 d of age. Mean daily yield and 305-d yield were significantly lower for the animals in the earliest calving group of <700 days, compared with animals in the higher AFC groups. However, above the target AFC of 701 to 759 days, milk yield did not increase significantly. There was no significant difference between the four AFC groups in terms of days in milk in first lactation or calving interval. Length of the dry period was significantly lower in the early AFC group compared to the three higher AFC categories.

6.5 Postpartum live weight and primiparous performance of first lactation heifers

Table 10: Number of heifers, mean (±SE): age, live weight and mature weight (%), yield and days in milk of heifers, which did not complete first lactation and calved between 2007 and 2017 at: <500; 501 to 550; 551 to 600; 601 to 650 and >651 kg of postpartum live weight

	Post calving live weight, kg					
	<500	501 to 550	551 to 600	601 to 650	>651	P value
Animals						
Animals, no	74	119	131	103	60	-
Age at first calving, d	681 (7.5) [e]	720 (6.0) [d]	771 (6.7) [c]	807 (6.4) [b]	826 (8.4) [a]	<0.001
Weight at first calving, kg	470 (2.1) [e]	530 (1.7) [d]	573 (1.6) [c]	621 (1.8) [b]	688 (2.4) [a]	<0.001
Mature weight, %	67.9 (0.41) [e]	76.0 (0.33) [d]	81.8 (0.31) [c]	88.1 (0.35) [b]	97.3 (0.46) [a]	<0.001
Incomplete first lactations						
Animals, No.	7	12	15	18	9	-
Age at first calving, d	685 (24.0) [c]	725 (18.3) [b, c]	775 (16.4) [a, b]	798 (15.0) [a, b]	795 (21.2) [a]	<0.001
Weight at first calving, kg	477 (5.8) [e]	531 (4.5) [d]	575 (4.0) [c]	615 (3.7) [b]	679 (5.2) [a]	<0.001
Mature weight, %	69 (1.4) [e]	78 (1.1) [d]	82 (1.0) [c]	88 (0.9) [b]	95 (1.2) [a]	<0.001
Milk yield, L/d	17 (5.0)	20 (3.8)	20 (3.4)	25 (3.1)	17 (4.4)	0.518
Days in milk, d	192 (63.0)	243 (48.1)	245 (43.0)	306 (39.3)	184 (55.6)	0.379

[a, b, c, d, e] Means followed by differing superscript letters differ significantly

Table 11: Number of heifers, age, live weight and mature weight (%), yield and days in milk of heifers, which completed first lactation, and calved between 2007 and 2017 at: <500; 501 to 550; 551 to 600; 601 to 650 and >651 kg of postpartum live weight

	Post calving live weight, kg					
	<500	501 to 550	551 to 600	601 to 650	>651	P value
Animals, no	74	119	131	103	60	-
Mean age at FC, d [1]	681 (7.5) [d]	720 (6.0) [c]	771 (6.7) [b]	807 (6.4) [a]	826 (8.4) [a]	<0.001
Mean weight FC, kg [1]	470 (2.1) [e]	530 (1.7) [d]	573 (1.6) [c]	621 (1.8) [b]	688 (2.4) [a]	<0.001
Mean mature weight, % [1]	67.9 (0.41) [e]	76.0 (0.33) [d]	81.8 (0.31) [c]	88.1 (0.35) [b]	97.3 (0.46) [a]	<0.001
Complete first lactations						
Animals, No.	66	97	92	63	29	-
Mean age at FC, d [1]	680 (7.9) [e]	715 (6.6) [d]	768 (6.7) [c]	798 (8.1) [b]	845 (11.9) [a]	<0.001
Mean weight FC, kg [1]	469 (2.3) [e]	531 (1.9) [d]	573 (1.9) [c]	621 (2.3) [b]	691 (3.5) [a]	<0.001
Mean mature weight, % [1]	67.8 (0.44) [e]	75.9 (0.37) [d]	81.9 (0.38) [c]	88.1 (0.46) [b]	97.6 (0.67) [a]	<0.001
Mean milk yield, L/d [1]	28.4 (0.73) [c]	32.0 (0.60) [b]	33.0 (0.62) [a, b]	33.2 (0.74) [a, b]	35.7 (1.10) [a]	<0.001
Mean 305 day yield, L [1]	8673 (222) [c]	9738 (183) [b]	9976 (188) [a, b]	10132 (227) [a, b]	10897 (335) [a]	<0.001
Mean days in milk, d [1]	350 (8.8)	341 (7.2)	333 (7.4)	353 (9.0)	319 (13.2)	0.140
Mean calving interval, d [1]	395 (9.3)	387 (7.7)	389 (7.9)	406 (9.5)	372 (14)	0.337
Median dry period, d [2]	43 (32.3 - 49.8) [a]	43 (38.0 – 53.0) [a,b]	48 (38.8 - 57.0) [b, c]	47 (39.0 – 60.5) [a,b,c]	55 (43.0 – 62.0) [c]	0.01

[a, b, c, d, e] Means and medians followed by differing superscript letters differ significantly

[1] Mean (±SE) from GLM ANOVA [2] Median (interquartile range) from non-parametric Kruskall Wallis and multiple comparisons tests

6.5.1 All Animals

The largest proportion, 26.9% (n=131) of animals calved in the live weight range of 551 to 600 kg (Table 10), followed by 24.4% (n=119) in the range 501 to 550kg, 21.1% (n=103) at 601 to 650kg, 15.2% (n=74) at <500kg and 12.3% (n=60) at >651kg. Age at first calving differed significantly between all groups, with the optimal mean AFC of 720 days seen in the weight range 501 to 550kg, which is below target. Live weight of heifers resulted in a mature weight at FC that was significantly different between all groups, with the weight ranges 551 to 650 kg containing animals which met the target of 85 to 90% of mature weight.

6.5.2 Incomplete first lactation

Mean values for age at first calving suggest age only differed significantly between the two lowest weight categories (<500 kg and 501 to 550 kg) and highest weight category (>651 kg) (Table 10). Yield and DIM did not differ between live weight categories for heifers that died/were culled before the end of first lactation.

6.5.3 Complete first lactation

Age at first calving differed significantly between all groups, with the lowest AFC seen in the lowest weight category <500kg, followed by 501 to 500kg, 551 to 600kg, 601 to 650kg and >651kg (Table 11). The target AFC of 701 to 759 days was observed in the mean values for the live weight groups ranging from 501 to 650kg. Live weight of heifers resulted in mature weight differences between all groups, with the target mature weight percentage of 85 to 90% reflected in the mean mature weight value for the liveweight range 601 to 650kg. Animals calving at <601kg had mean mature weights well below the target of 85 to 90%. Mean daily yield and 305 d yield were significantly lower in the lowest weight group. Although the highest yield was seen in animals with the highest live weight, yield was not significantly different between groups above a weight of 551 to 600 kg or 81% mature weight. No differences between the 5 groups were present with regards to days in milk and calving interval. Dry period length differed significantly, with animals in the lower weight ranges of <500 to 550 kg exhibiting a significantly shorter median dry period compared with animals that calved within the highest weight range (>651 kg).

