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Growth curves of New Zealand Holstein-Friesian, Jersey and Holstein-Friesian-Jersey crossbred heifers

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Abstract

There are differences in the proportion of target live weight (LWT) achieved between the main breeds of dairy heifers in New Zealand, suggesting a potential difference in growth pattern. The objectives of this study were to model growth curves of dairy heifers through random regression of Legendre polynomials, and to compare growth curves of the main breeds. Data comprised of 1,653,214 LWT records obtained from 189,936 dairy heifers in 1,547 herds. The fourth-order Legendre polynomial was the best at predicting LWT, with a relative prediction error (RPE) of less than 4% for the whole dataset and for Holstein-Friesian, Jersey and Holstein-Friesian-Jersey crossbred (F×J) heifers. The regression coefficients of the growth curve differed among breeds for the intercept (α_0; P<0.001), linear effect (α_1; P<0.001), quadratic effect (α_2; P<0.001), cubic effect (α_3; P<0.001) and quartic effect (α_4; P<0.001). At all ages Holstein-Friesian heifers were heavier than F×J which were heavier than Jersey heifers (P<0.001). The percentage difference among the breeds varied throughout the growth curve, indicating that the main breeds of dairy heifers in New Zealand exhibited different growth patterns that were non-linear. The different growth patterns for each breed should be considered when formulating target LWTs and growth rates.

Keywords: growth curve; growth; live weight; dairy heifer; New Zealand; Legendre polynomial

Introduction

Random regression of Legendre polynomials has been used to model growth curves of sheep (Sarmento et al. 2011) and beef cattle (Meyer 2005; Nobre et al. 2003). In random regression, a fixed growth trajectory that is the average for the population is fitted. Each individual animal's curve is the deviation from the average trajectory. It is, therefore, important to ensure that the average growth trajectory is accurate (Sarmento et al. 2011).

The predominant dairy breeds in New Zealand are Holstein-Friesian (33.5%), Jersey (10.1%) and Holstein-Friesian-Jersey crossbred (F×J; 47.2%) (Livestock Improvement Corporation & DairyNZ 2016). Holstein-Friesian is a later maturing and heavier breed compared with the lighter and early maturing Jersey (Leche 1971). Jersey heifers attained puberty at a younger age compared with Holstein-Friesian heifers (Hickson et al. 2011), further emphasising their earlier maturity. Positive heterosis for mature live weight (LWT) is found in New Zealand F×J cattle (Harris 2005; Harris et al. 1996). Estimates of heterosis were 9.4 kg (Harris 2005) and for the 2015-16 season heterosis of F×J mature cows was 10.3 kg (E Donkersloot, personal communication). It would be expected that growing F×J heifers would also exhibit heterosis for LWT, resulting in a growth curve that is different to Holstein-Friesians and Jerseys.

Industry target LWTs for dairy heifers are 30% of mature LWT at six months of age, 60% at 15 months (mating) and 90% at 22 months (precalving) (Burke et al. 2007). These targets were adopted in New Zealand to optimise milk production and reproduction in heifers. Heifers that grew faster attained puberty earlier than heifers that grew slower (Lammers et al. 1999; MacDonald et al. 2005). Heifers that were heavier before first-calving had greater first-lactation milk production than did lighter heifers (MacDonald et al. 2005; McNaughton & Lopdell 2013; van der Waaij et al. 1997). However, differences in the proportion of target LWT achieved between breeds have been reported (Handcock et al. 2016; McNaughton & Lopdell 2013), indicating that the appropriate target percentage may be different among breeds.

The first objective of this study was to evaluate Legendre polynomials of different orders to test if they would be a good model for the growth of dairy heifers. The second objective was to compare the growth pattern of Holstein-Friesian, Jersey and F×J heifers.

Materials and methods

Dataset

The data comprised of 1,656,433 LWT records obtained from 189,936 dairy heifers located in 1,547 herds recorded in the Livestock Improvement Corporation database. Heifers were spring-born between the 2006-07 and 2013-14 dairy seasons, and had at least two LWT records between birth and 12 months of age and two LWT records between 13 months of age and first calving at approximately two years of age, or 24 months of age if the heifer did not have any recorded calving dates. Only heifers with known dam and sire were included in the dataset.

Heifers were classified as either Holstein-Friesian, Jersey or F×J based on the following breed criteria: heifers that were at least 87.5% (14/16) Holstein-Friesian were classified as Holstein-Friesian; heifers that were at least

87.5% (14/16) Jersey were classified as Jersey; heifers that were neither Holstein-Friesian nor Jersey, but for which proportion Holstein-Friesian plus proportion Jersey was greater than 87.5% (14/16) were classified as F×J. Heifer that were more than 12.5% (2/16) of any breed other than Holstein-Friesian or Jersey were discarded. There were 48,026 Holstein-Friesian; 12,407 Jersey; and 129,503 F×J heifers.

