Weight, height, and relative-reliability indicators as a management tool for reducing age at first breeding and calving of dairy heifers

M. Duplessis,^{*1} R. I. Cue,^{†2} D. E. Santschi,[‡] D. M. Lefebvre,[‡] and R. Lacroix[‡]

^{*}Département des Sciences Animales, Université Laval, Québec, G1V 0A6, Canada

[†]Department of Animal Science, McGill University, Ste-Anne-de-Bellevue, Québec, H9X 3V9, Canada

[‡]Valacta, Ste-Anne-de-Bellevue, Québec, H9X 3R4, Canada

ABSTRACT

In Québec first calving occurs on average at 27 mo, whereas the target is 23 to 24.5 mo to maximize herd profitability. The aim of this study was to quantify current and future heifer growth using individual heifer random regressions and to generate indicators (such as heifer weight and height at 15 and 24 mo, average daily gain before and after 15 mo, age at which optimal weight for breeding is attained, i.e., 55% of mature weight, and reliability of the 15- and 24-mo weight predictions) that could be used as a practical on-farm tool. Dairy heifer weight estimated by heart girth circumference and height measured at the withers (from 0 to 27 mo) were obtained from the Valacta database (DHI agency, Ste-Anne-de-Bellevue, QC, Canada) from 1995 to 2012. Indicators were calculated based on the current situation of Holstein (HO), Ayrshire (AY), Jersey (JE), and Brown Swiss (BS) heifer growth in Québec. Heifers with less than 2 records were excluded from the analysis. Mature weights were determined by weight at calving of cows from third or greater lactation for a given breed and were 710 kg for HO, 625 kg for AY, 470 kg for JE, and 670 kg for BS. Estimated weights at 15 and 24 mo were 425 and 627, 334 and 482, 297 and 429, and 379 and 560 kg for HO, AY, JE, and BS, respectively, which are heavy enough for breeding and calving, except for AY. Relative reliabilities of the 15- and 24-mo weight predictions were on average 89 and 60%, respectively, based on measurements up to 15 mo. For HO, AY, JE, and BS, wither heights at 15 and 24 mo were 134 and 143, 125 and 134, 122 and 131, and 130 and 140 cm, respectively. Age at optimal breeding weight was 13.6, 15.5, 12.6, and 14.5 mo for HO, AY, JE, and BS, respectively. These data suggest that it is realistic to expect a first calving at 24 mo for HO, JE, and BS. A growth delay was observed for AY;

average daily gain was 655 and 538 g/d before and after 15 mo, respectively. The average daily gain before and after 15 mo was 848 and 747 g/d for HO, 603 and 486 g/d for JE, and 775 and 662 g/d for BS, respectively. These indicators could be calculated for an individual heifer and on a herd-level basis and used on farm as a management tool for reducing age at first breeding and at first calving.

Key words: heifer growth, age at first breeding, age at first calving

INTRODUCTION

Moore et al. (1991) reported that, on average, age at first calving for Holstein (HO) heifers in Québec was 28.2 mo, whereas 26.5 mo was reported 15 yr later by Pietersma et al. (2006). Despite the slight decrease in the 1990s, age at first calving has not declined over the past 10 yr in Québec, Canada, and is still higher than the recommendation of 23 to 24.5 mo to maximize farm profitability (Ettema and Santos, 2004; Pellerin and Gilbert, 2008). A similar trend in the United States was observed; average age at first calving for HO heifers was 26.9 mo between 1980 and 2004 (Hare et al., 2006), which represents a decrease of 1.3 mo compared with results reported by Nieuwhof et al. (1989) between 1966 and 1986. Using field data from Québec, Pietersma et al. (2006) showed that, at 14 mo, HO and Ayrshire (AY) heifers were large enough to be bred because 59 and 56% of mature BW were already attained at this age, respectively. According to the NRC (2001), the first breeding can occur when 55% of mature BW is reached. These data suggest that it is possible to achieve a first calving at 24 mo. However, in 2013 average age at first calving was still higher than the recommendation and was 27 mo in Québec for HO heifers (Valacta, 2013). Three assumptions can be proposed to explain the delay at which age at first calving occurs: (1) suboptimal ADG; (2) delayed breedings; and (3) underestimation of heifer weight at which first breeding should occur, and hence projected weight at calving.

