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The effect of dairy heifer pre-breeding growth rate on first lactation milk yield in spring-calving, pasture-based herds

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ABSTRACT

Optimising heifer growth rate may offer an opportunity to improve lifetime milk yield per cow, enhancing the environmental and economic efficiency of dairy farming operations. The effect of dairy heifer pre-breeding average daily weight gain (**ADG_{PB}**) on first lactation milk yield was investigated. This observational study employed a data set comprising 265 Holstein-Friesian, or Holstein-Friesian-cross-Jersey heifers from seven commercial, spring-calving, pasture-based dairy herds, where the major component of the diet was grazed grass. These were weighed at birth and prior to breeding and ADG_{PB} was calculated. Milk recordings were performed throughout the heifers' first lactation and 305-day yield figures calculated from these records. Yields were corrected to 4% fat and 3.1% protein to create standardised 305-day milk yield (**SMY**), which was the outcome of interest. Median ADG_{PB} was 0.72 kg/day. Median 305-day yield was 5 967 kg. Linear regression was used to investigate the effect of weight and genetic, age and first calving factors on SMY. Pre-breeding average daily weight gain, age at first calving and predicted transmitting abilities for milk protein production and calving interval were all significant in the final model, which also included the random effects of farm and month of calving within year. ADG_{PB} was quadratically related to first lactation SMY, with an ADG_{PB} of 0.82 kg/day corresponding to the maximum predicted SMY. The model predicted that a heifer growing at 0.82 kg/day would produce 1 120 kg more SMY than a heifer growing at 0.55 kg/day, 218 kg more than a heifer growing at 0.7 kg/day and 103 kg more than a heifer growing at 0.90 kg/day. Manipulation of heifer growth rate may offer a viable method of increasing first lactation milk yield.

Implications

This study examined the relationship between growth rate prior to a dairy heifer's first breeding and her subsequent milk production in spring-calving herds where grazed grass formed the major component of the diet. Increasing growth rate prior to first breeding, up to 0.82 kg/day, was associated with higher milk yield per cow in first lactation, with a very minor detrimental effect on milk yield above this threshold. Aiming for higher growth rates in early life may offer an opportunity to increase milk production during first lactation.

Introduction

As the effects of agricultural processes on our environment become ever more apparent, it is clear that these processes need to become more efficient in order to reduce their environmental impact. If milk production per cow can be improved within existing dairy systems, the impact of dairy farming on our environment could be reduced per unit of product. Increasing average daily weight gain (**ADG**) in early life may offer an opportunity to do this.

Studies investigating the association between ADG prior to first breeding and subsequent lactation performance have delivered equivocal results. A meta-analysis by Soberon and Van Amburgh (2013) found that for every 1 kg increase in pre-weaning ADG, first lactation milk yield could be expected to rise by 1 550 kg. Chuck et al. (2018) later concurred, also finding that there was a positive relationship between early life growth and subsequent milk production. Others have not found an effect of increasing early-life ADG on first lactation milk yield (Kiezebrink et al., 2015). Complicating matters further, some have suggested that the relationship between early life growth rate and first lactation milk yield is not necessarily linear. Both Zanton and Heinrichs (2005) and Gelsinger et al. (2016) demonstrated a quadratic relationship between ADG (pre-pubertal and pre-weaning, respectively) and first lactation milk yield. Possible mechanisms for the observed effects include greater body size or body condition at calving of faster-growing heifers and, in seasonal systems, the impact of ADG on age at first calving (**AFC**) and consequent lactation length. The influence of ADG on mammary development and age at puberty has also been proposed (Roche et al., 2015).

A possible confounding issue is whether any of this research is relevant to the low input, seasonally calving, pasture-based system typical in Ireland, New Zealand and other temperate dairy regions. There has been little research carried out on this topic in these systems, the

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majority having been undertaken in more intensive indoor systems, for example in the US (Soberon et al., 2012) and Canada (Kiezebrink et al., 2015). While accepting the heterogeneity inherent in all of these systems (Mee and Boyle, 2020), confinement systems have adopted a different cow genotype to that typical of a pasture-based system. There are also major differences between these two systems when nutritional and reproductive management, production goals and type and incidence of disease are considered (Mee and Boyle, 2020). Thus, there is a knowledge gap surrounding the effects of early life ADG in pasture-based systems.

The results derived from the small number of studies that have been carried out in grass-based systems are also conflicting. Macdonald et al. (2005) in a New Zealand study found that an accelerated pre-pubertal growth rate had a negative impact on milk yield when corrected for early lactation BW. Meanwhile, an Australian study found that pre-pubertal ADG had a significant, positive effect on lactation performance (Chuck et al., 2018). Further studies are necessary to elucidate the relationship between early life ADG and first lactation performance within the context of a pasture-based system, particularly in Ireland, where full-time grazing is typically alternated with a period of confinement over winter. Thus, the aim of this study was to investigate the relationship between average daily weight gain between birth and breeding ($\mathbf{ADG_{PB}}$) and first lactation milk production in cows in spring-calving herds with pasture-based production systems. The authors hypothesised that a relative increase in ADG_{PB} would be associated with an increase in first lactation 305-day yield.