Initial data cleaning was completed by calculating the mean and standard deviation of LWT for each age (in months), and for each breed. Liveweight records that were more than four standard deviations from their corresponding breed-age mean were removed (Cue et al. 2012; Pietersma et al. 2006). This method was iterated until no more records were deleted (Cue et al. 2012; Pietersma et al. 2006).

Growth curve model

Legendre polynomials of order two, three and four were fitted to LWT data using random regression to obtain an average growth curve for each heifer using ASReml (Gilmour et al. 2015).

The goodness of fit achieved with the model was evaluated using the Akaike information criterion (AIC), coefficient of correlation (r), the coefficient of determination (r^2), the mean square prediction error (MSPE), mean prediction error (MPE) and relative prediction error (RPE) (O'Neill et al. 2013).

The MSPE was calculated as follows:

$$\text{MSPE} = (A_m - P_m)^2 + S_P^2(1-b)^2 + S_A^2(1-r^2)$$

Where A_m and P_m are the mean actual and predicted LWTs, respectively; S_A^2 and S_P^2 are the variances of the actual and predicted LWT, respectively; b is the slope of the regression of actual (A) on predicted (P) and r^2 is the coefficient of determination of A and P.

The three components of the MSPE are: mean bias $(A_m - P_m)^2$, line bias $S_P^2(1-b)^2$ and random variation $S_A^2(1-r^2)$. The proportion of MSPE that comes from random variation should be high if the model is predicting with good accuracy. If the proportion of random variation is low then there is a large proportion of the MSPE from the mean or line bias (O'Neill et al. 2013).

The MPE and RPE were calculated as follows:

$$\text{MPE} = \sqrt{\text{MSPE}}$$

$$\text{RPE}\ (\%) = \left(\frac{\text{MPE}}{A_m}\right) \times 100$$

The smaller the RPE, the more accurate the predictions are.

For all goodness of fit and accuracy measurements, the fourth-order Legendre polynomial predicted LWT the best (Table 1) and was selected as the most appropriate model to use.

To remove outlier observations the relative measurement error (RME) was calculated as:

$$\text{RME} = \left(\frac{Predicted\ LWT - Actual\ LWT}{Predicted\ LWT}\right) \times 100$$

Any actual LWT between three and 23 months of age that had an absolute RME greater than 18% (mean + four standard deviations) was considered an outlier and removed from the dataset. The RME calculates the percentage deviation of the actual LWT from the predicted LWT by assuming that the predicted LWT is the "true" value. At birth, one, two and 24 months of age the accuracy of the fourth-order polynomial was low (data not shown). Actual LWTs were not removed at these ages as the predicted LWT was not accurate enough to be defined as the "true" LWT. The new dataset (order4-clean) included 1,653,214 observations (0.2% of data removed) on the same 189,936 animals. An order-four Legendre polynomial was fitted to the cleaned dataset and was used for subsequent analysis.

Statistical Analysis

The individual regression coefficients were used to estimate LWT at 3, 6, 9, 12, 15, 18 and 22 months of age for each heifer. The least-squares means of the regression coefficients for each breed and for LWT were analysed using a linear mixed model in SAS version 9.4 (SAS Institute Inc). The model included the fixed effects of breed, birth year, age of dam (2 years old; n = 13,717, greater than 2 years old; n = 176,219), island (North; n = 90,353, South; n = 99,583), the interaction between birth year and island, and the random effect of herd of birth. Deviation from median birthdate (within herd) was fitted as a covariate.

Results

Total cleaned dataset

For the cleaned dataset of 1,653,214 LWTs on 189,936 heifers, the fourth-order polynomial predicted LWT with an RPE of 3.5% and an average bias between predicted and actual LWTs of 0.001 kg (Table 2). The MSPE was 72.8 kg^2 which predominantly came from random variation (0.997) with only a small proportion attributed to the line bias (0.003) and none to mean bias (0.000; Table 2).

Breed effects

The RPE for the different breeds ranged from 3.4 to 3.7% (Table 2). The bias between predicted and actual LWTs ranged from -0.607 to 1.340 kg (Table 2). The proportion of MSPE that came from random variation was high (0.964-0.998) and from the line bias and mean bias were low (0.002 -0.008 and 0.000-0.030, respectively) for all breeds.