Using mixed-model methodologies and random regressions, Cue et al. (2012) have developed a model

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¹Current address: Valacta, Ste-Anne-de-Bellevue, Québec, H9X 3R4, Canada.

²Corresponding author: Roger.Cue@McGill.ca

allowing prediction of future growth curves of each individual heifer based upon the weight and height measurements of each heifer, which are updated thereafter as new measurements are available. These authors concluded that age at first calving in Québec above the recommended value could be explained by dairy producers not having accurate tools to predict individual heifer weight at first calving and then preferring to wait 2 or 3 mo for first breeding to ensure that heifers would be large enough at calving (Cue et al., 2012).

This study was undertaken to create an on-farm practical tool to quantify current and future growth of HO, AY, Jersey (**JE**), and Brown Swiss (**BS**) heifers using a predicting model based on random regressions as developed by Cue et al. (2012). To do so, the work of Cue et al. (2012) was extended to report on the current situation of heifer growth in Québec. From the model, indicators were generated, based on observations of the heifer (such as heifer weight and height at 15 and 24 mo, ADG before and after 15 mo, age at which optimal weight for breeding is attained, and relative reliabilities of the 15- and 24-mo weight predictions) that dairy producers could use to aid management decisions about heifer reproduction. Moreover, this study provides a portrait of the current state of heifer growth in Québec for the most popular breeds (i.e., HO, AY, JE, and BS). It is expected that the adoption of this on-farm tool by dairy producers and specialists in Québec would increase the number of dairy-heifer growth measurements, allow better prediction of individual heifer growth, reduce age at first calving, and thereby improve farm profitability.

MATERIALS AND METHODS

Data Collection

Weight, estimated by heart girth circumference, and wither-height data of dairy heifers (from 0 to 27 mo)

were obtained from the Valacta database (DHI agency, Ste-Anne-de-Bellevue, QC, Canada) from 1995 to 2012. The same data set used by Pietersma et al. (2006) and Cue et al. (2012) formed part of this study and was updated to take into account measurements from 2006 to 2012. A complete description of data recording and extraction from the Valacta database was given previously (Pietersma et al., 2006; Cue et al., 2012). Briefly, estimated BW and height records were measured by Valacta technicians in dairy farms participating in the heifer recording option. Body weight was estimated using calibrated weight tapes measuring heart girth circumference. Because electronic scales are not commonly available on Québec dairy farms, estimated BW using a tape is a practical and reliable technique (Heinrichs et al., 1992). For HO, AY, JE, and BS heifers, a total of 401,474, 20,668, 3,226, and 3,563 estimated BW records and 359,650, 18,066, 2,796, and 3,416 wither-height records were collected, respectively.

Mature BW was estimated from Valacta BW records of multiparous cows from the 4 studied breeds (i.e., HO, AY, BS, and JE) from 2007 to 2012. Random regressions were used with a linear model based on a Wilmink function on DIM to estimate average BW at calving (Wilmink, 1987). Mature BW represents the average estimated weight at calving for multiparous cows from third, fourth, and fifth lactations within each breed.

Data Verification

This study was carried out in 2 steps: step one was an update of estimates of equation parameters for HO, AY, and BS breeds of the study of Cue et al. (2012) and an initial estimation of the same parameters (for weight and height) for JE heifers. The second step was an examination of the population growth curves and various indicators that might be used to monitor and assist in improving heifer growth and achieving recommended age at first calving.

Table 1. Numbers of animals and records, before and after editing, for weight (step one)

Item	Holstein	Ayrshire	Jersey	Brown Swiss
Number of animals, before	147,024	7,475	1,788	1,464
Records, initially	401,474	20,668	3,226	3,563
After removing records more than 4 SD from the respective breed-age mean				
Number of animals	145,828	7,439	1,766	1,457
Records	399,437	20,589	3,188	3,555
After imposing the requirement of age at first observation <5 and >19 mo for the last observation				
Number of animals	12,695	572	165	317
Records	91,665	4,746	892	1,497
After imposing the requirement of 4+ records per heifer				
Number of animals	11,269	515	165	317
Records	87,844	4,592	892	1,497

Table 2. Numbers of animals and records, before and after editing, for height (step one)