Material and methods

Data

The data set used in this study was as per Hayes et al. (2019). This comprised data from 399 heifers born in the spring of 2015 and 2016 on a convenience sample of seven dairy farms in Counties Wicklow and Kildare in the Republic of Ireland. The farms were chosen because they were part of a herd health management programme run by University College Dublin ongoing at the time of data collection (Hayes et al., 2019). On these farms, the majority of the herd calved between January and April and the major component of the diet was grazed grass. Data were collected at individual heifer level. They included birth weight, weight prior to the individual farm's mating start date (**MSD**) (in the summer of 2016 or 2017, the year following the heifer's birth year), breed, the cows' predicted transmitting abilities (**PTA**) and sub-indices of the economic breeding index (**EBI**) (Teagasc, 2014) and estimated mature bodyweight calculated from the maintenance sub-index (McParland et al., 2017). Weight data were collected by the farmers using their own electronic weigh scales (Hayes et al., 2019). Average daily weight gain was calculated from the birth and pre-breeding weights. Age at MSD ranged from 379 to 472 days, with a median of 444 days (interquartile range (**IQR**) 436–452). Eighty-five per cent (339 out of 399) of heifers were Holstein Friesian (**HF**), with the remainder HF-Jersey crosses. Of the seven farms, two had a proportion of HF-Jersey cross heifers, the other farms having exclusively HF animals. Mean BW at birth was 35.54 kg, with a standard deviation of 5.12 kg. Mean BW at MSD was 344.99 kg, with a standard deviation of 36.6 kg. Further detail on the specifics of this data set, and the variation between farms, is available in Hayes et al., 2019. This original data set was expanded to include each heifer's age and body condition score immediately after first calving and date of first calving. These data were retrieved from the records of the herd health management programme run by University College Dublin (Hayes et al., 2019). Milk recording data were collected from individual cows from their first calving in the spring of 2017 or 2018 (two years after their birth year) until dry-off in the winter of 2017 or 2018. These were then accessed through the Irish Cattle Breeding Federation (**ICBF**) database. Data accessed included number of milk recordings taken during the cows' first lactation. Cows were only retained in the data set when they had three or more milk recordings taken during their lactation. Figures for 305-day milk yield calculated from milk recordings carried out every twelve weeks (i.e. 3–4 milk recordings per lactation, depending on lactation length) have previously been found to be well correlated with 305-day yields predicted from four-weekly milk recordings (Berry et al., 2005). Also retrieved from the ICBF database were 305-day yields of milk, fat and protein. Irish Cattle Breeding Federation calculates 305-day yields using a test day model (ICBF, 2018). The figures for total 305-day milk yield in kilograms were corrected to 4% fat and 3.1% protein content, creating a standardised 305-day milk yield (**SMY**) figure for each animal using the following formula (Faverdin et al., 2011):

$$MY_{standardised} = \frac{MY_{ACT}(0.44 + 0.0055(FY - 40) + 0.0033(PY - 31))}{0.44}$$

where MY_{ACT} = recorded yield in kilograms, FY = recorded milk fat yield in grams and PY = recorded milk protein yield in grams. Cows were excluded from the data set when they had no recorded first calving date and consequently no first lactation or when they had no recorded 305-day yield data. Possible outliers were identified for further consideration when SMY or ADG_{PB} lay outside three standard deviations of the mean. These were then individually evaluated and removed if SMY or ADG_{PB} were considered to be biologically implausible.

Statistical analysis

Data management and statistical analysis were carried out in R version 3.6.1 (R Core Team, 2019). Distributions of data from potential explanatory variables were visually assessed for normality. Scatter plots were visually assessed for linearity of the relationships between potential explanatory variables and the outcome variable, SMY. These comparisons of the relationship revealed a non-linear relationship between ADG and SMY (Fig. 1). A mixed effects linear regression model was used to investigate the effect of ADG_{PB} and other explanatory variables on milk yield in the cows' first lactation, with SMY as the outcome variable. This was performed using the 'lme4' (Bates et al., 2015) and 'lmerTest' (Kuznetsova et al., 2017) packages in R. Univariate analysis was conducted using a mixed effects linear regression model with farm and month of calving within year as random effects and SMY as the outcome variable. Variables significant at $P < 0.2$ in the univariate analysis were carried forward to multivariable analysis. Candidate variables were also screened for correlation. Where variables were moderately to highly correlated (>0.6), the variable with the lowest *P*-value

Table 1
Output from a multivariable regression model with farm of origin and month of calving within year as random effects, demonstrating the effect of ADG_{PB}, AFC, PTA for protein production and PTA for calving interval on the first lactation 305-day milk yield of 265 dairy cows from seven Irish herds.