A multiple linear regression was calculated to predict 305 d milk yield based on age and live weight at first calving. The predicted 305 d milk yield was equal to:

305 d milk yield = 3809 + 2.95 AFC + 6.69 LWFC (r^2=0.1028, P <0.001)

At a constant AFC, 305 d milk yield increased by 6.69 L for every 1 kg increase in live weight at FC. Live weight was more significant than age in predicting 305 d milk yield (P<0.001 vs P=0.056), which was reflected in the r^2 values for the individual linear regression model (Table 12), however overall, age and live weight at first calving accounted for only 10.28% of the variation in 305 d first lactation milk yield.

Table 12: Individual regression equations for 305-d milk yield in first lactation with respect to live weight and age at first calving

Response variable	Intercept	Slope	r^2	*P*-value
Age at first calving	4966	6.417	0.073	<0.001
Live weight at first calving	4711	9.026	0.096	<0.001

6.6 Culling and survival through first lactation

Heifers that completed first lactation had a lesser (P < 0.05) average LWFC (560 ± 3.5 kg) than those that did not (582 ± 8.3 kg). Mean mature weight was also lower (P<0.05) for heifers that completed (80.0% ± 0.49) versus those that didn't (83.4% ±1.15). No significant difference was present in age at first calving, however animals that completed had a lesser mean AFC of 748 ± 4.3 days compared to 761 ±10.1. Of all the heifers that calved, a total of 61 were culled before the end of first lactation.

Table 13: Culling rationale of 61 primiparous heifers which did not complete first lactation and calved between 2007 and 2017, categorised according to stage of lactation

	Stage of lactation, d						
	0 to 10 (n=0)	10 to 50 (n=7)	50 to 100 (n=2)	100 to 200 (n=17)	200 to 300 (n=11)	>300 (n=24)	%
Culling reasons							
Infertility	0	0	1	6	3	16	42.6
Injury	0	2	0	5	2	2	18.0
Lame	0	0	0	2	2	2	9.8
Died	0	0	0	0	3	2	8.2
Mastitis	0	1	0	1	1	1	6.6
Downer cow	0	0	0	0	0	1	1.6
Calving difficulty	0	2	0	0	0	0	3.3
Udder	0	0	0	2	0	0	3.3
Production	0	0	1	1	0	0	3.3
Other	0	2	0	0	0	0	3.3

Of all heifers culled in first lactation, 39.3% (n=24) were culled at an age >300 days with the main reason being infertility, responsible for over a third of all culls (Table 13). The second highest cause of culling was injury, followed by lameness. The survival analysis indicated that 21.3% were culled within the first 100 DIM (2.5% of all heifers), which increases to 81.3% (10% of all heifers) between 100 and 727 DIM (Figure 10).

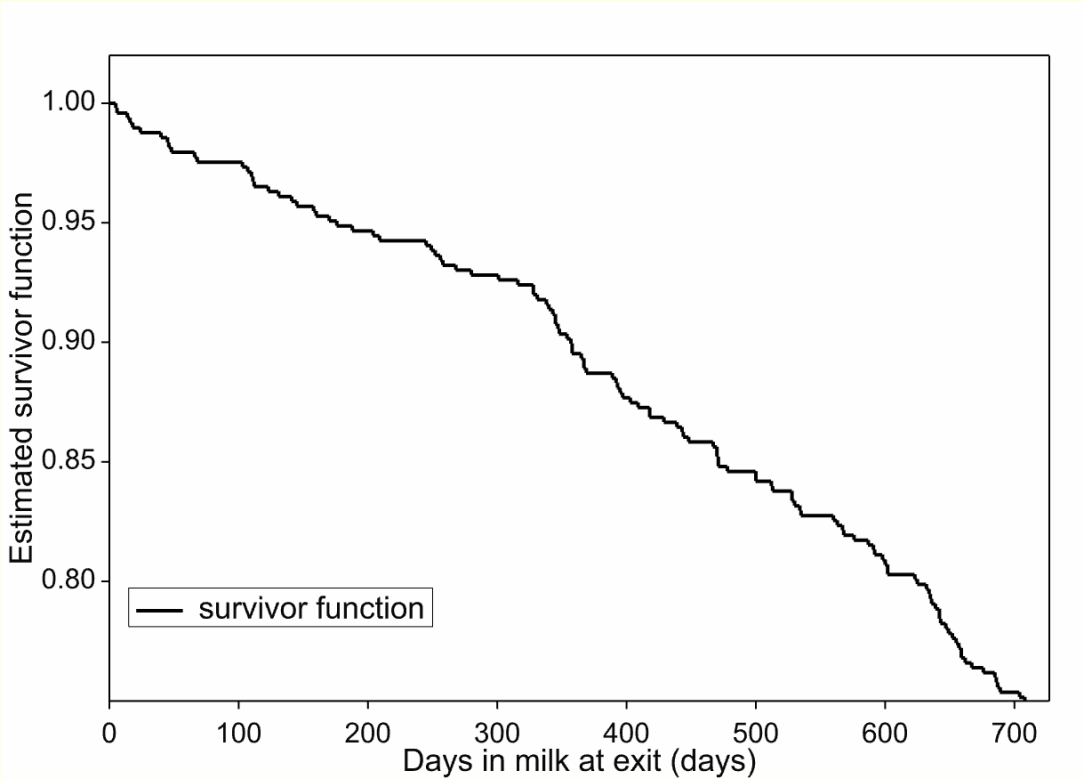

Figure 10: Kaplan-meier curve of primiparous heifer survival through first lactation

6.7 Longevity

6.7.1 Age at first calving and longevity

Of the 487 animals born between 25/01/07 and 06/02/15 that reached first lactation, 12.5% (n=61) were culled in lactation 1, 13.76% (67) in lactation 2 and 14.5% (n=71) in lactation 3. Overall, 40.9% (n=199) were culled in total before the end of third lactation. Analysis of longevity data could only be completed for cows that had exited the herd at conclusion of the study, giving a total of 276 animals.