Item	Holstein	Ayrshire	Jersey	Brown Swiss
Number of animals, before	131,312	6,861	1,585	1,396
Records, initially	359,650	18,066	2,796	3,416
After removing records more than 4 SD from the respective breed-age mean				
Number of animals	130,370	6,789	1,467	1,323
Records	356,194	17,962	2,635	3,324
After imposing the requirement of age at first observation <5 and >19 mo for the last observation				
Number of animals	12,028	482	95	29
Records	86,105	3,784	616	236
After imposing the requirement of 4+ records per heifer				
Number of animals	10,654	422	91	27
Records	82,407	3,624	604	230

Given the fact that data records were obtained from nonedited on-farm measurements, editing to remove any data-entry mistakes was required; see Cue et al. (2012) for examples of calves recorded as weighing 900 kg at 2 mo of age. Tables 1 and 2 present numbers of animals and records before and after editing, for parameter estimation for weight and height, respectively. For step one, initial estimates, based on Cue et al. (2012), were used to compute the expected weight and height for a given age. Individual observations from the raw data set more than 4 standard deviations from the expected weight or height for age were removed. This procedure was iterated upon until no more observations were removed. Heifers having less than 4 measurements and having their first measurement after 5 mo, or their last one before 19 mo, were removed from the data set for estimation of equation parameters. Fixed-effects regression estimates and random-effects variance-covariance components were then estimated, as explained below (sections: Curve Modeling for Weight and Height).

For the second step of the study, looking at the population heifer growth curves, the same basic data-validation approach was used, using the estimated parameters, fixed effects, and variance components, to remove outliers. The predicted growth curves (using the estimated parameters from the first step of this study)

for each heifer that had at least 2 measurements (for weight or height) were calculated using the approach outlined in Cue et al. (2012). Tables 3 and 4 present the numbers of records before and after editing, to remove invalid records, and to impose the requirement of at least 2 records per animal, up to either 15 or 24 mo.

Data Analysis and Calculations

Curve Modeling for Weight. Weight data records were analyzed as described by Cue et al. (2012). Briefly, weight data were analyzed using R (version 1.15.2) package nlme. The statistical model fitted linear and quadratic fixed-effect regressions on age (in mo) as well as intercept, linear, and quadratic random regressions for each animal, and a residual variance modeled as a power function of the expected weight for age, power of the mean. The statistical model for each of the 4 breeds was

$$Y_{ij} = a_0 + a_1 \times \text{age}_{ij} + a_2 \times \text{age}_{ij}^2 + b_{0i} + b_{1i} \times \text{age}_{ij} + b_{2i} \times \text{age}_{ij}^2 + e_{ij},$$

where Y_{ij} is the weight of the i th animal at the j th age (in mo); a_0 is the overall, fixed-effect population inter-

Table 3. Numbers of animals and records by 15 and 24 mo, for weight (step two)

Item	Holstein	Ayrshire	Jersey	Brown Swiss
Number of animals, before	147,024	7,475	1,788	1,464
Records, initially	401,474	20,668	3,226	3,563
After removing records more than 4 SD from the respective breed-age mean				
Number of animals	145,828	7,439	1,766	1,457
Records	399,437	20,589	3,188	3,555
After imposing the requirement of 2+ records by 15 mo				
Number of animals	60,078	2,774	395	568
Records	202,030	9,820	1,334	1,673
After imposing the requirement of 2+ records by 24 mo				
Number of animals	80,392	3,835	535	780
Records	314,726	15,532	1,921	2,673

Table 4. Numbers of animals and records by 15 and 24 mo, for height (step two)

Item	Holstein	Ayrshire	Jersey	Brown Swiss
Number of animals, before	131,312	6,861	1,585	1,396
Records, initially	359,650	18,066	2,796	3,416
After removing records more than 4 SD from the respective breed-age mean				
Number of animals	130,370	6,789	1,467	1,323
Records	356,194	17,962	2,635	3,324
After imposing the requirement of 2+ records by 15 mo				
Number of animals	54,612	2,470	300	532
Records	181,921	8,611	1,069	1,590
After imposing the requirement of 2+ records by 24 mo				
Number of animals	73,007	3,418	409	727
Records	283,633	13,584	1,555	2,546