Variable	Estimate (kg of milk[1])	SE of the estimate	*P*-value
ADG_{PB} (kg/day)			
Linear term	25 421	9 431	<0.01
Quadratic term	−15 527	6 430	<0.01
AFC (months)[2]			
23	Ref	Ref	
24	−22	254	
25	38	246	
26	−217	265	
27	−807	330	0.03
PTA for protein production (kg)	59	11	<0.01
PTA for calving interval (days)	82	31	0.01

Abbreviations: ADG_{PB} = average daily weight gain between birth and first breeding; AFC = age at first calving; PTA = predicted transmitting ability of the appropriate sub-index of the economic breeding index; Ref = reference category.
[1] 305-day milk yield, standardised to 4% fat and 3.1% protein.
[2] Number of heifers per category: 23 = 6, 24 = 44, 25 = 160, 26 = 46, 27 = 9.

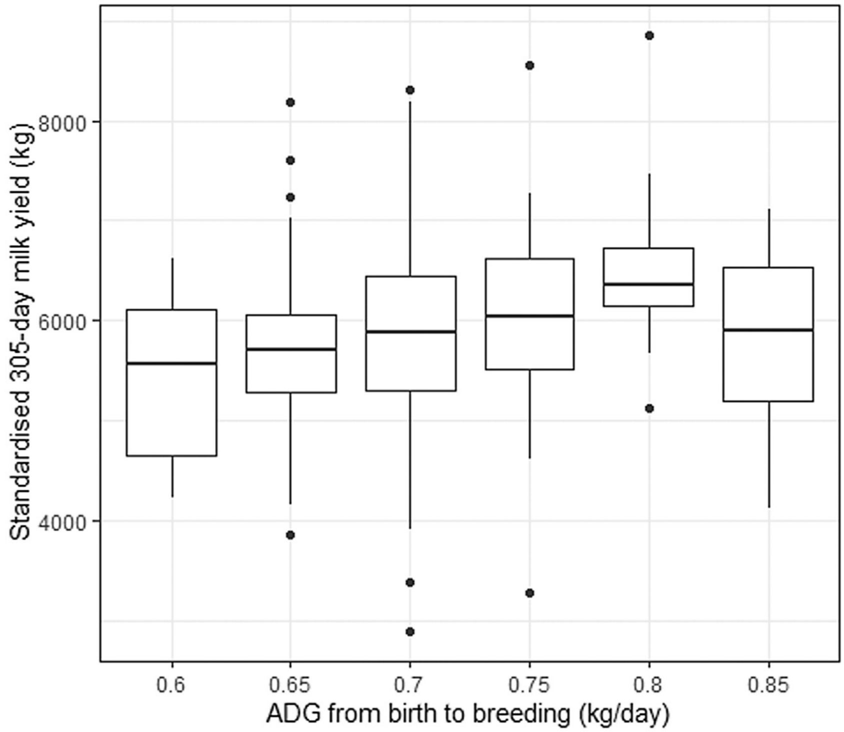

Fig. 1. Boxplot demonstrating the distribution of 305-day milk yield standardised to 4% fat and 3.1% protein across the ADG (between birth and first breeding) of 265 dairy cows from seven Irish herds. ADG = average daily weight gain. Box = interquartile range; midline = median; whiskers = 1.5 times the interquartile range; dots = outliers.

from the univariate analysis was brought forward to the multivariable analysis. The multivariable model was constructed using a backward stepwise method with farm and month of calving within year as random effects and SMY as the outcome variable. At each iteration, the variable with the highest *P*-value ≥0.05 was removed, and *P*-values for the remaining variables were recalculated. This continued until all variables retained within the model were significant at $P < 0.05$. Once completed, all the variables dropped during the backwards elimination stage were retested one at a time for inclusion in the model. Finally, all biologically plausible two-way interactions were tested. The function of the final mixed model may be expressed as

$$y_{ijk} = \beta_{0\ ijk} + \beta_1 X_{1\ ijk} + \beta_{1.2} X^2_{1\ ijk} + \beta_2 X_{2\ ijk} + \beta_3 X_{3\ ijk} + \beta_4 X_{4\ ijk} + e_{ijk}$$

where y is SMY for the *i*th cow, within the *j*th month of calving within year, on the *k*th farm, β_1 is the coefficient for ADG_{PB}, $\beta_{1.2}$ is the coefficient for the quadratic term ADG_{PB}, β_2 is the coefficient for AFC group, β_3 is the coefficient for PTA for protein production and β_4 is the coefficient for PTA for calving interval where X is the respective covariate for cow i.