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Table 14: Number of heifers and median (interquartile range) lifespan, parities per lifetime, lifetime days in milk and days in milk over lifespan of 276 Holstein first lactation dairy heifers according to age at first calving (days)

	Age at first calving, d				
	Early; <700 (n=79)	Target; 701 to 759 (n=92)	Late; 760 to 879 (n=90)	Very late; >880 (n=15)	P value
Lifespan, d	1615 (1304.5 – 1987.0)	1635 (1336.8 – 2036.3)	1570 (1202.5 - 1898.3)	1648 (1355.5 – 2384.0)	0.567
Parities per lifetime	3 (2.0 – 4.0) [a]	3 (2.0 – 4.0) [a, b]	2 (1.0 – 3.0) [b]	2 (1.0 – 4.0) [a, b]	0.041
Lifetime DIM	845 (552.0 – 1181.5)	795 (521.0 - 1103.3)	695 (393.3 – 955.0)	667 (436.5 - 1250.5)	0.177
DIM / lifespan	0.54 (0.410 – 0.600) [a]	0.48 (0.390 - 0.550) [b]	0.45 (0.320 – 0.530) [b]	0.40 (0.320 - 0.520) [b]	<0.001

[a, b,] Medians followed by differing superscript letters differ significantly according to non-parametric Kruskall Wallis and multiple comparisons tests

Table 15: Number of heifers and median (interquartile range) lifespan, parities per lifetime, lifetime days in milk and days in milk over lifespan of 276 Holstein first lactation dairy heifers according to live weight at first calving (kg)

	Post calving live weight, kg					
	<500 (n=57)	501 to 550 (n=78)	551 to 600 (n=71)	601 to 650 (n=52)	>651 (n=18)	P value
Lifespan, d	1703 (1394.0 – 2046.0) [a]	1756 (1342.8 - 2079.0) [a]	1548 (1254.0 – 1963.5) [a]	1507 (1172.5 - 1890.3) [a, b]	1291 (866.0 – 1569.3) [b]	0.006
Parities	3 (2.0 – 4.0) [a]	3 (2.0 - 4.0) [a]	3 (2.0 – 4.0) [a, b]	2 (1.0 - 3.0) [b, c]	1 (1.0 – 2.0) [c]	<0.001
Lifetime DIM	916 (659.0 – 1178.0) [a]	888 (536.0 – 1214.8) [a]	686 (468.5 – 1061.0) [a]	681(389.5 - 921.5) [a, b]	404 (76.8 – 640.0) [b]	<0.001
DIM/ lifespan	0.54 (0.450 – 0.580) [a]	0.51 (0.390 - 0.590) [a, b]	0.45 (0.370 – 0.550) [a, b]	0.44 (0.320 - 0.530) [b]	0.33 (0.140 – 0.410) [c]	<0.001

[a, b,c] Medians followed by differing superscript letters differ significantly according to non-parametric Kruskall Wallis and multiple comparisons tests

There was no significant relationship observed between AFC and total lifespan (Table 14), or lifetime days in milk, although there was a trend for reduced lifetime DIM in animals with an older AFC (P=0.177), with a difference of 178 days between the lowest (<700 days) and highest AFC groups (>880 days). There were outliers present in the analysis for total DIM, indicating the large spread of the data. Number of parities per lifetime was significantly higher in the lowest AFC group (<700 days) compared to the group with an AFC of 760 to 879 days. Longevity index, calculated as DIM/lifespan and representing the proportion of each animal's lifetime spent productive, was significantly higher in the lowest AFC group (<700 days) than all other groups, with animals calving at <700 days spending on average 54% of their life in a productive state. DIM/lifespan decreased with increasing AFC, with animals with an AFC of >880d spending only 40% of their life in a productive state.

6.7.2 Live weight post calving and longevity

Lifespan was significantly shorter for animals calving in the highest live weight group >651 kg than animals with weights ranging from <500 to 600 kg (Table 15), with the longest lifespan observed in the two lightest weight categories (<500 and 501 to 550 kg). Parities per lifetime were significantly lower in the heaviest group (>651 kg), than in the categories <500 to 600 kg with heifers calving at >651 kg lasting for a median of only one lactation. Lifetime DIM was significantly lower in animals in the weight range >651 kg compared to animals in the first three weight categories (<500 to 600 kg) and this is demonstrated in the survival analysis (Figure 11), where survival was significantly decreased in the highest live weight group >651 kg (log rank test P<0.001). Longevity (DIM/lifespan) was significantly different between the lowest live weight category <500 kg and categories >601 kg, with animals calving >651 kg spending only 33.1% of their lifetime productive, compared to 54% for animals calving at <500 kg.

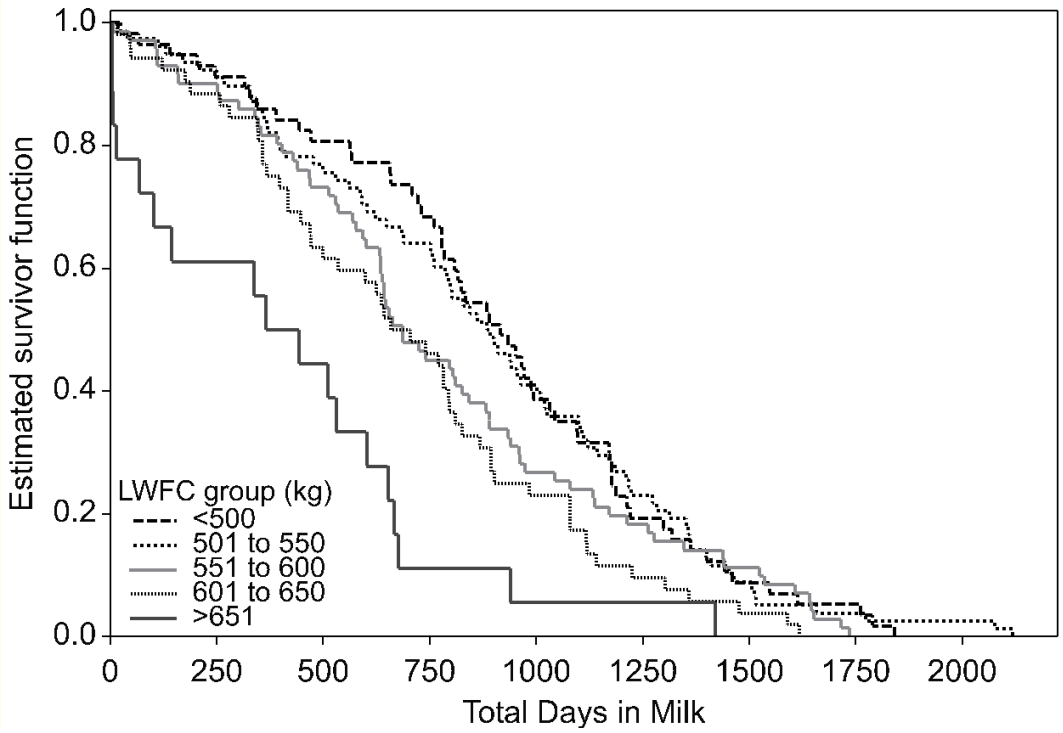

Figure 11: Kaplan-meier curve showing survival time in days in milk according to live weight post first calving category

The relative importance of age at first calving, live weight at calving and 305 d milk yield in first lactation together with respect to total lifetime productivity (DIM/lifespan) were assessed by multiple linear regression. A significant regression equation was found ($P<0.001$) with an r^2 of 0.4697. AFC and LWFC showed significant negative correlations with DIM/Lifetime, with coefficients of -0.028 and -0.057 respectively, suggesting that animals that were older and heavier at calving had reduced lifetime efficiency, supporting the results of the previous GLM analysis. Age, weight and yield in first lactation were all significant predictors of lifetime efficiency, however individual r^2 values suggested yield in first lactation was the strongest predictor of lifetime efficiency compared to either weight or age ($r^2=0.3585$, $P<0.001$ vs $r^2=0.0737$, $P<0.001$; $r^2=0.0424$, $P<0.001$).

