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Is it possible to accurately estimate lactation curve parameters in extensive beef production systems?

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ABSTRACT

Objective: The objective was to characterize the lactation curve applying 3 different models using multiparous grazing beef cows.

Materials and Methods: Milk production data from 99 British crossbred multiparous cows grazing native pastures were analyzed. Lactation was assessed 15 d postpartum and then monthly until weaning (180 d postpartum) using a milking machine after an oxytocin injection. Total milk production and lactation curve were characterized using Wood (WD) and Wilmink (WIL) models, and both were compared with spline functions. Comparison was made applying adjusted coefficient of determination (R^2adj) and MSE.

Results and Discussion: Cubic splines with 5 equally spaced knots (CS5) presented the best adjustment (lowest Akaike information criterion and Bayesian information criterion). The R^2adj values were 0.55, 0.54, and 0.53 (the greater the better) and MSE values were 2.54, 2.59, and 2.47 (the lower the better) for WD, WIL, and CS5, respectively. Estimated milk production for the lactation period was 1,277, 1,255, and 1,195 kg for WD, WIL, and CS5, respectively. Milk peak was predicted to happen at 32, 25, and 36 d postpartum, with a production of 8.74, 8.21, and 8.40 kg for WD, WIL, and CS5, respectively. No differences were evident in the lactation curves (95% CI).

Implications and Applications: The proposed method and frequency used to assess grazing beef cattle milk production accurately estimate the lactation curve. The Wood model, used worldwide, was a precise estimator of the lactation curve, which in our case was verified applying splines. These results provide key information to calculate grazing beef cow requirements.

Key words: beef cattle, milk production, energy requirements, native pastures, Wood model

INTRODUCTION

Livestock production systems are characterized by a high dependence on climatic conditions. Consequently, there is a high variation in forage allowance between and within years because native pastures are the main source of nutrition. They present a marked seasonality with maximum forage production in spring and summer and minimum in winter (Carvalho et al., 2006), which coincides with the final stage of gestation and the onset of the calving period.

Extensive systems demand high energy requirements for maintenance and production (Montaño-Bermudez et al., 1990). The efficiency of cow-calf systems is defined by the ability to transform pasture nutrients into kilograms of weaned calves (Jenkins and Ferrell, 1992). Moreover, milk is the main source of nutrients for calves, and it is highly correlated with the weaning weight of calves (Totusek et al., 1973); thus, it is important to better understand milk production during the lactation period in these conditions.

Many models have been proposed to characterize milk production and the lactation curve in dairy cattle, such as the model proposed by Wood (1967) or Wilmink (1987). Both have also been used to describe lactation curves in beef cattle (Albertini et al., 2012; Espasandin et al., 2016). These models have a low number of parameters and are accessible to use and apply. The Wood and Wilmink models are the most used models to describe the lactation curve among different production systems, both in dairy and beef cows.

Other functions such as splines are used to estimate milk production, which have the advantage of providing extra flexibility in the shape of fitted lactation curves (White et al., 1999) and improved accuracy when few samples are available (Macciotta et al., 2005). Assessing daily milk production in beef cows is difficult, but 6 samples per lactation were enough to obtain a high determination coefficient using the milking machine method (Albertini et al., 2012).

The aim of the present study was to characterize the lactation curve of multiparous beef cows under grazing conditions in Uruguay with splines and the parametric models published by Wood (1967) and Wilmink (1987).

The authors declare no conflicts of interest.

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MATERIALS AND METHODS

Location

Data used in the analysis of milk production of beef cows was from different experiments carried out at the National Institute of Agricultural Research (33°26′9363″S, 54°49′4932″W), Uruguay, between 2006 and 2016.

The grasslands were composed of 80 to 85% perennial summer grasses, with *Paspalum notatum* and *Axonopus affinis* being the most important (Ayala et al., 1993). The average annual production was estimated at 3,425 kg of DM/ha, with a digestibility of OM of 53, 56.5, and 57.5% and a CP percentage of 11, 9, and 8% for winter, spring, and summer, respectively (Bermúdez and Ayala, 2005). Average annual rainfall and temperature in the area were 1,350 ± 233 mm and 17 ± 0.72°C, respectively.

