J. Dairy Sci. 107:1500–1509
https://doi.org/10.3168/jds.2023-23926

Modeling daily yields of milk, fat, protein, and lactose of New Zealand dairy goats undergoing standard and extended lactations

M. Boshoff,[1] N. Lopez-Villalobos,[1]* C. Andrews,[1] and S-A. Turner[2]†
[1]School of Agriculture and Environment, Massey University, Palmerston North 4410, New Zealand
[2]Dairy Goat Co-operative (NZ) Limited, Hamilton 3206, New Zealand

ABSTRACT

This study aimed to assess the milk production data for New Zealand dairy goats in either a standard lactation (SL; ≤305 d in milk [DIM]) or extended lactation (EL; >305 and ≤670 DIM) using a random regression (RR) with third- and fifth-order Legendre polynomials, respectively. Persistency of EL was defined as (B/A) × 100, where A was the accumulated yield from d 1 to 305, and B was the accumulated yield from d 366 to 670. On average, goats in SL produced 1,183 kg of milk, 37 kg of fat, 37 kg of protein, and 54 kg of lactose. The average production of milk, fat, protein, and lactose in EL were 2,473 kg, 78 kg, 79 kg, and 112 kg, respectively. The average persistences for milk, fat, protein, and lactose yields during EL were 98%, 98%, 102%, and 96%, respectively. The relative prediction errors were close to 10% and the concordance correlation coefficients >0.92, indicating that the RR model with Legendre polynomials is adequate for modeling lactation curves for both SL and EL. Total yields and persistency were analyzed with a mixed model that included the fixed effects (year, month of kidding, parity, and proportion of Saanen) as covariates and the random effects of animal and residual errors. Effects of year, month of kidding, and parity were significant on the total yields of milk, fat, protein, and lactose for both SL and EL. The total milk yield of first-parity goats with SL was 946 kg and the total milk yield of second-parity goats with SL was 1,284 kg, making a total of 2,230 kg over 2 years. The total milk yield of a first-parity goat with EL was 2,140 kg. Thus, on average, a goat with SL for the first and second parity produced 90 kg more milk than a first-parity goat subjected to EL. However, a second-parity goat subjected to EL produced 43 kg more milk (2,639 kg) than a goat with SL following the second and third parity (1,284 kg + 1,312 kg). These data, along with the various other benefits of EL (e.g., fewer offspring born and reduced risk of mastitis, lameness, and metabolic problems in early lactation), indicate that EL as a management strategy holds the potential to improve dairy goat longevity and lifetime efficiency without compromising milk production.
Key words: goat, extended lactation, persistency, random regression, milk yield

INTRODUCTION

The lactation curve is defined as a 2-dimensional graphic representation of daily milk yield throughout an animal's lactation. The x-axis represents the days after parturition (defined as DIM) and the y-axis represents the daily yield of milk, fat, protein, or lactose. The shape of a typical lactation curve is usually described as increasing at a relatively high rate until peak production is reached, after which it declines at a slower rate until the end of the lactation. Numerous mathematical models have been developed to describe the lactation curves of dairy cows (Macciotta et al., 2011) and goats (Groenewald and Viljoen, 2003; Macciotta et al., 2008; Brito et al., 2017). As described by Macciotta et al. (2008), the main parameters of the lactation curve are the day of peak lactation, daily yield at peak, rate of decrease in yield after the peak (the inverse of which is known as persistency of lactation and measures the ability of the animal to maintain a constant yield after the lactation peak), and total lactation yield (which can be estimated from the area under the lactation curve). The prediction of total milk yield from a few herd tests in early lactation allows farmers to identify low-producing animals that may be culled from the herd at the end of lactation, and the detection of perturbations of the standard lactation (**SL**) curve can allow the identification of animals suffering from disorders that affect milk production long before any clinical signs appear (Ben Abdelkrim et al., 2021). Furthermore, knowledge of the parameters of the lactation curve is also useful for evaluating overall farm productivity and profitability (Butler et al., 2010; Lehmann et al., 2019), and to inform breeding decisions (Douhard

Received July 3, 2023.
Accepted September 28, 2023.
*Corresponding author: n.lopez-villalobos@massey.ac.nz
†Current address: Fonterra Co-operative Group Limited, Hamilton 3200, New Zealand.

et al., 2014). Since 1980, genetic evaluation of dairy cattle has been performed accounting for the shape of the lactation curve of individual cows using random linear regression (Jamrozik and Schaeffer, 1997).

In a random regression (**RR**), a fixed curve for the population is calculated and individual curves are fitted as deviations from the population curve. This technique models the covariance between repeated records taken on the same animal over time and allows the prediction of variances and covariances for time points along the trajectory, even though few observations are made, but using information from all other measurements (van der Werf et al., 1998). Furthermore, RR using orthogonal Legendre polynomials have been reported as a suitable method to model the lactation curves of dairy goats (Brito et al., 2017; Arnal et al., 2019) and sheep (Kominakis et al., 2001; Marshall et al., 2023). These models are useful for comparing the efficacy of different management strategies in milk production systems.

Extending the lactation of dairy cows beyond 305 d is a management strategy of many dairy cattle systems when cows fail to become pregnant (Dematawewa et al., 2007; Steri et al., 2012) or to reduce calving frequency and take advantage of high-yielding cows through prolonged lactation (Lehmann et al., 2019). It is frequently reported that, even under nonlimiting nutritional conditions, milk yield continuously decreases after the standard 305-d period in dairy cows (Grainger et al., 2009). Although the typical lactation curve (increase phase, peak, and decrease phase) is still observed, it occurs over a longer period (Grainger et al., 2009). Dematawewa et al. (2007) compared 9 models for their suitability for modeling 999-d extended lactations (**EL**) of US Holstein cows. The conclusion of the study was that the Rook et al. (1993), Dijkstra et al. (1997), and Wood (1967) models were adequate to describe the lactation curves of 999-d EL of daily yields of milk, fat, and protein. Steri et al. (2012) concluded that polynomial models showed better fitting performances for average patterns in Italian Holstein cows when compared with 3 or 4 parameter models but showed poor prediction ability at the extremes of the lactation trajectory.