7.0 Discussion

7.1 Rearing period morbidity and mortality

7.1.1 Perinatal mortality

In this study, analysis of mortality data during the rearing period highlighted low levels of perinatal mortality, 0.8%, compared to previous UK findings of between 7.8% (Esslemont and Kossaibati, 2002) and 7.9% (Brickell et al., 2009a). This is likely due to the fact that still births and deaths of male calves were not routinely recorded on the farm database and were therefore excluded from the analysis, as opposed to previous studies which have included these in perinatal mortality (Esslemont and Kossaibati, 2002; Brickell et al., 2009a). It is also possible that heifer calves that died within the first 48 hours of life were not always tagged for identification purposes and therefore their death not recorded on the system. Levels of perinatal mortality are often poorly documented on many commercial farms (Ortiz and Pelaez. 2008), with a number of livestock data packages recording heifers as members of the herd only when they have reached first lactation, leading to widespread underestimation of true mortality rate (Wathes et al., 2008). Mortality during the perinatal stage can be due to a number of factors, which include calving practice, twinning and age of the dam (Svensson et al., 2003; Svensson and Liberg, 2006). The level of maturity and pelvic size of the dam can be particularly important, with greater amounts of calf mortality occurring in primiparous dams, often due to inadequate skeletal development, particularly when heifers calve below 24 months of age (Johanson and Berger, 2003). The accurate monitoring of perinatal mortality is therefore essential to ensure calving supervision is appropriate and heifers are of the correct size and proportion of maturity to calve more easily (Raboisson et al., 2013). In addition, improvements in the ability to record mortality in farm livestock databases would enable further evaluation of whether higher levels of perinatal mortality are observed in primiparous dams calving at less than 23 months and/or below target mature weight.

7.1.2 Neonatal mortality and morbidity

In this study, neonatal mortality rate, categorised as calves born alive that die within 48 hours and 30 days of life, was 8.4%, which is towards the higher end of UK findings previously, ranging from 0 to 12% (Brickell et al. 2009a). In a study of 19 UK farms, Brickell et al. (2009a) found that 67% of deaths were recorded as having the cause

unknown, with many producers not assessing and/or recording detailed reasons for mortality. Similar results were found in this study, with 62% of all deaths in the neonatal period simply recorded as 'died'.

Target mortality rates up to one month of age have been proposed to be 3% (Heinrichs and Radostits, 2001), however in practice these rates can be much greater (Wathes et al., 2008; Brickell et al., 2009a). Improvements in the recording of mortality rates, by inclusion of the potential cause of mortality during the neonatal period, could enable a better understanding of risk factors and inform management decisions that may be applied to reduce and prevent calf mortality (Wathes et al., 2008). In this study, the other main reasons causing neonatal mortality, were pneumonia and enteric disease, which were also the primary reasons recorded for treatment during this period, with 206 treatments administered to neonatal calves over approximately three years, between 31/10/13 and 29/11/16.

Inadequate intake or intake of poor quality colostrum can impact on survival and disease level in neonatal calves (Blum and Hammon, 2000; Raboisson et al., 2016). Failure to obtain sufficient immunoglobulins (Ig), defined as failure of passive transfer (FPT), in an adequate timeframe can increase the risk of mortality and compromised health (Raboisson et al., 2016) and this occurs in 11 to 50% of calves (Chigerwe et al., 2008; Windeyer et al., 2014; MacFarlane et al., 2015). In the present study, a colostrum pasteuriser was not fitted until 2017, nor was colostrum quality routinely tested, which may have led to inadequate colostrum management and administration, potentially contributing to the neonatal calf morbidity and mortality rates. However, it would be difficult to assess the exact contributory effect on mortality rates as colostrum absorption and feeding procedure may well have differed between calves, especially when a number of different calf rearers were used (Brickell et al., 2009a).

The herd observed in this study had an all-year-round calving pattern. Up until 2012, calves were reared indoors in small groups, until 1 month of age, when they were moved into larger groups of up to 16 calves. From 2012 onwards, individual outdoor hutches were used for calves of less than 3 weeks of age. An 'all-in/all-out' housing system was not in place throughout the study period and calves were often moved between age groups depending on growth rate, which may have compromised group stability and potentially increased the risk of disease (Lorenz et al.,2011). A study by Pedersen et al. (2009), which compared stable and dynamic group housing of calves, found that the mixing of new born calves with calves of greater ages resulted in more than double the levels of pneumonia and diarrhoea and lower live weight gain

compared to calves maintained in homogenous groups of similar age (810 ± 2.0 g/days vs. 870 ±2.5). Furthermore, housing calves in larger groups of >9 has been shown to lead to greater mortality rates (Losinger and Heinrichs, 1997), with calves in smaller groups of 6 to 9 exhibiting a lower incidence of BRD and higher growth rates compared to groups of 12 to 18 calves (Svensson and Liberg, 2006).

Interestingly in this study, greater neonatal mortality was found between 2012 and 2014, which was following the introduction of individual outdoor calf hutches. This contradicts previous studies, which found lower disease incidence and mortality rates in calves housed outdoors in individual hutches, compared with calves reared indoors (McKnight, 1978; Waltner-Toews et al., 1986; Earley et al., 2004, Lorenz et al., 2011). However, in this study, calves housed in hutches were still mixed with older calves at three weeks of age, potentially increasing the risk of infection. Older calves, which have been exposed to higher levels of disease-causing agents can transmit disease to younger calves, whose immune system is not yet fully functional (Lorenz et al., 2011). The calves were also moved indoors, introducing the risk of greater levels of respiratory disease due to higher temperatures and inadequate ventilation (Davis and Drackley, 1998). A cryptosporidium outbreak was also present on farm during this time, along with some incidences of calf diphtheria. This could perhaps explain the higher levels of mortality seen after the hutches were introduced, however a large number of calves were simply recorded as ‘died’ and without detailed reasons for mortality, it is not possible to conclude definitively that the deaths were a result of a virus, bacteria or protozoa.

Season of birth also had a significant effect on neonatal mortality rates in this study, which was in accordance with previous findings (Johanson and Berger, 2003; Raboisson et al., 2013). Calves born in winter (December to February) exhibited significantly lower survival probability rates than calves born in other seasons. Similarly, overall morbidity rate was also highest during winter and 50% of all disease treatments were administered during this season, mainly for pneumonia. It is possible that the high levels of mortality and morbidity observed in winter could have been due to inadequate thermal insulation and/or nutrient provision during colder weather conditions (Earley et al., 2004; Lorenz et al., 2011; Raboisson et al., 2013). At a lower critical temperature of 10-15 ^{o}C in the first two weeks of life and 6-10 ^{o}C after this (Webster, 1984; Davis and Drackley, 1998), calves require extra energy to support basic maintenance requirements, due to cold stress, and this energy should be obtained from increased milk replacer feed rates in young calves (Soberon et al., 2012). Insufficient feeding levels combined with outdoor housing in low temperatures

could therefore have been responsible for the higher morbidity and mortality rates observed in winter.