Database

Ninety-nine British crossbred multiparous (4 to 10 yr old) cows over 7 yr were analyzed. Data corresponded to an original Hereford × Angus crossbred herd that was consistently served with Angus; therefore, the breed of cow was described as a proportion of Angus. Cows calved in spring (from mid-September to the end of October), and they were managed on native pastures with similar forage allowance (8–10 kg of DM/kg of live weight). No treatments were applied to the animals.

Cows were weighed at calving and monthly until weaning (180 d postpartum; autumn), and their BCS assessed visually was recorded at the same time on a 1- to 8-point scale (1 = thin, 8 = fat) as reported by Vizcarra et al. (1986). Calves were weighed at birth and monthly until weaning. Table 1 shows the estimated mean of cow body live weight and BCS by different periods: parturition (d 0) and 1 to 60, 61 to 120, and 121 to 180 d postpartum. Calf birth and weaning body live weight (corrected to 180 d) averaged 36.3 ± 0.22 and 180.5 ± 2.58 kg, respectively (mean ± SE).

Milk production was assessed between 15 and 30 d postpartum and monthly until weaning (i.e., d 30, 60, 90, 120, 150, and 180). Milk production was estimated using a milking machine after an oxytocin injection; the protocol used was proposed by Quintans et al. (2010). Briefly, cows were separated from calves, and each cow was injected intramuscularly with 10 to 20 IU of oxytocin (Hipofamina, Laboratorio Dispert SA, Montevideo, Uruguay) to facilitate milk letdown. Cows were milked approximately 2 min after the injection. At least 8 h later cows were milked again using the same protocol. Calves remained separated from cows in another paddock during these hours. A milking machine (Ruakura, Ruakura, New Zealand) was used in each milking, and it was removed after milk flow had ceased. Milk was weighed and recorded to calculate 24-h milk production, assuming linearity. In addition, milk samples of 47 cows were analyzed for fat, protein, and lactose.

Statistical Analysis

An ANOVA was performed to determine the fixed effects to be included in the model. As a result, year of the experiment, cow breed proportion, and sex of calves were included as fixed effects. Cow effect was included as a random effect and BCS at calving as a covariate.

The average lactation curve was estimated accounting for individual data from the fortnightly and monthly samplings. Lactation curve was first characterized using linear, quadratic, and cubic splines with different numbers of knots (2 to 6). Splines are special functions defined in parts by polynomials derived from the use of a thin, flexible strip called a "spline" to draw smooth curves through a set of points (Guo and White, 2005). The spline functions are continuous at the breakpoints (called knots) between one segment and the next (White et al., 1999).

These functions were adjusted using the PROC GLIMMIX procedure of SAS (version 9.4, SAS Institute Inc., Cary, NC), and the goodness of fit used to compare the adjustment of those functions was the Akaike information criterion (**AIC**) and the Bayesian information criterion (**BIC**). The function with the smallest AIC and BIC was the one selected to characterize the milk lactation curve.

In addition, the lactation curve was modeled with 2 widely used models published by Wood (1967, **WD**) and Wilmink (1987, **WIL**). The same fixed and random effects were used in this analysis. The WD [1] and WIL [2] models are as follows:

$$y = at^b \exp(-c \times t), \quad [1]$$

$$y = a + b \exp(-0.05 \times t) + ct, \quad [2]$$

Table 1. Average body live weight (BLW, kg) and BCS of multiparous cows (mean ± SE) by postpartum period

	Days postpartum			
Item	**0**	**1–60**	**61–120**	**121–180**
Cow BLW	419 ± 1.8	441 ± 3.6	447 ± 3.1	449 ± 3.2
Cow BCS	4.06 ± 0.02	4.07 ± 0.05	4.2 ± 0.04	4.2 ± 0.04

where y is daily milk production (kg); t is day of lactation; and a, b, and c are parameters that define milk production at the beginning of lactation, rate of increase to the lactation peak, and rate of decline after the peak, respectively. The value of the exponent $-0.05 \times t$ of the WIL equation determines the occurrence of milk peak day. The WD and WIL models were adjusted using the PROC NLMIXED procedure of SAS (version 9.4 SAS Institute Inc.).