cept; a_1 is the overall, fixed-effect population average coefficient of regression of weight on age; a_2 is the overall, fixed-effect population average regression coefficient of weight on age², b_{0i} is the random intercept specific to the i th animal, $b_{0i} \sim N(0, \sigma_{b_0}^2)$, where $\sigma_{b_0}^2$ is the variance of random intercepts; b_{1i} is the random coefficient of regression of weight on age for the i th animal, $b_{1i} \sim N(0, \sigma_{b_1}^2)$, where $\sigma_{b_1}^2$ is the variance of random linear regression coefficients; b_{2i} is the random coefficient of regression of weight on age² for the i th animal, $b_{2i} \sim N(0, \sigma_{b_2}^2)$, where $\sigma_{b_2}^2$ is the variance of random quadratic regression coefficients; e_{ij} is the random residual error associated with the j th weight measurement on the i th animal, and $e_{ij} \sim N(0, \sigma_{e|age}^2)$, where $\sigma_{e|age}^2 = \sigma^2 |Xb|^{\text{POM}}$, POM is power of the mean, and Xb

Table 5. Parameters estimates for weight and height curves for the 4 breeds of dairy heifers

Item ¹	Holstein	Ayrshire	Jersey	Brown Swiss
Weight				
b_0	35.3511	35.6775	18.5384	35.9895
b_1	28.1419	22.1374	21.0152	24.6821
b_2	−0.14580	0.14787	−0.16287	−0.11938
$\sigma_{b_0}^2$	113.099	100.718	66.6634	0.04650
$\sigma_{b_0b_1}$	−23.217	−14.540	−9.372	−0.8383
$\sigma_{b_1}^2$	20.2547	15.5009	19.823	15.1148
$\sigma_{b_0b_2}$	0.81313	0.37549	0.37719	−0.01950
$\sigma_{b_1b_2}$	−0.65941	−0.29665	−0.58952	−0.35155
$\sigma_{b_2}^2$	0.03090	0.01485	0.02231	0.01216
σ_e^2	0.31463	0.24908	19.2556	0.93358
POM	1.2298	1.2638	0.4101	1.0022
Height				
A	148.972	139.424	136.784	146.975
b	0.4862	0.4646	0.4727	0.4740
k	0.1039	0.1014	0.1001	0.0957
σ_A^2	25.966	40.113	25.086	12.467
σ_{Ab}	0.0167	0.0682	−0.0668	0.0447
σ_b^2	0.0006886	0.001428	0.0007259	0.0005995
σ_{Ak}	−0.05570	−0.09515	−0.09993	−0.004942
σ_{bk}	−0.0002872	0.000116	0.00006280	−0.0002064
σ_k^2	0.0003067	0.0004693	0.0005845	0.0000855
σ_e^2	4.4975	4.9715	4.0071	3.2699

¹ b_0 = intercept; b_1 = linear regression coefficient; b_2 = quadratic regression coefficient; σ = the appropriate variance or covariance of corresponding random terms ($\sigma_{b_0}^2$ = variance of the random intercepts for weight, σ_{Ab} = covariance between A , the random effect for mature height, and b , the random effect pertaining to initial birth height, and so on); POM = power of the mean; A = mature height of the animal; b = parameter meaning that the equation does not go through the origin at time zero; that is, at heifer birth in the present case; k = parameter that influences the rate of maturing.

Figure 1. Estimated BW and standard deviation measured by heart girth circumference using calibrated tapes during heifer growth for Holstein (a; HO), Ayrshire (b; AY), Jersey (c; JE), and Brown Swiss (d; BS).

corresponds to the expected value for each observation. Parameter estimates are presented in Table 5.

Curve Modeling for Height. As for weight data, height data records were analyzed as described by Cue et al. (2012) using a nonlinear random regression model. Briefly, height data were analyzed using R and the nlme package according to the Brody/monomolecular equation $[A(1 - be^{-kt})]$ with random regression effects for A , b , and k for each animal, and $t = \text{age (in mo)}$. In the Brody equation, A represents the mature height of the animal and b is a parameter meaning that the equation does not go through the origin at time zero; that is, at heifer birth in the present case. The parameter k influences the rate of maturing. The statistical model for each of the 4 breeds was

$$h_{ij} = (A + A_i) \left[1 - (b + b_i) \times e^{-(k+k_i)t_j} \right] + e_{ij},$$

where h_{ij} is the height of the i th animal at the j th age (in mo) and A_i , b_i , and k_i are the random effects corre-

sponding to the fixed effects A , b , and k , for the i th animal. The residual variance (σ_e^2) was tested to see if a constant variance was appropriate, or whether a residual variance as a function of the expected height or age was more appropriate; a constant variance provided the best-fitting model. Parameter estimates are presented in Table 5.