7.1.3 Heifer mortality and morbidity between 1 and 6 months of age

In this study, of the 924 heifer calves that were alive at one month of age, 3.78% (n=35) died or were culled during the first 6 months of life, similar to previous findings of 3.4% on 19 UK farms (Brickell et al., 2009a). The main cause of mortality during this period was 'died', followed by pneumonia. Pneumonia was also the main cause of ill health for which treatment was administered, accounting for 97.6% of all recorded treatments. A low serum IgG concentration due to the breakdown of passively acquired antibodies in calves over one month of age can increase the risk of respiratory disease such as pneumonia (Earley et al., 2004). Corbeil et al. (1984) showed a correlation between Ig concentrations in calves and incidence of pneumonia and diarrhoea in the first 12 weeks of life, with peak onset of pneumonia occurring between 2 and 4 weeks when serum IgG_1 and IgG_2 and IgA concentrations were at their lowest. Animals of different ages exhibit varying amounts of colostral immunity and response to infection exposure, highlighting the need to keep calves in homogenous groups (Lorenz et al., 2011).

7.1.4 Heifer mortality and morbidity between 6 months and first calving

The main cause of mortality in heifers between 6 months and one year of age in this study was emergency culling, as seen previously (Svensson et al., 2006; Brickell et al., 2009a). The main reason for treatment of ill health in these older calves was pneumonia, however this was at much lower levels than for calves aged between 1 and 6 months of age. In the period between one year and calving, the majority, 67%, of animals were culled due to infertility. This is similar to results found previously, with one of the most common culling reasons between 1 year and calving being failure to conceive (Brickell et al., 2009a; Brickell and Wathes, 2011), indicating the need to assess factors affecting fertility in dairy heifers. The number of services per conception was not routinely recorded on the farm database for heifers in this study and therefore could not be evaluated, as is the case on many commercial farms, where heifer fertility is frequently poorly monitored (Brickell et al., 2009b). Other studies that evaluated conception rates in dairy heifers, have shown that primiparous heifers are often given many more chances to conceive compared with mature cows, inevitably leading to increased AFCs (Wathes et al., 2008; Brickell et al., 2009b). Serving heifers, that may never conceive, multiple times is costly and can add to the

investment required. Improvements in recording of heifer services may enable increased selection, allowing farmers to identify at a younger age heifers which are at risk of poor fertility (Brickell et al., 2009b). It is also essential to monitor growth and development throughout rearing to ensure that heifers have reached the correct stature and live weight for breeding to avoid unnecessary and/or untimely insemination (Wathes et al, 2008).

7.1.5 Heifer morbidity and age at first calving

In the present study, AFC was significantly higher (820d ±11.5, $P<0.05$) for heifers that received five or more treatments in total compared to those that received none (771 ± 12.4) or one (769 ± 12.4), indicating that the amount of disease may have contributed to differences in growth rate and therefore attainment of puberty. Greater amounts of morbidity, especially during the neonatal period, can result in lower circulating plasma IGF-1 concentrations, which are responsible for growth and immune function in dairy heifers (Kerr et al., 1991; Lammers et al., 1999). The circulating IGF-1 levels can be altered by disease, with calves exhibiting an immune response and cytokine production decreasing their food intake, leading to depressed growth and subsequent reduced IGF-1 concentration (Radcliff et al., 2004; Quigley et al., 2006). Brickell et al. (2007) found that smaller calves that had lower plasma IGF-1 concentrations at one month of age were less likely to survive due to a higher susceptibility to infections, compared to those with a higher feed and energy intake. In contrast, calves with higher IGF-1 concentrations at 30, 180 and 450 days were younger at first breeding and therefore calving ($P < 0.05$ to 0.001). The AFC data from this study highlight the need to monitor calf and heifer development using live weight, stature and/or girth, either directly or with precision technology. This would allow growth rate to be matched to target and management/nutrition to be adjusted appropriately and in a timely manner.

Further analysis from this study could involve looking at the influence of morbidity in different rearing stages on attainment of AFC and LWFC. However, due to treatment data being poorly recorded on the study farm and too few animals for which treatment data was available having calved by the end of the study period, this was unfortunately not possible.

In total, of the heifers born in this study, 18.8% failed to calve for the first time and make it into first lactation, due to mortality and/or culling. The number of replacement heifers available was influenced by mortality throughout the rearing period and major

losses can have a huge impact on rearing costs, cost of milk production and farm efficiency, requiring greater numbers of heifers to be reared and severely restricting selection strategies and future herd genetic fitness (Ortiz-Pelaez, 2008; Brickell et al., 2009b).

7.2 Age and live weight at first calving

Currently in the UK, the average AFC is 30 months, equivalent to 913 days (Hanks and Kossaibati, 2016). In the present study, the mean AFC for the study period was lower than this, at 759 days or 24.9 months, which was towards the upper end of the 22 to 24 month AFC recommendations. However, there was a large range in AFC, from 557 to 1071 days (18.3 to 35.2 months), which may be attributed to differences in breeding age due to farm management, variable growth rate during rearing or differing reproductive efficiency (Wathes et al., 2014). Unlike in block calving systems where an age at first calving of 24 months is required to maintain calving pattern, all-year-round calving systems aren't tied to this timeframe and there can often be the temptation to increase the rearing period length for heifers that aren't considered big enough for breeding at 13 to 15 months (Dingwell et al., 2006), with 27% of all heifers in this study not calving until after 800 days of age.

Heifers were served by a commercial company using artificial insemination (AI), with heat detection via tail paint and visual observation. Ease of handling and heat detection are key determinants of successful insemination, with more excitable heifers found to have lower pregnancy rates (Cooke et al., 2012). A lack of handling of heifers can lead to increased levels of cortisol and lengthened time to puberty and visual observations of oestrus have been found to fail to detect up to 37% of animals (Stevenson et al., 2008). However, as heifer conception rate was not routinely recorded on the farm database, it is not possible to define whether the older ages at first calving observed in this study were due to multiple failed inseminations, heifers 'slipping through the net' for selection, or heifer breeding being delayed until the heifers in question were considered of an appropriate size. It is therefore possible that a combination of these factors could have increased the age at conception and subsequent AFC seen in this study.