The Wood and Wilmink models and splines functions were compared using the adjusted coefficient of determination (**R^2adj**) and the MSE. The most suitable is the one with the highest R^2adj and the lowest MSE. Additionally, a 95% CI was constructed for each day of lactation to compare the estimated daily production for each of the curves.

RESULTS AND DISCUSSION

The lactation curve was characterized using linear, quadratic, and cubic splines with different numbers of knots (2 to 6). The spline function that presented the lowest value of AIC and BIC was selected to characterize the lactation curve of the multiparous cows and it was compared with the Wood and Wilmink models. The cubic spline with 5 equally spaced knots (**CS5**) was selected because it had the lowest AIC and BIC values (data not presented). Thus, the linear and quadratic splines were not analyzed in this study. Procedures used to assess the nonlinear models (Wood and Wilmink) are based on the maximum likelihood method, whereas the spline functions (estimated by generalized mixed models) base their estimates on the restricted maximum likelihood method. Thus, models and spline functions were compared using R^2adj and MSE instead of the models' comparison criteria most frequently used (AIC and BIC).

The Wood model had the highest R^2adj compared with cubic splines and Wilmink, but CS5 had the smallest MSE (better adjustment) compared with WD and WIL (Table 2). The 3 applied functions to characterize the lactation curve of multiparous beef cows presented good adjustment (R^2adj and MSE). Cubic splines with 5 equally spaced knots had the best adjustment between all tested splines models (smaller AIC and BIC). The Wood and Wilmink parametric models described the expected shape as well as the splines, which are flexible and highly determined by the data structure. The described curve presents a typical lactation curve's shape with an ascending phase to a maximum peak and a steadily decreasing phase thereafter (Garcia and Holmes, 2001; Chilibroste et al., 2002; Macciotta et al., 2011). No significant differences in total milk production nor in the shape of the curve were evident when Wood, Wilmink, and cubic splines were compared applying a 95% CI. A slight numerical difference of 7 to 5% of the total milk production was detected (Table 3), which could be explained by the fact that the splines better fit individual variation. Total milk production was estimated as the area under the curve; thus, when using flexible functions (splines), the shape of the curve better adapts to the observed data.

Table 2. Adjusted multiple coefficient of determination (R^2adj) and MSE of the 3 estimated methods

Method	R^2adj	MSE
Cubic spline with 5 knots	0.53	2.47
Wood (1967) model	0.55	2.54
Wilmink (1987) model	0.54	2.59

The estimated production variables for each model are presented in Table 3. Total milk production estimated by WD was 6.8% higher than the estimated by CS5 and 1.8% higher than those by WIL. The days to milk peak occurred around the third, fourth, and fifth week for WIL, CS5, and WD models, respectively (Figure 1). There were no differences in estimated milk production at peak day between models ($P > 0.05$), because the milk peak day estimated presented a range from 25 to 36 d. No significant differences were evident between models within the 95% CI. The Wilmink model showed an earlier peak occurrence compared with the other 2 evaluated models. The reason for this observation may be based on the parameter k used in this analysis ($k = 0.05$) that is usually applied as a constant (Wilmink, 1987).

All milk production peaks estimated in this study ranged between 3.5 to 5 wk with a production of 8.2 to 8.7 kg/d, consistent with those reported in the literature. Hohenboken et al. (1992) described a milk lactation curve of beef cows with the peak at wk 4.4 postpartum with 8.4 kg/d applying the Wood model. Working in grazing conditions similar to ours and applying the Wood model, Espasandin et al. (2016) reported a peak production at wk 5 postpartum with a lower production compared with the present study (5.2 vs. 8.7 kg/d). That difference could be explained by the age of the cows (primiparous vs. multiparous). In fact, it was reported that older cows have 16 to 28% higher milk production than primiparous cows (Rodrigues et al., 2014), and according to Pimentel et al. (2006), those differences occur mainly at the peak, where multiparous cows have greater production than primiparous cows. Moreover, López Valiente et al. (2018), working