Following finalisation of the model, the goodness of fit was assessed using the R^2, distribution of residuals and a q-q plot. Residuals were found to be randomly distributed with a mean of 0. They were also found to line up uniformly along a line on a q-q plot. Standardised 305-day milk yield was predicted from the final model and used to identify the ADG_{PB} at which maximal SMY was predicted to occur. The predicted difference in SMY between the optimum ADG_{PB} and a range of different ADG_{PB} was then calculated.

Results

Descriptive analysis

Of the heifers ($n = 399$) in the Hayes et al. (2019) data set, 265 remained in the milk yield data set after exclusions had been applied. From farms A, B, C, D, E, F and G, the final data set contained 26, 21, 34, 11, 43, 44 and 86 cows, respectively. Pre-breeding average daily weight gain ranged from 0.52 to 0.91 kg/day, with a median of 0.72 kg/day (IQR 0.68 to 0.76 kg/day) (Fig. 2). Standardised 305-day milk yield ranged from 2 889 to 8 859 kg, with a median of 5 967 kg (IQR 5 368 to 6 494 kg) (Fig. 3). Age at first calving ranged from 673 to 816 days, median 737 days (22 to 27 months, median 24 months). Body condition score at calving was recorded in 251 of the study animals. This ranged from 3 to 3.5, with a median of 3.25.

Univariate analysis

Following univariate analysis, the following variables were taken forward for consideration in the multivariable milk yield model: ADG_{PB}, estimated mature bodyweight, AFC, sub-indices of the EBI for maintenance and health and PTA of the EBI for kg of milk, kg of fat, kg of protein, calving interval and calf survival. Breed, birth date and weight, body condition score at first calving and beef and calving sub-indices of the EBI were not significant at univariate analysis.

Multivariable analysis

Pre-breeeding average daily weight gain as a quadratic polynomial term ($P < 0.01$), AFC categorised by month ($P < 0.01$), PTA for protein production ($P < 0.01$) and PTA for calving interval ($P < 0.01$) were all significant in the final linear model, which also included farm and calving month within year as random effects (Table 1). In this model, an ADG_{PB} of 0.82 kg/day maximised yield (Fig. 4), with any further increase resulting in a reduction in SMY. Heifers with an ADG_{PB} of 0.82 kg/day were predicted to produce 1 120 kg more SMY than those with an ADG_{PB} of 0.55 kg/day. Heifers growing at this optimal rate were predicted to produce 103 kg more SMY than those with an ADG_{PB} of 0.90 kg/day (Table 2). An AFC of between 23 and 25 months was associated with greater SMY than older categories. An AFC of 26 months was associated with a 217 kg reduction in SMY compared

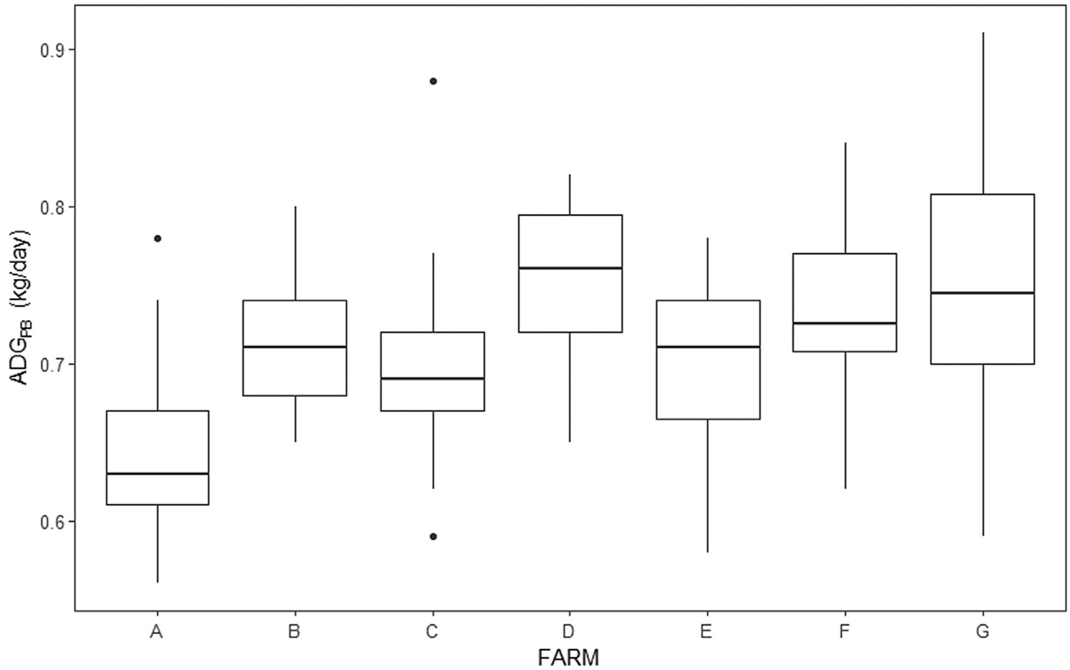

Fig. 2. Boxplot demonstrating the distribution of average daily weight gain between birth and first breeding (ADG$_{PB}$) across 265 dairy heifers from seven Irish herds. Box = interquartile range; midline = median; whiskers = 1.5 times the interquartile range; dots = outliers.