Indicator Calculations. Six indicators for each breed were computed from the second-step edited data set, that is to say the valid data, with a requirement of 2 or more records per heifer: (1) estimated weight at 15 and 24 mo; (2) estimated height at 15 and 24 mo; (3) ADG before and after 15 mo; (4) age at which optimal weight for breeding is attained, i.e., 55% of mature weight (NRC, 2001); (5) relative reliability of the 15-mo weight prediction; and (6) relative reliability of the 24-mo weight prediction. Indicators of weight and height at 15 and 24 mo were calculated from respective curve parameter estimates. Average daily gain before and after 15 mo was obtained from the first derivative

Table 6. Indicators calculated from 1995 to 2012 records

Indicator	Holstein		Ayrshire		Jersey		Brown Swiss	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Mature weight (kg)	710	65	625	64	470	64	670	61
Optimal weight at first breeding ¹ (kg)	391		344		259		369	
Weight at 15 mo (kg)	425	34	334	29	297	26	379	36
Weight at 24 mo (kg)	627	39	482	48	429	27	560	43
Height at 15 mo (cm)	134.0	4.8	125.0	7.0	122.0	4.0	130.0	5.3
Height at 24 mo (cm)	143.0	5.9	134.0	8.0	131.0	4.0	140.0	6.2
ADG (g/d)								
Before 15 mo	848	76	655	66	603	57	775	79
After 15 mo	747	40	538	82	486	25	662	32
Age at optimal breeding weight (mo)	13.6	1.4	15.5	1.4	12.6	1.4	14.5	1.7
Relative reliabilities obtained from data before 15 mo								
Relative reliability for 15-mo weight prediction (%)	87	15	90	14	92	12	87	13
Relative reliability for 24-mo weight prediction (%)	43	14	69	14	60	11	67	14
Relative reliabilities obtained from data before 24 mo								
Relative reliability for 24-mo weight prediction (%)	67	27	82	18	74	19	80	18

¹Based on 55% of mature weight according to NRC (2001).

Figure 2. Estimate wither height and standard deviation during heifer growth for Holstein (a; HO), Ayrshire (b; AY), Jersey (c; JE), and Brown Swiss (d; BS).

Figure 3. Histogram of the recommended optimum age at first breeding (mo) for Holstein heifers raised in Québec, from 1995 to 2012. Color version available online.

of the weight quadratic equation. Age at which optimal weight for breeding is attained was calculated from the roots of the weight quadratic equation, using 55% of breed-average mature weight (NRC, 2001). Relative reliability of the 15- and 24-mo weight prediction was calculated as the prediction error variance, relative to that expected to be obtained when a heifer was measured routinely every 3 mo, starting at 2 mo of age, i.e., at 2, 5, 8, 11, and 14 mo of age for measurements that could be taken before a heifer is large enough to be first bred and at 2, 5, 8, 11, 14, 17, 20, and 23 mo for continuing measurements to monitor growth to calving. Three-monthly recording was chosen as a baseline because it was initially thought that this was likely to provide a reasonable monitoring of growth without requiring excessively repetitive measuring.

RESULTS AND DISCUSSION

Estimated BW growth curves by random regression using population-parameter estimates for HO, AY, JE, and BS heifers, as well as the estimated standard deviation, by month of age are presented in Figure 1. As expected, HO was the heaviest breed throughout growth, followed by BS, AY, and JE. The same trend was observed for height growth curves (Figure 2). Ma-

ture weight, optimal weight at first breeding, as well as indicator results are shown in Table 6. Most experiments studying heifer growth were carried out on HO heifers and to a lesser extent, on JE heifers; studies reporting growth data on AY and BS heifers are scarce.

Mature weights reported in this study are higher than those from Van Amburgh et al. (1998) and NRC (2001), mainly due to Canadian genetic, environmental, and management changes. Selection for milk production has led to a correlated response in BW (Berry et al., 2003; Oltenacu and Broom, 2010). A recent report by Sewalem et al. (2014) presented a genetic trend of +0.75 kg/yr, and a phenotypic trend of +1.83 kg/yr, in Québec HO, and Cue (2010) reported an estimated genetic trend of +0.45 kg/yr for cow BW in Québec AY. Annual reports of Valacta over the last 15 yr show a trend for increased cow and heifer BW. The average whole-herd BW for HO was 596 kg in 1998 and was 654 kg in 2012 (Valacta, 2013). Notwithstanding that this is a raw, unadjusted average and does not take into account the proportion of heifers in a herd, nor the DIM when the estimated cow BW was recorded (mostly at the first test day after calving), cow BW has steadily increased (approximately 3.8 kg/yr) in HO, and a similar picture for the other breeds is observed. Likewise, the raw, unadjusted heifer BW (normally recorded at