In dairy goat systems, which are rapidly expanding globally due to the increased demand for nonbovine milk, EL has been associated with a similar or even a higher milk production than SL (Gendron and Reveau, 1995; Salama et al., 2005; Goetsch et al., 2011). Dutch farmers have thus increased the number of goats with EL (production of milk for more than 12 mo without kidding) as an intentional management decision (Van den Brom et al., 2019). This management tool has been also practiced by New Zealand dairy goat farmers. Lactation curves within a prolonged lactation in goats are highly persistent, and goats may continue to be milked for 2 to 4 years and sometimes bred only once during a lifetime (Linzell, 1973). High-producing goats could maintain lactation up to 2 years with production level upwards of 3 to 4 L/d (Salama et al., 2005). As such, EL may be of particular interest to the dairy goat industry, especially given the drive to reduce the production of surplus young in many countries. However, modeling and comparing the lactation curves of goats in EL and SL are needed to accurately assess the efficacy of this management strategy. Gaining an understanding of the lactation curve of goats would aid in determining whether EL is accompanied by a progressive decrease in milk yield, akin to cattle, or whether milk yield remains stable or recovers from any initial decline during the following season (not seen in cattle).

As far as the authors are aware, no previously published studies have reported on the modeling of EL in dairy goats. Therefore, the objective of this study was to describe the lactation curves for milk, fat, protein, and lactose of dairy goats subjected to SL (305-d) and EL (670-d) of different parities in a large commercial herd in New Zealand.

MATERIALS AND METHODS

Ethics Statement

The present study was conducted using existing phenotypic and pedigree information from a large commercial herd, which is a supplier of the Dairy Goat Cooperative (NZ) Ltd. Therefore, no animal experiments were carried out, and animal care committee approval was not needed.

Data

A dataset with herd test records and animal information was obtained from the Livestock Improvement Corporation Ltd. database. The dataset comprised 35,053 herd test records for daily yields of milk and percentages of fat, protein, and lactose from 5,054 lactations of 2,920 dairy goats kidding between 2015 and 2020 in a large commercial herd in New Zealand. Daily yields of fat, protein, and lactose were obtained by multiplying daily milk yields by the respective component percentages.

The animal information included unique identification of animal, sire and dam, date of birth and parturition, parity number in which the lactation started, and proportion of Saanen, Toggenburg, Alpine, Nubian, and "unknown" and "other" breeds. Crossbreeding occurred, with very few first-cross or purebred animals. The structure of the dataset is provided in more detail in Table 1.

Table 1. Number of animals, lactations, and herd test records, and average breed composition of the studied population of New Zealand dairy goats classified by proportion of Saanen

Proportion of Saanen (%)	Number[1]			Breed					
	Anim	Lact	HT	Saanen	Toggenburg	Alpine	Nubian	Other	Unknown
>87.5	44	85	509	0.990	0.002	0.000	0.000	0.002	0.005
>75.0 to ≤87.5	25	35	231	0.841	0.014	0.000	0.000	0.032	0.113
>50.0 to ≤75.0	277	474	3,355	0.623	0.015	0.000	0.000	0.021	0.341
>25.0 to ≤50.0	1,011	1,725	12,414	0.390	0.015	0.000	0.001	0.026	0.567
>12.5 to ≤25.0	856	1,422	9,881	0.222	0.011	0.000	0.001	0.027	0.739
>0.0 to ≤12.5	700	1,298	8,564	0.103	0.006	0.001	0.001	0.032	0.857
0	7	15	99	0.000	0.225	0.004	0.000	0.008	0.763
Total	2,920	5,054	35,053						

[1]Anim = number of animals; Lact = number of lactations; HT = number of herd test records.

The data were split into 2 datasets, one with SL (up to 305 DIM) and the other with EL (up to 670 DIM). A lactation was considered to be “standard” when herd tests occurred between 15 and 305 DIM and the animal in that lactation did not have herd tests after 305 DIM. To standardize lactation length, SL that ended before 305 d were predicted forward to “complete” a 305-d lactation, and lactations that exceeded 305 d by up to 20 d were truncated to 305 d. This resulted in a dataset that contained 8,542 herd tests corresponding to 2,132 SL. On average, 4 herd tests were carried out each year by the farm with bimonthly intervals (except in January) to cover the production season (September, November, February and May).

A lactation was considered to be “extended” when the herd tests occurred between 15 and 670 DIM. As with the SL, the length of lactation was standardized by either predicting forward or truncating the lactation curve to 670 d. This dataset for EL contained 26,493 herd test records corresponding to 2,922 lactations. On average, 9 herd tests were carried out to cover the yields of goats undergoing EL (September, November, February, May, and June of the first year, and September, November, February and May of the following year).

Modeling Lactation Curves

Modeling of 2,922 EL up to 670 d was based on 26,499 herd tests for daily yields of milk, fat, protein, and lactose using a RR model fitting a fifth-order Legendre polynomial. The RR model was represented as follows:

$$y_{jt} = (\beta_0 P_0 + \beta_1 P_{1t} + \beta_2 P_{2t} + \beta_3 P_{3t} + \beta_4 P_{4t} + \beta_5 P_{5t}) + (\alpha_{0j} P_0 + \alpha_{1j} P_{1t} + \alpha_{2j} P_{2t} + \alpha_{3j} P_{3t} + \alpha_{4j} P_{4t} + \alpha_{5j} P_{5t}) + e_{it},$$

where y_{jt} represents the daily yield for doe parity j in day t of the lactation after kidding, β_0 to β_5 are fixed regression coefficients representing the lactation curve of the population, α_{0j} to α_{5j} are RR coefficients for doe parity j, P_0 to P_{5t} are orthogonal polynomial functions of order 0 to 5 as defined below, and e_{jt} is the random residual error. Coefficients of the orthogonal polynomial at day t were calculated as follows:

$$P_{0t} = 1,$$

$$P_{1t} = x,$$

$$P_{2t} = \frac{1}{2}\left(3x^2 - 1\right),$$

$$P_{3t} = \frac{1}{2}\left(5x^3 - 3x\right),$$

$$P_{4t} = \frac{1}{8}\left(35x^4 - 30x^2 + 3\right), \text{ and}$$

$$P_{5t} = \frac{1}{8}\left(63x^5 - 70x^3 + 15x\right),$$

where $x = -1 + 2\frac{(t-1)}{(1-670)}$. Modeling of 2,132 SL up to 305 DIM was based on 8,554 herd tests for daily yields of milk, fat, protein, and lactose using a RR model fitting a third-order Legendre polynomial. The estimates of β’s and α’s were obtained using the Restricted Maximum Likelihood procedure in ASReml version 4.2 (Gilmour et al., 2021). The polynomials of order 2, 3, 4, 5, and 6 were tested. Based on the Akaike information criterion (smallest is best), an orthogonal polynomial of order 3 was considered the best fit for modeling lactation curves of milk, fat, protein, and lactose for SL. An orthogonal polynomial of order 5 was considered the best fit for modeling lactation curves of milk, fat, protein, and lactose for EL.