Table 1 Prediction accuracy of Legendre polynomials of order two, three and four for the prediction of live weight of New Zealand spring-born dairy heifers

Model	N	r	r^2	MSPE $(kg)^2$	MPE (kg)	RPE (%)	AIC
Order2	1,656,433	0.993	0.987	168	12.95	5.37	11,996,927
Order3	1,656,433	0.995	0.990	132	11.48	4.76	12,020,779
Order4	1,656,433	0.997	0.994	81	9.00	3.73	11,769,901
Order4-clean	1,653,214	0.997	0.994	73	8.53	3.54	11,664,415

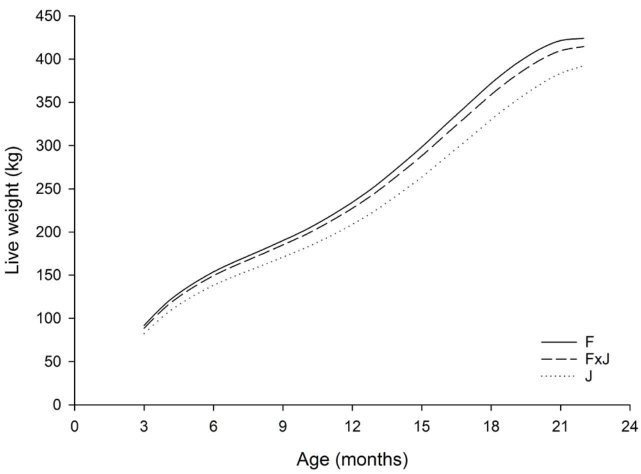
r: coefficient of correlation, r^2: the coefficient of determination, MSPE: mean square prediction error, MPE: mean prediction error, RPE: relative prediction error, AIC: Akaike information criterion

Table 2 Prediction accuracy of the fourth-order Legendre polynomial for the prediction of live weight (LWT) of Holstein-Friesian, Jersey and Holstein-Friesian-Jersey crossbred (F×J) dairy heifers

Category	Total	Breed		
		Holstein-Friesian	Jersey	F×J
Number of records	1,653,214	399,716	99,785	1,153,713
Mean Actual LWT (A; kg)	241.25	257.75	209.89	238.24
Mean Predicted LWT (P; kg)	241.25	257.14	211.23	238.34
Regression of A upon P				
Intercept	-0.985	-1.145	-0.064	-0.848
Slope	1.004	1.007	0.994	1.003
r^2	0.994	0.994	0.994	0.994
Bias (P-A; kg)	0.001	-0.607	1.340	0.096
MSPE (kg)^2	72.8	78.4	59.0	72.0
Proportion of MSPE				
Mean bias	0.000	0.005	0.030	0.000
Line bias	0.003	0.008	0.006	0.002
Random variation	0.997	0.987	0.964	0.998
MPE (kg)	8.5	8.9	7.7	8.5
RPE (%)	3.5	3.4	3.7	3.6

R^2: the coefficient of determination, MSPE: mean square prediction error, MPE: mean prediction error, RPE: relative prediction error.

Figure 1 Predicted growth curves from three to 22 months of age for Holstein-Friesian (F), Jersey (J) and Holstein-Friesian-Jersey crossbred (F×J) dairy heifers



Growth curve model – shape and parameters

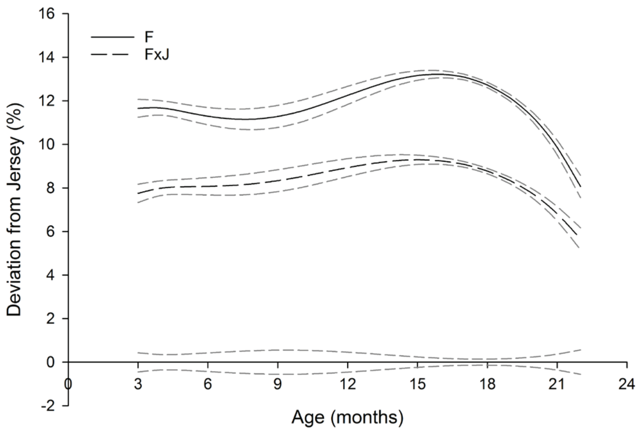
The regression coefficients are displayed in Table 3 and differed among breeds for the intercept (α_0; P<0.001), linear effect (α_1; P<0.001), quadratic effect (α_2; P<0.001), cubic effect (α_3; P<0.001), and quartic effect (α_4; P<0.001). Figure 1 illustrates the average growth curve of Holstein-Friesian, Jersey, F×J heifers. Out of the breed groups, Holstein-Friesian heifers were the heaviest (P<0.001) at all ages, followed by F×J heifers who were intermediate (P<0.001). Jersey heifers were the lightest throughout (P<0.001).