with the 23-month category, while an AFC of 27 months was associated with a 807 kg reduction. A one day increase in calving interval PTA was associated with a 82 kg increase in SMY while a 1 kg increase in protein PTA resulted in a 59 kg increase in SMY. Of the model variance attributed to random effects, the effect of farm was associated with the most variation followed by year and calving month within year. The pseudo R^2 for the fixed effects only was 0.17, while the pseudo R^2 for the full model was 0.68, implying that a substantial portion of variation was due to the random effects.

Discussion

This was a retrospective, observational study of cows in a pasture-based, spring-calving production system, which assessed the impact of early-life growth rate on milk production during their first lactation. The authors had previously investigated the effect of pre-pubertal growth rate on reproductive performance in maiden heifers (Hayes et al., 2019). Few studies have investigated the relationship between ADG and first lactation milk yield within a pasture-based system

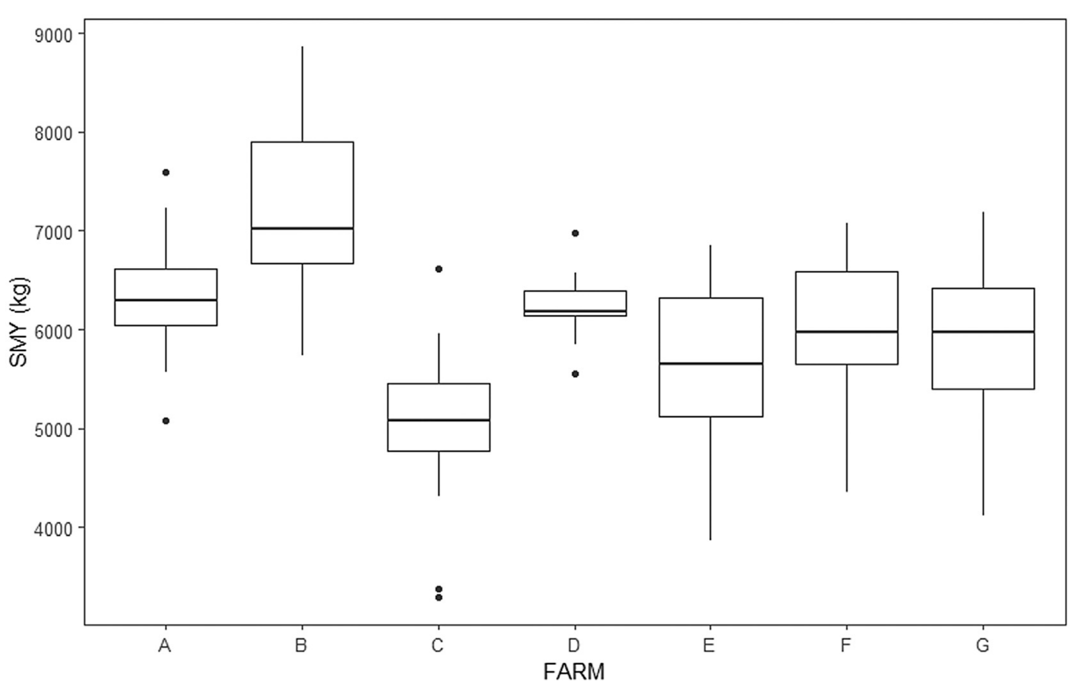

Fig. 3. Boxplot demonstrating the distribution of 305-day milk yield standardised to 4% fat and 3.1% protein (SMY) across 265 first lactation dairy cows from seven Irish herds. Box = interquartile range; midline = median; whiskers = 1.5 times the interquartile range; dots = outliers.