Estimates of random regressor coefficients (α_0 to α_3 or α_0 to α_5, depending on the trait) of each doe parity were used to estimate the daily yields at each day of the lactation; 1 to 305 d for SL and 1 to 670 d for EL. Then, the predicted yields at each day of the lactation were summed to obtain an estimated total milk yield produced by each doe in the corresponding parity.

The definition of persistency according to Macciotta et al. (2008) is the rate of decline after peak yield; however, this is not suitable in the present study due to the highly variable lactation curves of goats in EL. Thus, the measure used for the persistency of EL was defined as the estimated yield produced from d 366 to d 670 divided by the estimated yield produced from d 1 to d 305 and expressed as a percentage. The higher this ratio, the higher the persistency. A more persistent lactation will have a flatter curve, with the persistency proportion approaching 100%.

Measures of Goodness of Fit

Different measures of goodness of fit were obtained using the GLM procedure of SAS version 9.4 (SAS Institute Inc.). The first measure was the bias between the means of actual (**A**) and predicted (**Pr**) values. The second measures were the intercept, slope, and R^2 of the regression line of the A on Pr values for daily yields of milk, fat, protein, and lactose. The third measure of goodness of fit was the relative prediction error (**RPE**) calculated as the square root of the mean squares of the errors (MSE) divided by the mean of the actual values (μ_A), multiplied by 100, as follows, $\text{RPE} = (\sqrt{\text{MSE}}/\mu_A) \times 100$. Two other measures of goodness of fit were the Pearson correlation coefficient and the Lin's concordance correlation coefficient (Lin, 1989) between A and Pr values. The Lin's concordance correlation coefficient (ρ_{ccc}) was calculated as follows:

$$\rho_{ccc} = \frac{2\sigma_{PrA}}{\sigma_{Pr}^2 + \sigma_A^2 + \left(\mu_{Pr} - \mu_A\right)^2},$$

where σ_{PrA} is the covariance, σ_{Pr}^2 and σ_A^2 are the variances, and μ_{Pr} and μ_A are the means of A and Pr values.

Statistical Analysis

The datasets of SL and EL were analyzed separately. All statistical analyses were performed using the statistical package SAS version 9.4. Descriptive statistics (mean, standard deviation, and coefficient of variation) for total yields and persistence were obtained with the MEANS procedure. We performed ANOVA for the estimated total yields, persistence, and estimates of regression coefficients using the GLIMMIX procedure of SAS with a linear model that included the fixed effects of year (2015–2020) and month (June, July, August, and September–October) of parturition and parity as class effects and proportion of Saanen as covariate, and the random effect of doe to account for repeated lactations in the same dataset. Least squares means for each class of the fixed effects and standard errors were obtained and used for mean comparisons using Fisher's least significant different test.

RESULTS

Descriptive statistics of total production of milk, fat, protein, and lactose in standard 305-d and extended 670-d lactations are presented in Table 2. The lactation curves for daily milk production of first- and second-parity goats subjected to 2 standard 305-d lactations are compared with the lactation curve of first-parity goats subjected to an extended 670-d lactation (Figure 1). Similarly, Figure 2 presents the lactation curves for daily milk production of second- and third-parity goats subjected to 2 standard 305-d lactations compared with the lactation curve of second-parity goats subjected to an extended 670-d lactation.

The measures of goodness of fit are presented in Tables 3 and 4 for the modeling of lactation curves for daily yields in SL and EL, respectively. The biases in the means of actual and predicted values was zero. In all cases, the intercepts of the regression lines of the actual on predicted values were negative but did not depart significantly from zero, and the slopes were all >1.0. The R^2 values in the modeling of SL were slightly greater than the R^2 values observed in the modeling of EL, which are reflected in lower RPE values for SL than for EL. However, all RPE values were close to 10%. The correlation and concordance correlation coefficients were >0.92 and close to 1.0.

The effects of year and month of parturition, parity number, and proportion of Saanen on 305-d and 670-d yields and persistency in EL are presented in Table 5. Parity number had the largest significant effect ($P < 0.001$) followed by parturition year ($P < 0.001$). Effect of parturition month was not significant on 305-d fat yield and persistency of EL for all production traits. The effect of proportion of Saanen fitted as a covariate was not significant.

Least squares means for total yields for each parity and month of calving are presented for SL in Table 6 and for EL in Table 7.

Table 2. Number of lactations (n), mean, SD, and CV for standard (up to 305 DIM) and extended (up to 670 DIM) lactations for yields of milk, fat, protein, and lactose and persistency in New Zealand dairy goats from 2015 to 2020

Trait[1]	n	Mean	SD	CV
Standard lactation yields up to 305 d	2,922			
Lactation length (d)		281	16	6
Milk (kg)		1,183	282	24
Fat (kg)		37	9	24
Protein (kg)		37	9	23
Lactose (kg)		54	13	23
Extended lactation yields up to 670 d	2,468			
Lactation length (d)		560	141	25
Milk (kg)				
d 1–305		1,152	266	23
d 366–67		1,112	247	22
d 1–670		2,473	513	21
Persistency (%)		98	19	19
Fat (kg)				
d 1–305		37	9	26
d 366–670		35	8	24
d 1–670		78	17	22
Persistency (%)		98	24	24
Protein (kg)				
d 1–305		36	9	24
d 366–670		36	8	22
d 1–670		79	16	21
Persistency (%)		102	23	23
Lactose (kg)				
d 1–305		53	13	25
d 366–670		49	12	25
d 1–670		112	25	22
Persistency (%)		96	23	24

[1]Lactation persistency is defined as the yield from d 366 to 670 divided by yield from d 1 to 305, expressed as a percentage.

DISCUSSION

Measures of goodness of fit presented in Table 3 indicate that RR with a third-order Legendre polynomial is an adequate technique for modeling the SL curves for the milk, fat, protein, and lactose yields of dairy goats in this commercial flock (Table 3). The biases in means were zero, the estimates of the intercepts were close to zero, and the slopes were all slightly greater than 1.0. This suggests that the models tended to over-

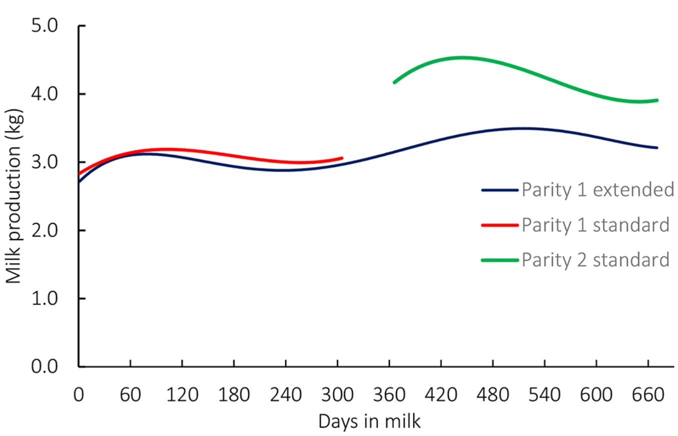

Figure 1. Examples of lactation curves in New Zealand dairy goats comparing a representative goat of parity 1 undergoing extended lactation and a representative goat of parity 1 and parity 2 undergoing 2 standard lactations.