However, as well 27% of heifers calving above 800 days of age in this study, 6.7% of heifers calved below 21 months, which can also have a detrimental effect on future performance. A younger AFC can result in decreased milk production due to sub-optimal development of the mammary tissue (Serjsen, 2005) and heifers calving

below 21 months are likely to still be growing in first lactation, with more nutrients partitioned for growth than fertility (Wathes et al., 2008). These heifers can struggle to compete for food with mature cows (Grant and Albright, 2001; Hayirli et al., 2002), possibly resulting in greater body weight and BCS losses. Excessive loss of condition during the first lactation impacts energy balance and can delay resumption of oestrus, impacting on fertility and subsequent calving interval (Ettema and Santos, 2004).

Together with age, live weight at calving also varied considerably in this study, ranging from 410 kg to 769 kg, with a mean weight of 567 kg at FC. Growth rate was not measured on this farm and selection criteria for AI was age and visual estimation of size/weight. A study by Dingwell et al. (2006) found that vets and farmers misjudged body weight of heifers in 81% of their attempts, often by as much as 97 kg, and this could explain the variation in LWFC. Surveys have highlighted that many farmers felt that measuring with a weigh scale was impractical on farm, requiring excessive amounts of time and investment (Heinrichs et al., 1992; Heinrichs et al., 2007). However, the wide variation in LWFC suggests that in order to accurately track growth rate and determine correct breeding weight/maturity, more efficient methods of weighing and/or measuring heifer development, which are easy to implement and quick to use, need to be developed.

Traditionally, heifer growth rates have been tracked against breed recommendations, with a live weight target of 550 to 650 kg at first caving for pedigree Holsteins (NRC, 2001; AHDB Dairy, 2012). However, this approach may be inappropriate for herds where there is large variation in size, especially due to modern breeding policies and production systems, which can result in animals varying greatly from breed standards (Bach and Ahedo, 2008). Physiological development of heifers is also dependent not on a particular weight, but a proportion of final mature size and composition (Freetly et al., 2001). It is therefore considered much more appropriate to measure, record and compare heifer growth against mature weight, with targets of 90% pre-calving and 85% post-calving (NRC, 2001, Margerison and Downey, 2005). However, at present, very few studies have evaluated mature weight post-calving and tend to focus on weight according to breed. In this study, mature weight was calculated as an average weight over the first week post-partum of mature cows in third lactation or above for each year that heifers calved. Ideally, in a herd that has wide variation in weight, the mature weight of each individual dam would have been used to evaluate their daughter, however due to data extraction restrictions in this study, this was not possible, which perhaps highlights the difficulty of implementing such a system on

commercial farms at present and potential alterations that are required for recording in dairy farm databases.

The target mature weight of 85% post-calving (Margerison and Downey, 2005) was achieved by only 17.8% of the heifers in this study, compared to the 28.3% which met breed weight recommendations. Only 12.1% of heifers met both of the AFC and LWFC targets; and only 4.9% the combined age and mature weight targets. Farm policy shifted in 2012 from calving at 23 months to calving at 26 months, due to younger calving heifers exhibiting poor performance and struggling to compete in the herd. However, the fact that only 12.1% of heifers met both the age and weight targets together suggests that although heifers were of an adequate age to calve at 23 months, they were below weight targets, which is more likely to be the reason for poor performance than the young calving age alone.

7.3 Influence on future performance

7.3.1 Productivity

Live weight and age are highly correlated, and as such it can be hard to separate the effects of each, with studies producing differing conclusions (Ettema and Santos, 2004; Serjsen, 2005; Cooke et al., 2013). First calving at less than 23 months is thought to result in reduced milk yield, due to insufficient development of the mammary gland (Serjsen, 2005). However, increasing AFC above 24 months does not appear to result in a significant increase in milk yield in first lactation (Ettema and Santos, 2004) and many studies therefore cite 23 to 24 months as the optimum calving age (Ettema and Santos, 2004; Wathes et al., 2008, Cooke et al., 2013; Boulton et al., 2017).

In the present study, animals in the youngest age category of <700 days (<23 months) did have significantly lower milk yields in first lactation, compared with animals calving at 701 to 759 days (23 to 24 months), 760 to 879 days (25 to 28 months) and >880 days (>28 months). The mean 305-d yield of heifers calving at <700 days was 9154 ± 178kg, compared to 10768 ± 381kg in heifers with an AFC of >800 days. However, these younger heifers did not meet recommended LW targets, with a mean LWFC of 502 ± 5.4kg, which was equivalent to 72.4 ± 0.79% of mature weight. It is therefore likely that the reduced yields were due to insufficient growth during the rearing period, rather than simply the young AFC. This highlights the need to monitor weight gain (Cooke and Wathes, 2014). As well as lower milk yield in heifers calving below targets

for weight, smaller heifers are also likely to encounter other issues, such as increased risk of dystocia and difficulty competing for feed with older cows, all of which can impact on performance in first lactation (Wathes et al., 2014). Even if initial milk yield is similar for smaller heifers, studies have shown that this is likely to decrease after 50 DIM, perhaps due to them being unable to consume sufficient nutrients to allow them to fulfil their lactation potential, along with requiring nutrients for growth (Ettema and Santos, 2004; Haworth et al., 2008).

In this study, above the target AFC category of 701 to 759 days (23 to 24 months), in which heifers averaged 79.1 ± 0.70% mature weight and 555 ± 4.8kg, milk yield did not significantly increase. Similarly, the live weight at calving analysis showed that milk yield was not significantly greater in heifers calving above the 551 to 600 kg LWFC category, suggesting that once an optimum age and weight were achieved, there was no further gain in milk yield by delaying age at first calving. This is an important observation, because it highlights the fact that although slightly higher yields may be obtained with a later AFC, the cost of rearing heifers for longer, taking into account feed, bedding, housing and labour, could outweigh the benefits of more litres (Boulton et al., 2017). Indeed, even if delaying first calving were to result in significantly increased milk yields in first lactation, Lin et al. (1988) found that heifers which calved earlier produced on average 1475 kg more milk during a 61 month productive period, which was due to a longer productive lifespan (Lin et al., 1988). This has been supported in a more recent study by Cooke and Wathes (2014), who found that although milk production in first lactation was reduced in heifers of a younger AFC, when milk production was evaluated over an extended period of five years, the benefits of calving earlier became more apparent. Heifers in the youngest AFC groups (<23 months and 23 to 25 months) produced total yields of 21072 ± 1400kg and 22477 ± 912 kg respectively, in contrast to heifers calving at >30 months, who produced only 15777 ± 1237 kg. Further analysis, following on from the present study, could therefore involve evaluating yields in second and third lactation in this herd in relation to AFC groups, to determine whether or not the lower milk yields found in the <700 days age category were compensated for over 3 lactations.

A number of studies have reported that live weight at FC has a greater effect on milk yield than AFC (Hoffman, 1997; Ettema and Santos, 2004), with Dobos et al. (2001) finding it to be at least twice as important in determining first lactation yields. The results in the present study supported these conclusions, with live weight found to be more significant than age in predicting 305 d milk yield, which was reflected in the r^2 values for the individual linear regression model. There was a weak overall

relationship between AFC, LWFC and milk yield, which indicates that weight and age were only significant up to a point, above which there was no substantial increase in yield and this point may be established using larger data sets. However, as previously mentioned, it can be hard to separate the effects of age and live weight at first calving and there is the issue of multicollinearity when looking at age and weight in combination, which must be considered in the context of these results.