Table 3. Estimated production variables for the cubic splines with 5 knots (CS5) function and the Wood (1967) and Wilmink (1987) models at 180 d of lactation

Item	CS5	Wood	Wilmink
Total milk production (L)	1,195	1,277	1,255
Mean production (L/d)	6.64	7.09	6.97
Milk peak day (d)	36	32	25
Milk at peak day (L)	8.40	8.74	8.21

on grazing conditions in Argentina, reported a maximum production at wk 14 postpartum with 6.5 kg/d in Angus cows. The difference in the moment of milk peak occurrence might be explained by the estimation method applied by these authors (quadratic regression). In addition, Rodrigues et al. (2014), working in southern Brazilian conditions, described a peak production around the ninth week of lactation with 6.3 and 6.6 kg/d in Angus purebred and Hereford × Angus, respectively.

Several authors applied the Wood model to estimate milk production in different breeds or crossbreeds and conditions. Hohenboken et al. (1992) worked with Angus and Angus × Holstein cows, and Maiwashe et al. (2013) worked with Bonsmara and Nguni cows. Under similar grazing conditions to those in the present study, Espasandin et al. (2016), working with primiparous Hereford, Angus, and their crosses, reported a good fit of the lactation curve applying the Wood model. Nevertheless, the Wood model has some limitations in accurately predicting milk production at the beginning and end of the lactation curve (Congleton and Everett, 1980; Macciotta et al., 2011). This mainly occurs when few data are available due to the great distance between calving and the first test day (Macciotta et al., 2005) or when the time between samplings is too long. According to Flores et al. (2013), the estimation errors of these models are produced by intervals of 90 to 120 d between samplings. Silvestre et al. (2006) also reported that both Wood and Wilmink models were affected by long intervals between samplings.

Parametric models (Wood and Wilmink) are used to estimate lactation curves of large and homogeneous groups of animals, with high-frequency samplings are unable to accurately estimate individual curves (White et al., 1999). Therefore, to estimate small, heterogeneous or individual lactation curves, with few observations, flexible functions with variable coefficients such as splines are recommended by Silvestre et al. (2006). Splines fit better to particular data sets and, according to White et al. (1999), could deal with unbalanced data, being able to estimate both genetic and environmental effects. Cubic splines were a good compromise among fitting performance, data sensitivity, smoothness, and parameterization in fitting average lactation curves (Druet et al., 2003; Silvestre et al., 2006).

Extensive production systems are highly dependent on climatic conditions, with a marked seasonality in forage availability. Furthermore, assessing milk production of beef cows under those conditions can be laborious. The method used to assess milk production (milking machine after oxytocin injection) and the proposed milking frequency (6 samplings per lactation on average) allowed accurate estimation of the lactation curve, for all tested methods. Results of the present study suggest that the milking method and frequency applied in the assessment of milk production should be recommended for beef cows under range conditions.

It has been reported that maintenance requirements may vary according to the level of milk production (Montaño-Bermudez et al., 1990). To accurately estimate cow requirements at each stage, it is necessary to know the lactation curve shape. The parameters estimated by the Wood model, in the present work, were 5.887, 0.9725, and 0.03058 for a, b, and c, respectively. These parameters are also needed for the precise estimation of maintenance requirements in beef lactating cows. Milk components (fat, protein, and lactose) are also necessary to estimate lactation requirements. Milk fat, protein, and lactose were