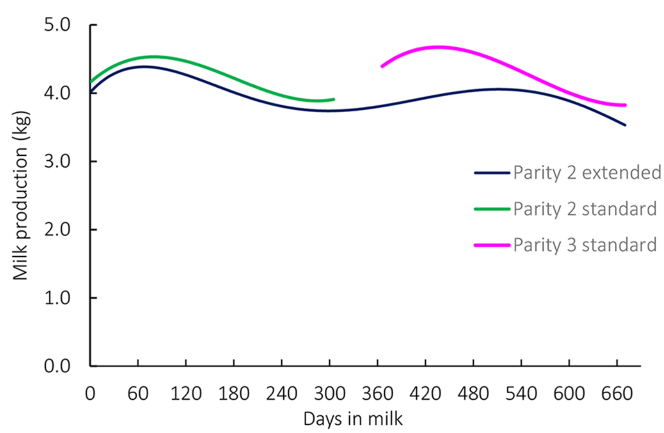

Figure 2. Examples of lactation curves in New Zealand dairy goats comparing a representative goat of parity 2 undergoing extended lactation and a representative goat of parity 2 and parity 3 undergoing 2 standard lactations.

Table 3. Measures of goodness of fit of the modeling of the actual (A) and predicted (Pr) 305-d lactation curves for yields of milk, fat, protein, and lactose, using random regression with a third-order Legendre polynomial (n = 13,991)[1]

	Mean			Regression of A on Pr					
Trait	A	Pr	Bias	Intercept (±SE)	Slope (±SE)	R^2	RPE (%)	r	ρ_{ccc}
Milk (kg/d)	3.87	3.87	0.00	−0.52 ± 0.01	1.13 ± 0.01	0.93	8.32	0.96	0.95
Fat (kg/d)	0.12	0.12	0.00	−0.02 ± 0.00	1.18 ± 0.01	0.91	10.49	0.96	0.93
Protein (kg/d)	0.12	0.12	0.00	−0.02 ± 0.00	1.14 ± 0.01	0.93	8.10	0.97	0.95
Lactose (kg/d)	0.18	0.18	0.00	−0.02 ± 0.00	1.13 ± 0.01	0.93	8.29	0.97	0.95

[1]RPE = relative predicted error; r = correlation coefficient; ρ_{ccc} = concordance correlation coefficient.

predict low actual values and under-predict high actual values, but the RPE were close to or less than 10%. According to Fuentes-Pila et al. (1996), an RPE <10% is considered satisfactory, and an RPE between 10% and 20% is relatively good for prediction models. However, a Lin's concordance correlation (Lin, 1989) close to 1 indicated that the actual and predicted values were in high agreement, with low biases in the mean and regression line of the predicted on the actual values. For 670-d EL, RR with a fifth-order Legendre polynomial was an adequate technique for modeling the EL curves of milk, fat, protein, and lactose yield. The RPE values obtained in the modeling of SL were lower than the values obtained in the modeling of 670-d EL, and the concordance correlation coefficient values obtained in the modeling of standard curves were stronger than in the modeling of the extended curves. This means that the modeling of SL tends to be more accurate than the modeling of EL, probably because EL was much longer, had 2 peaks, and had more variable lactation curves.

The 305-d (SL) milk, fat, and protein yields of the herd in the present study were higher than the overall averages reported for a total of 21 other dairy goat herds in New Zealand (Scholtens et al., 2020). The average production yields for SL were also greater than those reported for Alpine and Saanen goats in France (Bélichon et al., 1998), and both Maltese and Jonica goats in Italy (Pesce Delfino et al., 2011; Selvaggi and Dario, 2015). However, the production figures of this herd were similar to those reported for goats in the United States (García-Peniche et al., 2012; Castañeda-Bustos et al., 2014). Differences in the mean milk production values of dairy goat herds have previously been attributed to differences in breed, climate, seasonality (Montaldo et al., 2010), nutrition (Selvaggi and Dario, 2015), and other management factors (e.g., housing method; Castañeda-Bustos et al., 2014). This is also likely for the present study, with this herd being particularly high producing compared with other herds in New Zealand.

Scholtens et al. (2020), using a much greater sample size (n = 23,583 does), found that the Saanen breed had a significant effect on milk production traits. However, milk, fat, and protein yields for both SL and EL were unaffected by Saanen breed in the present study. This was probably because the herd was dominated by Saanen-crossbred animals with few purebred animals or other breeds (Table 1). Thus, due to low sample sizes for other breeds (e.g., Toggenburg, Alpine, and Nubian), the model was unlikely to be able to identify a breed effect such as reported by Scholtens et al. (2020) in New Zealand dairy goats.

We found that month of kidding, parity, and year had significant effects on the milk production of goats in both SL and EL. Similar effects of parity, season, and year have also been reported for Saanen goats in Mexico (Valencia et al., 2007), and both Alpine and Saanen breeds in Brazil (Brito et al., 2011). In the present study, goats kidding in June or July (winter) had a lower milk yield than those kidding from August to October (late winter and early spring), irrespective of whether they were in SL or EL. Given that the goats

Table 4. Measures of goodness of fit of the modeling of the actual (A) and predicted (Pr) 670-d lactation curves for milk and lactose, using random regression with a fifth-order Legendre polynomial (n = 22,378)[1]

	Mean			Regression of A on Pr					
Trait	A	Pr	Bias	Intercept (±SE)	Slope (±SE)	R^2	RPE (%)	r	ρ_{ccc}
Milk (kg/d)	3.71	3.71	0.00	−0.48 ± 0.01	1.13 ± 0.001	0.87	11.02	0.93	0.92
Fat (kg/d)	0.12	0.12	0.00	−0.01 ± 0.00	1.05 ± 0.001	0.88	11.27	0.94	0.93
Protein (kg/d)	0.12	0.12	0.00	−0.01 ± 0.00	1.06 ± 0.001	0.89	9.74	0.94	0.94
Lactose (kg/d)	0.17	0.17	0.00	−0.01 ± 0.00	1.03 ± 0.001	0.91	9.57	0.95	0.95

[1]RPE = relative predicted error; r = correlation coefficient; ρ_{ccc} = concordance correlation coefficient.