The rest of the observed variation in yield was likely to be due to post-partum management, nutrition and disease incidence (Van Amburgh et al., 1998), with feed intake in particular directly correlated with milk production (Grant and Albright, 2001). An interesting avenue of further research would be the comparison of intakes of heifers in first lactation with mature cows in third lactation or greater, in order to evaluate whether AFC and LWFC impact on their ability to compete with older cows in the herd. Grouping strategy and competition significantly affect time spent eating and total intake (Grant and Albright, 1995) and previous papers have advocated the benefits of grouping of animals of similar size or development stage in order to decrease variation within groups and increase feed intake and milk yield in heifers (Phelps, 1992; Grant and Albright, 2000; Grant and Albright, 2001). It would therefore be interesting to evaluate whether heifers that are younger at FC have greater DMI and increased milk yields when managed in a separate group.

The length of the dry period is crucial in influencing future performance, with a 60-day dry period thought to be optimal to maintain productivity and health (Akins, 2016). However, recent trends for shortened dry periods have been applied to increase lactation length and energy balance post-partum (Hayirli et al., 2002; Brickell and Wathes, 2011). In this study, the length of the subsequent dry period differed significantly between the heifers in the AFC groups and LWFC groups, with a median of only 43 days seen in the lowest AFC group of <700 days and lowest live weight categories of <500 kg and 501 to 550 kg. Decreasing the length of the dry period can compromise cow health and reproductive performance and colostrum quality has been reported to decrease when cows are continuously milked (Brickell and Wathes, 2011). Therefore, a balance must be obtained between increasing proportion of life spent productive and ensuring adequate dry periods, so that dairy cow health is not compromised.

7.3.2 Fertility

Younger calving heifers which are below targets for mature weight must continue to grow during first lactation, which can result in compromised fertility (Evans et al., 2006). Conversely, later calving heifers can be bigger and mobilise more fat in early lactation, which can delay conception (Wathes et al., 2008). However, studies into the effects of AFC on fertility have produced differing conclusions, with some finding that heifers with an AFC of 23 to 25 months have shorter calving intervals (Ettema and Santos, 2004; Eastham, 2012), whilst another study found no significant relationship between AFC and reproductive performance (Simerl et al., 1992). In this study, the calving interval did not differ between AFC groups and there was only a difference of 31 days between the highest and lowest age categories. Similarly, there was little variation in calving interval between live weight groups, with live weight at FC having no significant effect. The overall mean CI was 392 days, which although above the 365-d recommendations, is still below the UK average of 413 days (Hanks and Kossaibati, 2016).

Indeed, many researchers have argued that a slightly higher calving interval is not necessarily detrimental and propose that it is unrealistic for cows to calve every 365 days given the high yields currently produced (Knight, 2004). It would be interesting to evaluate services per conception in primiparous heifers and cows calving for the second time, to evaluate whether or not primiparous heifers exhibit a lower conception rate (Stevenson et al., 2008). As cows calving for the second time in this study were housed in the main barn with the rest of the herd, it follows that oestrus observation may have been more efficient, with heat detection checks carried out a number of times daily. In contrast, primiparous heifers were housed in a separate bulling shed, which may mean observations were less frequent and heat detection less efficient, however further analysis would be needed to determine whether or not this was the case.

7.3.3 Survival through first lactation

Of the heifers that were old enough to have completed first lactation at conclusion of this study, 17.6% were culled before reaching second lactation, which was similar to previous UK findings of 19% (Brickell and Wathes, 2011). The main cause of culling was infertility, which was responsible for 42.6% of all deaths, with reproductive performance one of the most common factors responsible for culling in first lactation (Esslemont and Kossaibati, 2002). Whether or not heifers completed was not

significantly associated with age at first calving, differing from previous studies (Bach, 2011; Cooke et al., 2013). However, animals that did complete first lactation had a lesser mean AFC (748 ± 4.3 days) than those that did not (761 ±10.1), with the non-significant result perhaps due to the wide spread in AFC. Live weight, and proportion of mature weight at first calving, were significantly lower for heifers that completed first lactation (560 ± 3.5kg; 80.0 ± 0.49%) than those that did not (582 ± 8.3kg; 83.4 ±1.15%). This could be due to heifers that calve at a higher live weight mobilising more fat in early lactation, resulting in negative energy balance and reducing the success of AI in relation to ovulation, subsequently compromising fertility (Villa-Godoy et al., 1990).

Bach (2011) found disease incidence in the rearing period to be significantly associated with survival in first lactation, with heifers that contracted BRD once, twice or three times less likely to calve for a second time. The treatment of disease in the present study was not routinely recorded on the farm database and instead was obtained from vet records. Due to the short time period for which data on health treatments was available and the fact that the majority of the heifers included in this treatment data had not completed first lactation at conclusion of the study, it was unfortunately not possible to investigate the effects of rearing period morbidity on survival through first lactation. Increased recording of morbidity data on farm databases would allow further analysis of the effects of rearing period treatment of disease on productivity and survival and would perhaps enable farmers to more easily detect and manage heifers with multiple incidences of disease (Brickell and Wathes, 2011; Bach, 2011).

7.3.4 Longevity

In recent years, there has been a shift from a focus solely on first lactation performance in heifers, to a greater interest in lifetime productivity and longevity (Wathes et al., 2014). Improving these can provide huge economic and environmental benefits, increasing the return on the initial investment made in the rearing period and decreasing the number of replacements required (Garnsworthy, 2004; Wathes et al, 2008).

In this study, mean lifespan, calculated as the difference between date of birth and exit from the herd, was 4.5 years, with a median of 4.4, which was slightly below the current UK median of 6.1 years (Hanks and Kossaibati 2016). Lifespan did not differ between AFC groups, however, heifers in the older AFC groups would have spent a

greater proportion of their life in a non-productive state, but still had a long lifespan, making them appear deceptively efficient. Total days alive is therefore a poor measure of efficiency and it is instead much more appropriate to look at proportion of life spent productive, calculated as DIM/lifespan (Haworth et al., 2008). The proportion of productive life, also known as the longevity index (LI), was greatest in animals calving in the two lowest AFC groups (<700 days and 701 to 759 days), which spent, on average, over half of their life in a productive state, compared to just 40% in the oldest AFC group (>800 days). These heifers calve earlier, so start lactating sooner, and with no difference in calving interval, start second lactation at a younger age. These findings support those of Cooke et al. (2013), who found that animals calving at 23 to 25 months had increased lifetime days in milk and spent 45% of their lives lactating compared to just 34% for heifers aged >30 months at calving.

Total DIM was not significantly different between AFC groups, differing from previous findings (Cooke et al., 2013), although there was a trend for reduced lifetime DIM in heifers with an older AFC. However, there were outliers present in this data, indicating the large spread around the median, which could have impacted on significance level.