Table 3 Least-squares means ± SEM of the regression coefficients of the growth curve modelled with a fourth-order Legendre polynomial fitted to Holstein-Friesian, Jersey and Holstein-Friesian-Jersey crossbred (F×J) dairy heifers

Breed	Holstein-Friesian	Jersey	F×J
α0	350.09^c ± 0.70	316.93^a ± 0.77	340.44^b ± 0.69
α1	179.14^c ± 0.39	166.04^a ± 0.43	175.37^b ± 0.38
α2	-16.70^a ± 0.36	-7.08^c ± 0.39	-13.90^b ± 0.35
α3	-3.26^a ± 0.33	3.20^c ± 0.36	-0.75^b ± 0.32
α4	-27.40^a ± 0.28	-21.38^c ± 0.30	-25.04^b ± 0.27

Values within row with different superscripts are significantly different (P<0.001)

Figure 2 Deviation of estimated live weight of Holstein Friesian (F) and Holstein-Friesian-Jersey crossbred (F×J) from Jersey heifers, derived from the fourth-order Legendre polynomial. Grey dashed lines represent 95% confidence intervals for each breed



The percentage deviation of estimated LWT of Holstein-Friesian and F×J from Jersey heifers is illustrated in Fig. 2. The size of the percentage deviation was variable over time, even though the ranking was consistent; Holstein-Friesian heifers were heavier than F×J which were heavier than Jersey (zero line). At three months of age Holstein-Friesian heifers were 11.7% heavier than Jersey; increasing to a maximum of 13.2% by 15 months of age. By 22 months of age the difference had decreased to 8.1%. Holstein-Friesian-Jersey crossbred heifers ranged between 5.7 to 9.3% heavier than Jersey heifers; the maximum difference occurred at 15 months of age. The difference between Holstein-Friesian and F×J was greatest between 16 and 18 months of age (4.0%) and was smallest at 22 months of age (2.4%).

Discussion

Legendre polynomials have been used to model lactation curves (Lembeye et al. 2016), LWT during lactation (Lembeye et al. 2016), growth curves of beef cattle (Meyer 2005; Nobre et al. 2003; Vazquez et al. 2013) and growth curves of sheep (Sarmento et al. 2011). To the authors' knowledge they have not been used to model growth curves of dairy heifers.

O'Neill et al. (2013) considered an RPE of less than 10% to be satisfactory for the prediction of dry matter intake in dairy cattle, Bryant et al. (2004) considered an RPE between 5% and 8% to be acceptable for predicting LWT at puberty; hence the selected fourth-order polynomial of the current study was a very good model for predicting LWT (RPE less than 4%). For analysis, the results for MSPE that are presented in Table 2 are in terms of the proportional contribution of each of the three components to the MSPE. If the model is predicting LWT well, then the proportion of MSPE that comes from random variation will be high, as this is due to animal variation rather than a consistent bias from the model (O'Neill et al. 2013). The high random variation and low mean bias and line bias found in the current study suggests that the selected growth curve model is robust.

As expected, Holstein-Friesian heifers were heavier than FxJ and Jersey heifers throughout the growth period studied (Livestock Improvement Corporation & DairyNZ 2016). However, the growth pattern was different for the breeds, as evidenced by the different alpha values among breeds. The intercept and linear effects were greater for Holstein-Friesians than for F×J and Jerseys, which reflects that the overall growth rate was fastest for Holstein-Friesians, intermediate for F×J, and slowest for Jerseys. The mean regression coefficient for the cubic effect was negative for Holstein-Friesians and positive for Jerseys (Table 3). This difference in direction of the cubic effect reflects that Holstein-Friesians appear to not be growing after 21 months, whereas Jerseys are still increasing in LWT. Greater absolute values for the quadratic, cubic and quartic effects create more curvature in the growth pattern compared with values closer to zero. Holstein-Friesians had greater absolute values for these effects compared with FxJ, which reflects that the percentage difference between the breeds varied over time. The numerical difference in regression coefficients was greater between F×J and Jersey than it was between F×J and Holstein-Friesian. This reflects that F×J were not directly intermediate between Jerseys and Holstein-Friesians, but the overall growth rate and growth pattern were more similar to Holstein-Friesians.

Results reported here suggest that random regression using Legendre polynomials can accurately predict LWT and growth curves of dairy heifers. The results also showed that the main breeds of dairy cattle in New Zealand exhibit different growth curves. When creating target LWTs and growth rates, the different growth patterns for each breed should be considered. Further research is required to formulate breed-specific target LWTs to optimise milk production and reproductive success.

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