Table 5. *F*-values for effects of year and month of parturition, lactation number, and proportion of Saanen for milk production traits in New Zealand dairy goats in a large commercial herd in the production seasons from 2015 to 2020

Trait	Year	Parity	Month	Saanen	Repeatability
Standard lactation yields up to 305 d					
Milk	73.49***	289.52***	6.46**	0.26	0.40
Fat	47.37***	203.62***	2.61	0.00	0.44
Protein	84.07***	372.76***	6.60***	0.00	0.41
Lactose	56.84***	273.18***	5.12**	0.05	0.41
Extended lactation yields up to 670 d					
Milk	35.23***	97.76***	8.20***	1.72	0.49
Fat	9.99***	62.00***	7.22***	0.25	0.50
Protein	30.59***	109.95***	8.86***	1.65	0.45
Lactose	20.68***	86.41***	6.93***	1.05	0.43
Persistency[1] (%)					
Milk	35.15***	162.89***	0.72	0.11	0.15
Fat	31.88***	167.59***	0.77	0.02	0.23
Protein	42.99***	240.92***	0.31	0.12	0.13
Lactose	24.12***	145.91***	1.01	0.02	0.15

[1]Lactation persistency is defined as the yield from d 366 to 670 divided by yield from d 1 to 305, expressed as a percentage.

**$P < 0.01$; ***$P < 0.001$.

in the present study were housed indoors and lactation yields were standardized to either 305-d or 670-d, this effect of month of kidding was likely due to the photoperiod. Several studies have also found that a longer or increasing photoperiod (such as June–October in this study) is linked to increased milk production in goats (Garcia-Hernandez et al., 2007; Flores et al., 2011; León et al., 2012; Russo et al., 2013; Zamuner et al., 2020). This was probably due to photoperiodic effects on mammary gland development, mammary activity, and voluntary feed intake (Dunshea et al., 1990; Neville et al., 2002; Garcia-Hernandez et al., 2007; Lacasse et al., 2014), although further research is required to confirm this.

Parity affected the milk, fat, protein, and lactose yields of goats, with first-parity goats producing 26% to 30% less than goats in their fourth parity when subjected to SL, and 18% to 20% less for EL. One explanation for milk production being lower during the first lactation is that does are still growing (McGregor and Butler, 2010). Growth and development partitions nutrient resources away from lactation; thus, peak milk production normally occurs when mature body weight has been reached (Sevi et al., 2000), which in goats occurs at 4 to 5 years of age (McGregor and Butler, 2010). An alternative, but not mutually exclusive, cause for increased milk production from parity 1 to 4 may be changes in the number or activity of mam-

Table 6. Least squares means and SE of 305-d lactation yields (kg) of milk, fat, protein, and lactose for parity and month of kidding of New Zealand dairy goats in a large commercial herd in the production seasons from 2015 to 2020[1]

		305-d milk		305-d fat		305-d protein		305-d lactose	
Effect	n	LSM	SE	LSM	SE	LSM	SE	LSM	SE
Parity									
1	1,122	946[d]	8	31[d]	0.3	29[d]	0.2	44[d]	0.4
2	559	1,284[c]	10	40[b]	0.3	41[c]	0.3	59[bc]	0.5
3	494	1,312[bc]	11	41[ab]	0.4	42[b]	0.3	60[bc]	0.5
4	430	1,351[a]	12	42[a]	0.4	43[a]	0.3	61[a]	0.5
5	210	1,328[ab]	16	40[b]	0.5	42[ab]	0.5	60[ab]	0.7
6	107	1,275[c]	21	39[c]	0.7	40[c]	0.6	58[c]	1.0
Month of kidding									
Jun.	153	1,202[c]	17	38	0.6	38[b]	0.5	55[b]	0.8
Jul.	1,721	1,237[b]	7	38	0.2	39[b]	0.2	56[b]	0.3
Aug.	855	1,278[a]	10	39	0.3	40[a]	0.3	58[a]	0.5
Sep.–Oct.	193	1,279[a]	17	40	0.6	40[a]	0.5	58[a]	0.8

[a–d]Least squares means with different superscripts, within effect, are significantly different ($P < 0.05$).

[1]n = number of does within each category.

Table 7. Least squares means and SE of 670-d lactation yields (kg) of milk, fat, protein, and lactose, and persistency for parity and month of kidding of New Zealand dairy goats in a large commercial herd during the production seasons from 2015 to 2020[1]

Effect	n	670-d milk		Persistency		670-d fat		Persistency		670-d protein		Persistency		670-d lactose		Persistency	
		LSM	SE	LSM	SE	LSM	SE	LSM	SE	LSM	SE	LSM	SE	LSM	SE	LSM	SE
Parity																	
1	850	2,140^{d}	19	113^{a}	0.6	69^{d}	0.7	116^{a}	0.8	69^{d}	0.6	122^{a}	0.7	97^{d}	0.9	113^{a}	0.8
2	458	2,639^{ab}	24	96^{b}	0.8	84^{a}	0.9	93^{b}	1.0	86^{ab}	0.8	98^{b}	1.0	120^{ab}	1.2	93^{b}	1.1
3	464	2,641^{ab}	24	91^{c}	0.8	83^{ab}	0.8	88^{c}	1.0	85^{ab}	0.8	92^{c}	0.90	120^{b}	1.2	87^{c}	1.0
4	408	2,696^{a}	26	89^{d}	0.92	85^{a}	0.9	86^{c}	1.1	87^{a}	0.8	89^{d}	1.1	123^{a}	1.3	84^{d}	1.1
5	199	2,625^{b}	34	88^{d}	1.3	81^{b}	1.2	85^{c}	1.4	84^{b}	1.1	88^{d}	1.3	119^{bc}	1.7	83^{d}	1.5
6	89	2,500^{c}	48	87^{d}	1.6	77^{c}	1.7	85^{c}	2.0	80^{c}	1.5	86^{d}	1.91	114^{c}	2.4	82^{d}	2.1
Month of kidding																	
Jun.	153	2,448^{b}	36	95	1.2	78^{b}	1.3	92	1.5	80^{c}	1.1	96	1.4	111^{b}	1.8	92	1.6
Jul.	1,718	2,487^{b}	14	93	0.4	78^{b}	0.5	91	0.5	80^{c}	0.4	95	0.5	112^{b}	0.7	89	0.6
Aug.	444	2,584^{a}	25	94	0.8	81^{b}	0.9	92	1.0	83^{b}	0.8	96	0.9	117^{a}	1.2	90	1.1
Sep.–Oct.	153	2,643^{a}	41	94	1.3	84^{a}	1.5	93	1.7	85^{a}	1.3	96	1.5	120^{a}	2.1	91	1.7

[a–d]Least squares means with different superscripts, within effect, are significantly different ($P < 0.05$).