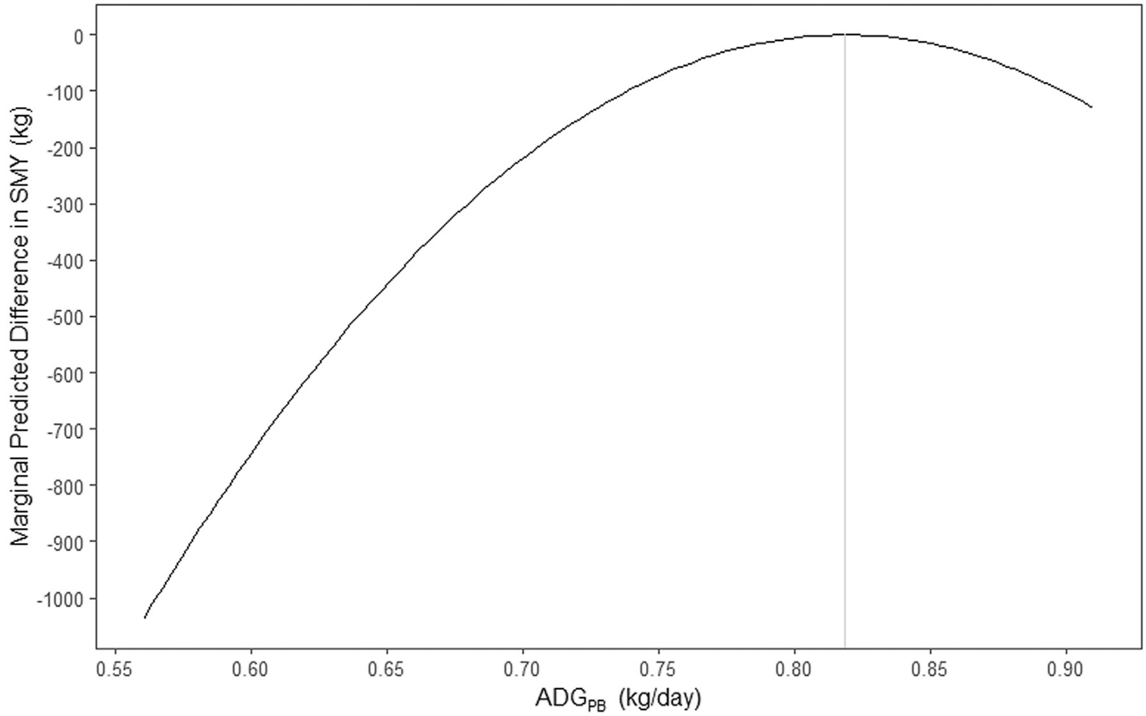

Fig. 4. Marginal predicted difference in 305-day milk yield standardised to 4% fat and 3.1% protein (SMY) of 265 dairy cows from seven Irish herds, as their average daily weight gain between birth and breeding (ADG$_{PB}$) deviates from the optimum 0.82 kg/day.

(Macdonald et al., 2005; Margerison et al., 2013; Chuck et al., 2018), only one of those being observational (Chuck et al., 2018).

The final SMY model contained the quadratic form of ADG$_{PB}$, AFC categorised by month, PTA for protein production and PTA for calving interval, with farm and month of calving within year as random effects. Multiple studies have demonstrated an effect of ADG at various stages prior to first mating on milk production in later life, particularly in the first lactation. However, the outcomes of these studies have not always been in agreement.

Many studies have demonstrated a positive effect of increasing ADG pre-weaning (Soberon et al., 2012; Soberon and Van Amburgh, 2013; Gelsinger et al., 2016) or pre-breeding (Soberon et al., 2012; Chuck et al., 2018) on first lactation milk yield. This is thought to be due to greater mammary parenchymal development in response to a higher plane of nutrition (Brown et al., 2005). In contrast, some studies have not identified a beneficial effect of increased ADG (Kiezebrink et al., 2015). In some cases, there has even been a negative impact associated with a greater ADG during the pre-breeding period (Hoffman et al., 1996; Sejrsen and Purup, 1997). This could have been due to earlier calving leading to lower BW during first lactation (Hoffman et al., 1996), effects on hormonal pathways (Sejrsen and Purup, 1997) or increased mammary fat deposition (Capuco et al., 1995).

There remains no concurrence when studies carried out in a pasture-based context are considered. Macdonald et al. (2005) found that increasing ADG in the pre-pubertal period had a negative effect on milk yield when corrected for early lactation bodyweight. Margerison et al. (2013) found that increasing ADG during the shorter pre-weaning period had a positive effect on first lactation milk yield. The findings of Chuck et al. (2018) contrasted further, demonstrating that there was a positive effect on yield of increasing ADG between 30d of age and breeding, but none from birth to 30d of age.

The magnitude of difference in growth rate in these various studies could offer some explanation as to the contrasting findings, particularly if the effect of growth rate is not linear but quadratic (Zanton and Heinrichs, 2005), as was identified in the current study. We found that the greatest difference in SMY was observed between the lowest growth rates (Table 2), indicating that the greatest benefit is to be gained from improving very low growth rates, as opposed to raising already moderate growth rates, or restricting very high rates. Our findings are comparable to those of Zanton and Heinrichs (2005), who, in a meta-analysis of eight studies, found that there was a quadratic relationship between pre-pubertal ADG and first lactation milk yield, with optimum yield achieved at 0.80 kg/day. A number of the experimental studies included in the meta-analysis compared conventional and accelerated growth rates to investigate the relationship between the two variables (Lammers et al., 1999; Radcliff et al., 2000). These studies found that the accelerated pre-pubertal growth rate impaired subsequent milk yield. Notably, the accelerated growth rates utilised in these studies were above the 0.82 kg/day threshold identified in the current study.