Figure 4. Estimated 24-mo phenotypic variance as a function of the 24-mo relative reliability (based on measurements up to 24 mo of age). Color version available online.

the first test-day after calving) in primiparous HO cows has increased from 559 kg in 1998 to 612 kg in 2012 (Valacta, 2013).

Weight and height at 15 and 24 mo for HO and JE reported in the current study are higher by about 70 kg and 10 cm as compared with data from Pennsylvania and New York heifers (Heinrichs and Hargrove, 1987; 1991), caused in part by the above-mentioned genetic change (Sewalem et al., 2014). This will have implications in terms of growth rates that can be expected and required, and it illustrates the need for continuing recording and monitoring to ensure that advice to producers remains appropriate; larger and heavier cows will translate into larger and heavier heifers. What is interesting and useful are not only the simple population descriptions of the various breed averages, but also the magnitude of the variability. For the 15-mo estimated BW (which would correspond to the approximate age when heifers would likely be bred) the standard devia-

tions were between 26 and 36 kg (Table 6). Likewise, for 24-mo BW, the standard deviations of the predicted values were between 27 and 48 kg. Both of these values indicate substantial variability among heifers.

In a meta-analysis studying the effect of prepubertal ADG on first-lactation production, Zanton and Heinrichs (2005) concluded that an ADG of 800 g/d for HO heifers could maximize total milk and protein yield. However, the work of Zanton and Heinrichs is hard to reconcile because they did not account for the mature weight of animals, and hence, it is not easy to relate their recommendation of ADG with these results. Although puberty is reached before 15 mo, ADG before 15 mo of age in the present study is higher by 48 g/d than is recommended for HO heifers.

Perhaps the most interesting indicator for dairy producers is age at optimal breeding weight. As stated by Cue et al. (2012), heifers are actually large enough to be bred at 14 to 15 mo of age and to calve at 24 mo, but

Figure 5. Relationship between the number of measurements on a Holstein heifer and its relative reliability. Color version available online.

dairy producers have had no way to estimate the age at which heifer BW is optimal for first breeding and to predict the BW at 24 mo and thus, presumably, prefer to wait 2 or 3 mo to be confident that their heifers will be mature enough. Using 55% of mature weight as a target, age at optimal breeding weight was attained at 13.6 ± 1.4 , 15.5 ± 1.4 , 12.6 ± 1.4 , and 14.5 ± 1.7 for HO, AY, JE, and BS, respectively. Table 6 shows that optimal weight at first breeding, i.e., 55% of breed average mature weight, was attained before 15 mo as weight at this age was higher than optimal weight at first breeding, except for AY. Figure 3 presents the distribution of recommended optimum age at first breeding (for HO); it can be seen that by 15 mo of age, 90% of heifers are large enough to be bred. Pietersma et al. (2006) reported that the number of breedings per conception in Québec was 1.29 for HO and 1.31 for AY. These data, combined with the fact that estimated BW

at 24 mo was higher than 82% of mature weight as recommended by NRC (2001), suggest that it is realistic to aim for a first calving at 24 mo for HO. The same recommendation could be made for JE and BS. At 24 mo, HO heifers had reached on average 88% of mature weight, whereas JE and BS heifers had attained 91 and 84% of mature weight, respectively. On the other hand, 77% of mature weight was reached at 24 mo for AY heifers, which is insufficient (NRC, 2001). Nevertheless, records collected from 2007 to 2012 for AY heifers show that age at first breeding was 14.3 mo and that 84% of mature weight was reached at 24 mo. This increase is mainly due to an improvement of ADG by 58 and 52 g/d before and after 15 mo, respectively. A question that arises is whether there are possible influences of milk or animal marketing forces that could act on age at first calving. It could be hypothesized that producers might deliberately follow a somewhat seasonal