[1]Lactation persistency is defined as the yield from d 366 to 670 divided by yield from d 1 to 305, expressed as a percentage. n = number of does within each category.

mary epithelial cells. Although mammary epithelial cell numbers have been shown to increase with parity in cattle (Miller et al., 2006), data for goats is lacking. It was interesting to find that the effect of parity on goats in extended and SL was similar, with peak lactation occurring following the fourth parity for both lactation types.

On average, goats subjected to EL for their first parity produced 90 kg less milk than goats that had 2 SL for their first and second parities (Tables 6 and 7). During their second parity, goats subjected to EL produced 43 kg more milk than goats that experienced SL for their second and third parity (Tables 6 and 7). Across all subsequent parities, we observed minimal differences (less than 25 kg) in the total milk yields of goats in one EL or 2 SL. Total fat, protein, and lactose yields were similar when comparing a single EL against 2 SL for all yields and parities (<5 kg difference; Tables 6 and 7). A similar pattern has also been reported by Salama et al. (2005). Thus, it seems that EL can be implemented without greatly affecting overall milk production or composition. Although further investigation into whether the preceding lactation type affects milk yield and composition during SL or EL is still required.

In addition, EL has a number of advantages that are independent of milk production. Sehested et al. (2019) reviewed the implications of EL in dairy cattle and highlighted that it will decrease the number of calvings per year (at the farm level) and reduce the many health risks associated with calving (e.g., mastitis, lameness, and metabolic problems in early lactation). Therefore, an EL management strategy holds the potential to improve dairy cow longevity and lifetime efficiency (Sehested et al., 2019). If longevity of cows or goats increases with EL, then the number of replacement animals required each year may also be reduced, thus enabling herd managers to be more selective of the replacement animals selected for genetic gain. Additionally, EL would have several welfare implications, including reductions in the number of surplus offspring annually, an effect that would be greater in goats than cattle, as they are polytocous (Meijer et al., 2021). Farm profitability could also benefit from EL through reduced costs of rearing replacement offspring, which represents the second largest annual expense after feed costs (Bach et al., 2008). Given that pregnant goats have higher feed requirements than nonpregnant goats (Castagnino et al., 2015), it is also likely that annual feed costs (the largest cost for dairy goat farms) would be reduced with EL, as goats in EL would spend fewer days pregnant. However, it was not possible to assess the effect of pregnancy on feed intake and lactation yields in the present study, as pregnancy diagnoses and mating records were not available.

In goats, EL has the potential to reduce operation costs along with maintaining or only slight reducing milk production, making it a promising system for the dairy goat industry. This strategy may not be as effective for dairy cattle systems due to modeled lactation curves showing a progressive, but gradual, reduction in milk production as EL continues (Steri et al., 2012; Kok et al., 2019; Lehmann et al., 2019; Niozas et al., 2019). However, a simulation study by Butler et al. (2010) reported that in a seasonal pasture-based system, an EL strategy with a 24-mo calving interval may be a viable alternative to culling nonpregnant cows and economically more suited to high-producing cows. Although situations exist where EL could be beneficial in the dairy cow industry, further research is needed to determine the cost-to-benefit ratio of this system before it is widely implemented. This is also the case for goats, where further research into the economic and welfare benefits of EL is needed.

CONCLUSIONS

This study is the first to assess and compare the lactation curves of goats in SL and EL. Our results indicate that the persistency of EL is high and that goats subjected to a 670-d EL will produce similar amounts of milk, fat, protein, and lactose compared with goats subjected to two 305-d SL. Further studies are required to evaluate the economic benefit of EL, accounting for a potential increase in goat longevity, lower replacement rate, and improved animal welfare, due to the smaller number of young offspring produced.

ACKNOWLEDGMENTS

This study was funded by a research contract between Massey University (Palmerston North, New Zealand) and the Dairy Goat Co-operative (NZ) Ltd. (Hamilton, New Zealand; grant no. 3000034707). The authors have not stated any conflicts of interest.

REFERENCES

Arnal, M., H. Larroque, H. Leclerc, V. Ducrocq, and C. Robert-Granié. 2019. Genetic parameters for first lactation dairy traits in the Alpine and Saanen goat breeds using a random regression test-day model. Genet. Sel. Evol. 51:43. https://doi.org/10.1186/s12711-019-0485-3.

Bach, A., N. Valls, A. Solans, and T. Torrent. 2008. Associations between nondietary factors and dairy herd performance. J. Dairy Sci. 91:3259–3267. https://doi.org/10.3168/jds.2008-1030.

Bélichon, S., E. Manfredi, and A. Piacère. 1998. Genetic parameters of dairy traits in the Alpine and Saanen goat breeds. Genet. Sel. Evol. 30:529–534. https://doi.org/10.1186/1297-9686-31-5-529.

Ben Abdelkrim, A., L. Puillet, P. Gomes, and O. Martin. 2021. Lactation curve model with explicit representation of perturbations as a phenotyping tool for dairy livestock precision farming. Animal 15:100074. https://doi.org/10.1016/j.animal.2020.100074.

Brito, L. F., F. G. Silva, A. L. Melo, G. C. Caetano, R. A. Torres, M. T. Rodrigues, and G. R. Menezes. 2011. Genetic and environmental factors that influence production and quality of milk of Alpine and Saanen goats. Genet. Mol. Res. 10:3794–3802. https://doi.org/10.4238/2011.December.14.9.

Brito, L. F., F. G. Silva, H. R. Oliveira, N. O. Souza, G. C. Caetano, E. V. Costa, G. R. O. Menezes, A. L. P. Melo, M. T. Rodrigues, and R. A. Torres. 2017. Modelling lactation curves of dairy goats by fitting random regression models using Legendre polynomials or B-splines. Can. J. Anim. Sci. 98:73–83. https://doi.org/10.1139/cjas-2017-0019.

Butler, S. T., L. Shalloo, and J. J. Murphy. 2010. Extended lactations in a seasonal-calving pastoral system of production to modulate the effects of reproductive failure. J. Dairy Sci. 93:1283–1295. https://doi.org/10.3168/jds.2009-2407.