Table 2
Predicted differences in SMY relative to an ADG$_{PB}$ of 0.82 kg/day across 265 first lactation dairy cows from seven Irish herds. As ADG$_{PB}$ increases, the difference between maximum SMY (predicted difference = 0) and the average for that ADG$_{PB}$ category falls until the optimum ADG$_{PB}$ of 0.82 kg/day is reached. As ADG$_{PB}$ increases beyond 0.82 kg/day, SMY once again deviates from the maximum.

ADG$_{PB}$ (kg/day)	Predicted difference in SMY[1] (kg)
0.55	−1 120
0.60	−742
0.65	−441
0.70	−218
0.75	−73
0.80	−5
0.82	0
0.85	−15
0.90	−103

Abbreviations: ADG$_{PB}$ = average daily weight gain between birth and breeding; SMY = 305-day milk yield, standardised to 4% fat and 3.1% protein.
[1] Relative to ADG$_{PB}$ of 0.82 kg/day.

The effect of ADG on subsequent milk yield may also be confounded by the absolute BWs of the animals, which may vary from study to study. For example, Soberon et al. (2012) and Macdonald et al. (2005) found contrasting results on the effect of peri-pubertal ADG on first lactation milk yield. However, mean birth weights, and presumably associated bodyweight at calving, differed between these two studies, with the calves from Soberon et al. (2012) weighing an average of 42 kg at birth, while the corresponding weights from the latter study were 37 kg for HF calves and 29 kg for Jerseys. However, neither birth weight nor bodyweight at MSD was significant in the context of this study. As such, it could be extrapolated that absolute BW at calving does not have as great an influence on first lactation milk yield as rate of bodyweight gain prior to calving. It is important to keep in mind that there will be correlation between these two variables, particularly in a pasture-based system, where start of mating is determined by the required calving pattern of the farm, rather than by age or weight of the heifer. For example, for two animals growing at the same ADG, the one with an earlier AFC will have a comparatively smaller BW at calving. In spite of these interactions though, the findings of this study indicate that rate of growth is still an important factor influencing first lactation milk yield.

Differences in study design could also explain some of these contrasting findings. Observational studies are more likely to conclude that there is a positive effect of increasing heifer liveweight at calving on subsequent milk yield than experimental studies (Roche et al., 2015). This could be due to differences in the timing or composition of weight gain, factors outside the scope of the studies such as colostrum management and parasite control, compensatory growth occurring outside of the period of data collection or lack of power in some experiments (Roche et al., 2015). Year of publication also appears to have an effect, with older studies more likely to conclude that there is a detrimental effect of increased ADG than more recent ones. This may be due to changes in animal genetics over time, with corresponding alterations in the way replacement dairy heifers respond to variation in growth rate. It is also possible that system (pasture-based vs confinement) and corresponding cow genotype have the potential to influence milk yield outcomes. As yet, however, there is insufficient research in pasture-based systems to have enough material to compare.

Age at first calving had a significant effect on SMY in the final model. Optimum milk yield was achieved at an AFC of between 23 and 25 months, with a reduction in SMY evident outside of this range. This is contrary to the findings of many other studies, where an older AFC has previously been associated with greater first lactation milk yield. Possible explanations put forward for this have included reduced risk of dystocia with an older AFC, partitioning less energy to growth during first lactation (Eastham et al., 2018), greater liveweight at calving (Dobos et al., 2001) or delayed AFC being associated with delayed puberty allowing more time for the mammary gland to grow in the allometric development phase (Roche et al., 2015). However, in the context of a seasonal, spring-calving system, an increase in AFC from 23 to 28 months will generally be associated with calving later in the year. Month of calving was included in our model as a random effect to account for seasonal variations over the year. However, in the context of seasonal milk production, calving month is correlated strongly with AFC. Because of this, it is still possible that some of the effect of AFC seen in the model is confounded by calving later in the year. Due to a reduction in the organic matter digestibility of grass in mid-summer (Beecher et al., 2015), as well as flat-rate concentrate feeding (common in seasonal systems) which may be administered to meet the needs of the February-calving majority, a later-calved heifer may not have the nutritional support to reach her potential yield. An additional practical consideration is that, although we analysed SMY, it is commonplace in seasonal systems to dry the whole herd off on a single date, therefore reducing the yield of later calving (and likely older) cows even further. Although it was beyond the scope of this paper to investigate the mechanism by which ADG_{PB} influences first lactation milk yield, the finding that an older AFC was associated with reduced SMY provides some evidence that, in pasture-based systems, the effect is not mediated through age.