pattern of age at first calving, perhaps to increase the number of heifers calving in later summer or early fall. This would in all likelihood result in delayed breeding to result in a larger number of heifers calving in late summer or early fall, without necessarily increasing heifer weight. To address this issue the average age at first calving, by month of calving, was examined; the monthly least squares means of age at first calving varied little, from 26.5 to 27.8 mo. In Quebec the quota production-management system basically requires individual producers to deliver one-twelfth of their annual quota in each month, thus the number of calvings has to remain fairly stable throughout the year. Depending upon the actual production in the province, then, if there is a shortfall in the autumn, producers may be allocated 1 or 2 extra days of production. For example, the provincial producers' federation (responsible for collective milk marketing) may decide in mid-August that the overall production is slightly below expectation and hence that they will allow each producer, during the month of October, to ship 32/31 of their monthly allocation. Because these decisions are not foreseeable and are only decided upon a couple of months ahead, they are most unlikely to be able to have any effect on either age or weight at first calving. By the time such and extra allocation is made, any heifer is already bred and hence its age at calving is immutable.

The presented tables and discussion deliberately excluded any effects of herd or year of birth. Including the effect of year in the model explained only between 0.5 and 0.7% of the sums of squares for each trait (15-mo weight, 24-mo weight, age at recommended first breeding). Herd was deliberately excluded from the model; the prediction model, as outline in Cue et al. (2012), is a phenotypic prediction model not specific to any individual herd. The objective of this study was to provide a useable portrait of heifer growth. If we had included year or herd as an effect in our presented descriptive results, then the results would only be applicable within year of birth, herd, or both, which would rather negate the utility. A wide range of optimal ages at first breeding are presented; some of which would have heifers calving for the first time 4 to 5 mo beyond a 24-mo target age at calving. Certainly, recommendations of optimal age at first calving would be higher in herds that experienced poor early heifer growth. Should that herd breed heifers at older ages, or improve heifer growth rates? That will depend upon the producer; what we can suggest is that it is quite possible, for all 4 breeds, to obtain growth rates such that heifers can calve at 24 mo of age.

The relative reliabilities of the prediction of 15-mo BW, from measurements up to 15 mo, averaged 87 to 92% (Table 6), with the standard deviations of these

relative reliabilities being 12 to 14%. The prediction of 24-mo BW from measurements up to 15 mo had, obviously, lower average relative reliabilities, 43 to 69%. When heifers were measured up until 24 mo, the average relative reliabilities ranged from 67 to 82%. The estimated phenotypic variance showed a linear decline with increasing relative reliability; see Figure 4 for the plot of estimated 24-mo phenotypic variance against the 24-mo relative reliability (for HO). Figure 5 shows the relationship observed between reliability and number of observations; it depends upon the pattern of just when the observations on a heifer are taken. A heifer with 2 weight measurements taken shortly after weaning will obtain a very low relative reliability for 15-mo predicted weight, whereas a heifer, also with 2 measurements, but these taken shortly before 15 mo may have a relative reliability approaching one. It can be seen that the relative reliability did not exceed 1.1, even for those animals with monthly measurements; some producers do record individual heifer weight and height each month. The change in the estimated phenotypic variance when the relative reliability goes from 1.0 (corresponding to 3-monthly recording) to 1.1 is quite small. It would therefore indicate that recording routinely at 3-monthly intervals (about 8 measurements per heifer, evenly spread throughout growth to first calving of the heifer) provides a sufficiently good description and prediction of the growth and that more frequent recording may not be economically justifiable nor necessary. The approach outlined here can be used to predict and monitor the growth curve of individual heifers and hence groups of animals. It should be noted that this is all predicated on measuring (weight and height) heifers in a producer's herd on a routine and continuous basis.

CONCLUSIONS

This study aimed to describe the current state of heifer growth in Québec for the most numerous breeds (i.e., HO, AY, JE, and BS) between 1995 and 2012. As compared with previous studies, mature weight, estimated weight measured by heart girth circumference, and wither height at 15 and 24 mo were higher in the present study, in part due to genetic gain. For HO, JE, and BS breeds, the age at which optimal breeding weight is attained allows targeting of a first calving at 23.5 to 24 mo, as recommended to maximize herd profitability. On the other hand, a growth delay was observed on AY heifers; a first calving at about 25.5 mo could be expected. The AY growth delay was ruled out from 2007 to 2012 by improving ADG and allowed first calving at the recommended age. This study presented indicators that could be calculated on a herd basis or

for each heifer within a herd and be used as a management tool to decrease age at first calving in dairy herds.

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