Castagnino, D., C. Härter, A. Rivera, L. Lima, H. Silva, B. Biagioli, K. Resende, and I. Teixeira. 2015. Changes in maternal body composition and metabolism of dairy goats during pregnancy. Rev. Bras. Zootecn. 44:92–102. https://doi.org/10.1590/S1806-92902015000300003.

Castañeda-Bustos, V. J., H. H. Montaldo, G. Torres-Hernández, S. Pérez-Elizalde, M. Valencia-Posadas, O. Hernández-Mendo, and L. Shepard. 2014. Estimation of genetic parameters for productive life, reproduction, and milk-production traits in US dairy goats. J. Dairy Sci. 97:2462–2473. https://doi.org/10.3168/jds.2013-7503.

Dematawewa, C. M. B., R. E. Pearson, and P. M. VanRaden. 2007. Modeling extended lactations of Holsteins. J. Dairy Sci. 90:3924–3936. https://doi.org/10.3168/jds.2006-790.

Dijkstra, J., J. France, M. S. Dhanoa, J. A. Maas, M. D. Hanigan, A. J. Rook, and D. E. Beever. 1997. A model to describe growth patterns of the mammary gland during pregnancy and lactation. J. Dairy Sci. 80:2340–2354. https://doi.org/10.3168/jds.S0022-0302(97)76185-X.

Douhard, F., M. Tichit, P. R. Amer, and N. C. Friggens. 2014. Synergy between selection for production and longevity and the use of extended lactation: Insights from a resource allocation model in a dairy goat herd. J. Anim. Sci. 92:5251–5266. https://doi.org/10.2527/jas.2014-7852.

Dunshea, F. R., A. Bell, and T. Trigg. 1990. Non-esterified fatty acid and glycerol kinetics and fatty acid re-esterification in goats during early lactation. Br. J. Nutr. 64:133–145. https://doi.org/10.1079/BJN19900016.

Flores, M. J., J. A. Flores, J. M. Elizundia, A. Mejía, J. A. Delgadillo, and H. Hernández. 2011. Artificial long-day photoperiod in the subtropics increases milk production in goats giving birth in late autumn. J. Anim. Sci. 89:856–862. https://doi.org/10.2527/jas.2010-3232.

Fuentes-Pila, J., M. A. DeLorenzo, D. K. Beede, C. R. Staples, and J. B. Holter. 1996. Evaluation of equations based on animal factors to predict intake of lactating Holstein cows. J. Dairy Sci. 79:1562–1571. https://doi.org/10.3168/jds.S0022-0302(96)76518-9.

Garcia-Hernandez, R., G. Newton, S. Horner, and L. C. Nuti. 2007. Effect of photoperiod on milk yield and quality, and reproduction in dairy goats. Livest. Sci. 110:214–220. https://doi.org/10.1016/j.livsci.2006.11.005.

García-Peniche, T. B., H. H. Montaldo, M. Valencia-Posadas, G. R. Wiggans, S. M. Hubbard, J. A. Torres-Vázquez, and L. Shepard. 2012. Breed differences over time and heritability estimates for production and reproduction traits of dairy goats in the United States. J. Dairy Sci. 95:2707–2717. https://doi.org/10.3168/jds.2011-4714.

Gendron, P., and A. Reveau. 1995. Extended lactations as an alternative. Chevre (Tours) 208:33–36.

Gilmour, A. R., B. J. Gogel, B. R. Cullis, S. J. Welham, and R. Thompson. 2021. ASReml User Guide Release 4.2 Functional Specification. VSN International Ltd., Hemel Hempstead, UK.

Goetsch, A. L., S. S. Zeng, and T. A. Gipson. 2011. Factors affecting goat milk production and quality. Small Rumin. Res. 101:55–63. https://doi.org/10.1016/j.smallrumres.2011.09.025.

Grainger, C., M. J. Auldist, G. O'Brien, K. L. Macmillan, and C. Culley. 2009. Effect of type of diet and energy intake on milk production of Holstein-Friesian cows with extended lactations. J. Dairy Sci. 92:1479–1492. https://doi.org/10.3168/jds.2008-1530.

Groenewald, P. C. N., and C. S. Viljoen. 2003. A Bayesian model for the analysis of lactation curves of dairy goats. J. Agric. Biol. Environ. Stat. 8:75–83. https://doi.org/10.1198/1085711031201.

Jamrozik, J., and L. R. Schaeffer. 1997. Estimates of genetic parameters for a test day model with random regressions for yield traits of first lactation Holsteins. J. Dairy Sci. 80:762–770. https://doi.org/10.3168/jds.S0022-0302(97)75996-4.

Kok, A., J. O. Lehmann, B. Kemp, H. Hogeveen, C. E. Van Middelaar, I. J. M. De Boer, and A. T. M. Van Knegsel. 2019. Production, partial cash flows and greenhouse gas emissions of simulated dairy herds with extended lactations. Animal 13:1074–1083. https://doi.org/10.1017/S1751731118002562.

Kominakis, A., M. Volanis, and E. Rogdakis. 2001. Genetic modelling of test day records in dairy sheep using orthogonal Legendre polynomials. Small Rumin. Res. 39:209–217. https://doi.org/10.1016/S0921-4488(00)00191-7.

Lacasse, P., C. M. Vinet, and D. Petitclerc. 2014. Effect of prepartum photoperiod and melatonin feeding on milk production and prolactin concentration in dairy heifers and cows. J. Dairy Sci. 97:3589–3598. https://doi.org/10.3168/jds.2013-7615.

Lehmann, J. O., L. Mogensen, and T. Kristensen. 2019. Extended lactations in dairy production: Economic, productivity and climatic impact at herd, farm and sector level. Livest. Sci. 220:100–110. https://doi.org/10.1016/j.livsci.2018.12.014.

León, J. M., N. P. P. Macciotta, L. T. Gama, C. Barba, and J. V. Delgado. 2012. Characterization of the lactation curve in Murciano-Granadina dairy goats. Small Rumin. Res. 107:76–84. https://doi.org/10.1016/j.smallrumres.2012.05.012.

Lin, L. I.-K. 1989. A concordance correlation coefficient to evaluate reproducibility. Biometrics 45:255–268. https://doi.org/10.2307/2532051.

Linzell, J. L. 1973. Innate seasonal oscillations in the rate of milk secretion in goats. J. Physiol. 230:225–233. https://doi.org/10.1113/jphysiol.1973.sp010185.