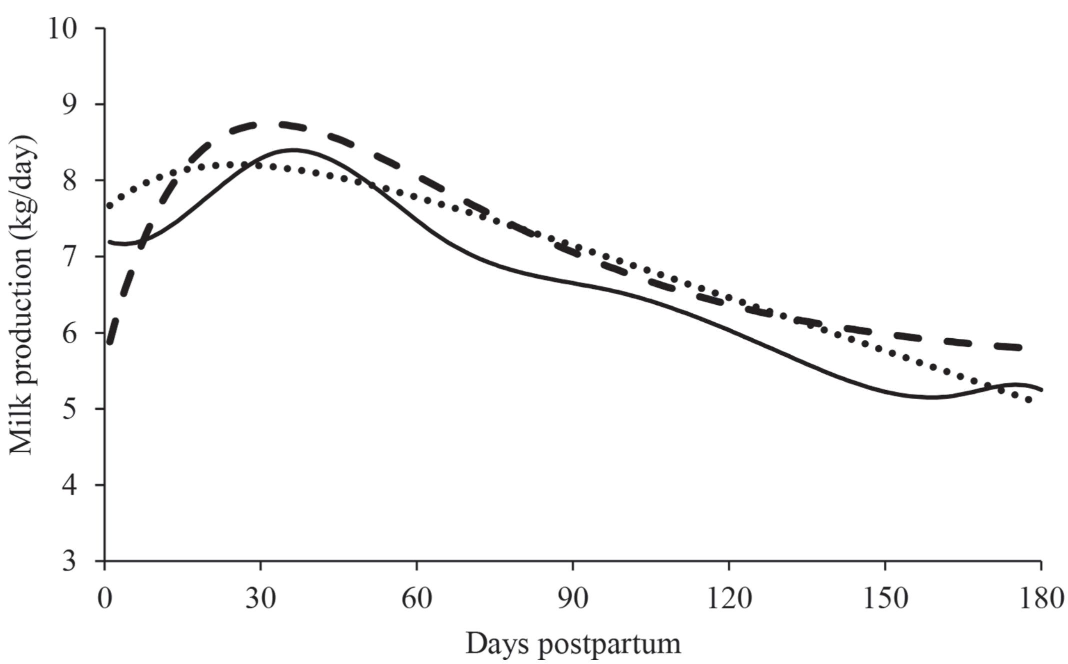

Figure 1. Lactation curves of multiparous cows for 180 d of lactation estimated with 3 different methods [sold line = cubic splines with 5 equally spaced knots; dashed line = the Wood (1967) model; dotted line = the Wilmink (1987) model].

2.16 ± 0.05, 3.13 ± 0.02, and 4.94 ± 0.01%, respectively. Milk protein and lactose percentages were consistent with those reported by the NRC (2016) in a review of several studies. In fact, the mean values were 3.38 ± 0.27 and 4.75 ± 0.91% for protein and lactose, respectively. Also, López Valiente et al. (2018), working in similar conditions to ours, reported 3.4 ± 0.11 and 4.9 ± 0.16% of protein and lactose in milk, respectively. In contrast, percentage of fat reported by the NRC (2016) was higher than that in our study (4.03 ± 1.24 vs. 2.16 ± 0.05%, respectively), but the variation coefficient in the study by the NRC was also higher (31 vs. 2%, respectively). It could be hypothesized that differences in fat content were due to genetic or environmental conditions. Indeed, assessments similar to ours, such as those by Astessiano et al. (2014) and López Valiente et al. (2018), found milk fat content closer to that presented in our study (2.7 and 2.8%, respectively).

Energy is the limiting factor in grazing cow-calf systems, with NE_m being around 70% of the required energy (Ferrell and Jenkins, 1985). Considering the significant proportion of the consumed energy used for maintenance, objective information that identifies animals with lower energy maintenance requirements and high productive performance is critical. This is even more important when forage availability is highly variable. The development of an EPD in maintenance energy is a relevant and challenging objective for extensive grazing situations. According to the equation proposed by Williams (2007) for the estimation of mature cow maintenance energy, both milk production and mature weight are needed. Goldberg and Ravagnolo (2015) reported cow mature weight under grazing conditions (similar to ours) being an outstanding contribution to extensive livestock systems. Furthermore, coefficients reported in the present study in terms of milk production and milk components for grazing cows make maintenance energy calculation possible. Consequently, all information needed to build an EPD for maintenance energy in grazing conditions is now available.

APPLICATIONS

Estimation of the lactation curve of grazing multiparous beef cows contributes to the accurate determination of nutritional requirements during lactation. Once requirements are determined, it will be possible to predict productive performance affected by milk production under different production circumstances. Furthermore, our results provide key information needed by breeding selection programs for the development of an EPD of maintenance requirements for grazing animals, unavailable until now.

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