The mean age at which animals exited according to lactation in this study was 2.7 with a median of 3, which was slightly below the UK median of 3.6 (Hanks and Kossaibati 2016). The total number of lactations differed significantly between AFC groups, with a median of 3 lactations for the youngest AFC groups (<700 days and 701 to 759 days), compared to just 2 lactations for animals calving at >759 days. However, in the lowest AFC group, milk yield in first lactation was compromised, and therefore it could perhaps be argued that calving between 701 and 759 days (23 to 24 months) is the best overall solution for optimum performance, ensuring a balance between productive life and milk yield, which is in agreement with previous findings (Ettema and Santos 2004; Brickell and Wathes 2011, Cooke et al., 2013; Cooke and Wathes, 2014).

Although a couple of previous studies (Haworth et al., 2008; Cooke et al., 2013) evaluated the effects of AFC on longevity index, none have evaluated LI in relation to LWFC, which multiple regression analysis revealed was a significant predictor of lifetime efficiency. In the present study, animals calving below 650 kg spent significantly more time in a productive state than animals calving >651 kg, with the highest longevity index, 54%, found in the lowest weight category of <500 kg. Lifetime DIM, survival and parities per lifetime were significantly lower in the higher weight at FC categories, with animals calving at >651 kg surviving for an average of only one

lactation. This, combined with the findings from the AFC analysis, suggests that animals that were heavier and older at first calving had reduced lifetime efficiency in terms of proportion of life spent productive, perhaps due to compromised fertility or severe negative energy balance in early lactation reducing their ability to fulfil their nutrient potential (Ettema and Santos, 2004; Haworth et al., 2008).

Multiple regression analysis of AFC, LWFC and milk yield in first lactation on longevity index revealed that yield had more of an influence than weight or age, with significant positive correlations between milk yield in lactation 1 and overall lifetime efficiency. A study by Haworth et al. (2008) found that heifers with low yields in first lactation also had lower yields in subsequent lactations, which could provide an early indicator of lifetime efficiency and impact on the decision on whether or not to retain these animals. However, as mentioned previously, it is difficult to separate the effects of AFC, LWFC and milk yield, with multicollinearity perhaps impacting on the results seen and further analysis of the combined effect of these factors is therefore required in future work.

Increasing the longevity index of animals is especially pertinent, given the increasing concern regarding the contributions of dairy cattle to environmental pollution, with the dairy sector responsible for 4% of total anthropogenic greenhouse gas emissions and 30% of nitrogen excretion by livestock (Garnsworthy, 2004). Dairy heifers in the non-productive rearing period make significant contributions to methane emissions on-farm and calving more heifers closer to the target calving age, without inducing longer calving intervals, would lead to a greater proportion of their life being spent in a productive state (Cooke and Wathes, 2014), resulting in more milk per day of life, reduced overall methane and nitrogen pollution and fewer replacements required on-farm (Garnsworthy, 2004).

7.4 Conclusion

In this study, optimum performance with regards to milk production, lifetime productivity and longevity was achieved with an AFC of 701 to 759 days (23 to 24 months), a LWFC of 551 to 600 kg and a proportion of mature weight at calving of 79 to 81%. Live weight at first calving was a greater predictor of first lactation performance than age. Milk yield was lower in heifers calving for the first time at <700 days (<23 months) and at a LWFC <500 kg, however above this AFC and LWFC, milk yields were not significantly greater, suggesting that once this optimal target AFC and LWFC were reached, there was no benefit to delaying AFC any further. Analysis of

the combined effects of weight and age revealed that both were significant in influencing lifetime performance and longevity. The proportion of life spent in a productive state was greatest in heifers calving for the first time at less than 759 days and a LWFC of 550 kg, with these animals spending on average 48 to 54% of their lives in a productive state. Calving at a LWFC >651 kg resulted in a decreased productive lifetime, further supporting the argument that there is little advantage to delaying calving above target weight. It is crucial that farms measure growth rate, in some way, during the rearing period to adjust management and feeding levels appropriately and ensure that heifers meet both age and weight targets at breeding to increase the likelihood of successful insemination and achievement of AFC and LWFC recommendations. Finally, this study shows that optimising AFC and LWFC has huge benefits for lifetime productivity and longevity; reducing the number of replacements required and increasing the overall efficiency of both youngstock rearing and the milking herd.

7.5 Future work and developments from this research

Further research is required to model the economic impacts of different rearing rates to first calving, with heifers reared either on a low input, forage-based diet for slower ADG and older AFC; or a high-input, high-protein diet for faster rates of gain and younger AFC. As touched on previously, one of the main arguments still presented by producers against a younger AFC is the extra expense that may be incurred by the higher feeding rate required to produce increased weight gain in heifers (Wathes et al., 2014). Cost analyses for a range of AFCs in different systems, which evaluate feed, bedding and labour expenses in the rearing period, as well as the impact of AFC/LWFC on milk yields and survival, would enable farmers to adjust feeding and growth rates appropriately, choosing the strategy most appropriate for their system.

This study has highlighted the effects of optimising age and live weight at calving on longevity and lifetime productivity. However, recent research suggests that other components of young stock management such as feed efficiency can also have significant impacts on whole farm efficiency and profitability (Berry and Crowley, 2013; Connor, 2014). Previous measures of feed efficiency have focused on conversion efficiency of the milking herd, calculated as milk production per unit of feed input (Hurley et al., 2016). However, the concept is rarely mentioned for the dairy heifer, which opens up the possibility of further study into methods of defining FE in young

stock and development of key performance indicators and benchmarking tools for producers to use on-farm.

Although this study did evaluate the impact of morbidity on age at calving, health data was only available for a small number of heifers for a limited period of time and the impact of disease on survival through first lactation could not be investigated. This is a problem seen throughout the industry, with heifer morbidity often poorly recorded (Brickell et al., 2007) and many software packages not recognising heifers as members of the herd until after first calving (Wathes et al., 2008). A larger-scale study into the impact of different diseases on growth rate and attainment of AFC/LWFC; as well as evaluation of different rearing period factors increasing disease incidence is therefore necessary to quantify the true impact of rearing period morbidity on heifer performance.

Due to modern breeding policies, breed recommendations for weight are often inappropriate in herds with a range of breeds and sizes and it is therefore much more appropriate to evaluate proportion of mature weight (Bach and Ahedo, 2008). However, one of the limitations in this study was extraction of the weights of dams in third lactation or greater in order to calculate mature weight. This problem is likely to be ubiquitous on commercial farms - especially those which don't routinely weigh animals - and strategies which allow easier determination of weight therefore need to be developed. Recent advances in the pig industry have included the development of imaging technology which allows dynamic modelling of pig live weight from top-view images, thereby reducing handling stress (Kashiha et al., 2014). At present, no such technology exists for use in the dairy industry, however this represents an interesting avenue of further research to improve calculation of average daily gain and mature weight on farms.

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