Macciotta, N. P. P., C. Dimauro, S. P. G. Rassu, R. Steri, and G. Pulina. 2011. The mathematical description of lactation curves in dairy cattle. Ital. J. Anim. Sci. 10:213-223.

Macciotta, N. P. P., C. Dimauro, R. Steri, and A. Cappio-Borlino. 2008. Mathematical Modelling of Goat Lactation Curves. CABI International. https://doi.org/10.1079/9781845933487.0031.

Marshall, A. C., N. Lopez-Villalobos, S. M. Loveday, A. Ellis, and W. McNabb. 2023. Modelling lactation curves for dairy sheep in a New Zealand flock. Animals 13:349. https://doi.org/10.3390/ani13030349.

McGregor, B. A., and K. L. Butler. 2010. Associations of mature live weight of Australian cashmere goats with farm of origin and age. Small Rumin. Res. 89:1–6. https://doi.org/10.1016/j.smallrumres.2009.10.013.

Meijer, E., V. C. Goerlich, R. Van den Brom, M. F. Giersberg, S. S. Arndt, and T. B. Rodenburg. 2021. Perspectives for buck kids in dairy goat farming. Front. Vet. Sci. 8:662102. https://doi.org/10.3389/fvets.2021.662102.

Miller, N., L. Delbecchi, D. Petitclerc, G. F. Wagner, B. G. Talbot, and P. Lacasse. 2006. Effect of stage of lactation and parity on mammary gland cell renewal. J. Dairy Sci. 89:4669–4677. https://doi.org/10.3168/jds.S0022-0302(06)72517-6.

Montaldo, H. H., M. Valencia-Posadas, G. R. Wiggans, L. Shepard, and J. A. Torres-Vázquez. 2010. Short communication: Genetic and environmental relationships between milk yield and kidding interval in dairy goats. J. Dairy Sci. 93:370–372. https://doi.org/10.3168/jds.2009-2593.

Neville, M. C., T. B. McFadden, and I. Forsyth. 2002. Hormonal regulation of mammary differentiation and milk secretion. J. Mammary Gland Biol. Neoplasia 7:49–66. https://doi.org/10.1023/A:1015770423167.

Niozas, G., G. Tsousis, C. Malesios, I. Steinhöfel, C. Boscos, H. Bollwein, and M. Kaske. 2019. Extended lactation in high-yielding dairy cows. II. Effects on milk production, udder health, and body measurements. J. Dairy Sci. 102:811–823. https://doi.org/10.3168/jds.2018-15117.

Pesce Delfino, R., M. Selvaggi, G. V. Celano, and C. Dario. 2011. Heritability estimates of lactation traits in Maltese goat. Int. J. Anim. Vet. Sci. 5:362–364. https://doi.org/doi.org/10.5281/zenodo.1057821.

Rook, A. J., J. France, and M. S. Dhanoa. 1993. On the mathematical description of lactation curves. J. Agric. Sci. 121:97–102. https://doi.org/10.1017/S002185960007684X.

Russo, V. M., A. W. N. Cameron, F. R. Dunshea, A. J. Tilbrook, and B. J. Leury. 2013. Artificially extending photoperiod improves milk yield in dairy goats and is most effective in late lactation. Small Rumin. Res. 113:179–186. https://doi.org/10.1016/j.smallrumres.2013.01.002.

Salama, A. A. K., G. Caja, X. Such, R. Casals, and E. Albanell. 2005. Effect of pregnancy and extended lactation on milk production in dairy goats milked once daily. J. Dairy Sci. 88:3894–3904. https://doi.org/10.3168/jds.S0022-0302(05)73075-7.

Scholtens, M. R., N. Lopez-Villalobos, D. Garrick, H. Blair, K. Lehnert, and R. Snell. 2020. Genetic parameters for total lactation yields of milk, fat, protein, and somatic cell score in New Zealand dairy goats. Anim. Sci. J. 91:e13310. https://doi.org/10.1111/asj.13310.

Sehested, J., C. Gaillard, J. O. Lehmann, G. M. Maciel, M. Vestergaard, M. R. Weisbjerg, L. Mogensen, L. B. Larsen, N. A. Poulsen, and T. Kristensen. 2019. Review: Extended lactation in dairy cattle. Animal 13:s65–s74. https://doi.org/10.1017/S1751731119000806.

Selvaggi, M., and C. Dario. 2015. Genetic analysis of milk production traits in Jonica goats. Small Rumin. Res. 126:9–12. https://doi.org/10.1016/j.smallrumres.2015.03.017.

Sevi, A., L. Taibi, M. Albenzio, A. Muscio, and G. Annicchiarico. 2000. Effect of parity on milk yield, composition, somatic cell count, renneting parameters and bacteria counts of Comisana ewes. Small Rumin. Res. 37:99–107. https://doi.org/10.1016/S0921-4488(99)00133-9.

Steri, R., C. Dimauro, F. Canavesi, E. L. Nicolazzi, and N. P. P. Macciotta. 2012. Analysis of lactation shapes in extended lactations. Animal 6:1572–1582. https://doi.org/10.1017/S1751731112000766.

Valencia, M., J. Dobler, and H. H. Montaldo. 2007. Genetic and phenotypic parameters for lactation traits in a flock of Saanen goats in Mexico. Small Rumin. Res. 68:318–322. https://doi.org/10.1016/j.smallrumres.2005.11.017.

Van den Brom, R., R. Klerx, P. Vellema, K. Lievaart-Peterson, J. W. Hesselink, L. Moll, P. Vos, and I. Santman-Berends. 2019. Incidence, possible risk factors and therapies for pseudopregnancy on Dutch dairy goat farms: A cross-sectional study. Vet. Rec. 184:770. https://doi.org/10.1136/vr.105346.

van der Werf, J. H. J., M. E. Goddard, and K. Meyer. 1998. The use of covariance functions and random regressions for genetic evaluation of milk production based on test day records. J. Dairy Sci. 81:3300–3308. https://doi.org/10.3168/jds.S0022-0302(98)75895-3.

Wood, P. D. P. 1967. Algebraic model of the lactation curve in cattle. Nature 216:164–165. https://doi.org/10.1038/216164a0.

Zamuner, F., K. DiGiacomo, A. W. N. Cameron, and B. J. Leury. 2020. Effects of month of kidding, parity number, and litter size on milk yield of commercial dairy goats in Australia. J. Dairy Sci. 103:954–964. https://doi.org/10.3168/jds.2019-17051.

ORCIDS

N. Lopez-Villalobos https://orcid.org/0000-0001-6611-907X
C. Andrews https://orcid.org/0000-0003-3049-1835
S-A. Turner https://orcid.org/0000-0003-2654-0673