The influence of genetics was represented by the PTAs for protein production and calving interval, both of which were significant in the final model. An association between genetic potential for milk yield and fertility has long been recognised, and the findings of this study are similar to previously reported antagonistic relationships (Lucy, 2001). Our results from the current and previous studies (Hayes et al., 2019) suggest that, along with genetic gains, increasing ADG and earlier calving may offer additional benefits to animal productivity in the short and potentially long term.

Farm and month of calving within year were included in the final model as random effects to account for clustering of data by farm and month and year of calving. The random effect of farm in particular was associated with much of the variance in the model. This reflects the importance of individual farm management on first lactation milk yield, as well as the degree to which this varies between farms. It also implies that it may be possible to mitigate some of the effects of a low ADG_{PB} on milk yield with good management practices. The variance attributed to the random effect of month of calving within year could be due to changes in weather, nutritional factors or changes in farm management practices over time. There was a high degree of unexplained residual variance in the final model, implying that unaccounted-for factors were also having an impact on SMY.

As Hayes et al. (2019) discussed, the data used in this study were collected via non-random sampling and may not be representative of the broader population. However, the farms were typical of the Irish dairy system as regards seasonality of milk production, proportion of grazed grass in the diet and youngstock management (Hayes et al., 2019). This consideration is equally relevant to the current study. In the same publication, we also noted that overall growth rate from birth to breeding alone was studied and it was not within the scope of either publication to assess how variation in growth rate at various stages throughout that time period affected outcomes. Studies that have been able to assess this though the collection of multiple sequential weight recordings have demonstrated that the effect of ADG on milk yield can vary depending on the period of growth studied. Chuck et al. (2018) weighed heifers at birth, 30d of age, breeding and calving, concluding that the growth stage between 30d of age and breeding had the greatest positive effect on first lactation milk yield. Sejrsen et al. (1982) and Macdonald et al. (2005) both found that the effect of ADG on subsequent milk yield differed according to whether the growth occurred in the pre- or post-pubertal growth phases. Soberon et al. (2012) suggested that increased energy intake (and by association, increased ADG) prior to weaning had an influence on heifers' ability to produce a positive milk yield response to increased post-weaning nutrient intake and ADG. All this indicates that not only the overall ADG but also the interaction of ADG and stage of growth (e.g. pre-weaning, weaning to puberty, puberty to breeding) will influence milk yield later in life. In Ireland in particular, the widely used hybrid system incorporates a period of winter housing, which can be associated with a reduced heifer ADG compared to subsequent periods of grazing, depending on the diet offered (Kennedy et al., 2013). The current study is unable to consider the effect of alterations in ADG within the overall birth to breeding life stage. In addition, the data set for the current study was limited to include only those animals with sufficient milk recording data for this analysis, reducing the number and thus limiting the power of this study. Despite these limitations, we have identified several key significant variables associated with SMY and ADG_{PB} that are consistent with previous studies, thus indicating that the study had a sufficient number of observations from which to extract statistically robust findings. In addition, though both the number of farms and the number of observations per farm were in some cases limited, these factors were accounted for in the model builds.

In practical terms, the previously discussed limitations of this research acknowledged, our findings indicate that the optimal ADG_{PB} of replacement dairy heifers in seasonal, pasture-based systems to maximise first lactation milk yield is 0.82 kg/day. Our previous research (Hayes et al., 2019) demonstrated a negative linear relationship between ADG_{PB} and days from MSD to conception. Together, these findings indicate that an ADG_{PB} of 0.82 kg/day will enhance reproductive performance while maximising first lactation yield. The median ADG_{PB} in this study was 0.72 kg/day, indicating that many of the study calves did not attain the optimal ADG_{PB} for first lactation milk yield. An additional practical consideration in implementing this advice is that control of ADG in pasture-based systems may be more difficult than in confinement systems, as grass growth and availability will vary over time, both in the short and long term. It must also be noted that further research will be necessary to determine whether this ADG_{PB} is optimal for economic performance. Ultimately, however, monitoring rate of growth would appear to be a useful method of assessing heifer progress towards her maximal potential milk yield.

Enhancing the efficiency of production by enhancing milk yield provides an opportunity to improve the overall economic and environmental efficiency of pasture-based dairy farms. A greater ADG between birth and breeding was associated with increased first lactation milk yield in dairy cows in a spring-calving, pasture-based system, with yield increasing with increasing ADG up to 0.82 kg/day. Additionally, AFC and genetic factors including PTAs for protein production and calving interval were significant in the final model. Thus, manipulation of heifer growth rate may offer a viable opportunity to improve the efficiency of pasture-based dairy enterprises.

Ethics approval

Not applicable.

Data and model availability statement

None of the data were deposited in an official repository. The data are available upon reasonable request.

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Declaration of interest

The authors declare that there are no conflicts of interest.

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