Estimation of Milk Losses from Sub-Clinical Mastitis of Holstein-Zebu Cows Using a Nonlinear Exponential Decay Model

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Estimation of milk losses from sub-clinical mastitis of Holstein-Zebu cows using a nonlinear exponential decay model.

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Abstract

We fitted a one-phase exponential decay function (primary term) to the relationship between the sum of the CMT scores of productive quarters (SCMT, 0 to 16) and daily milk production per cow (MPC, kg/day). We added the multiplicative factors test day (T, 1 to 12), days in milk (D, 2 to 196), months of age of cow (A, 25 to 209), and the number of productive quarts (Q, 1 to 4) to the model to adjust the primary term for their effects. We calculated a conversion factor (CF, 0 to 1) from the primary term as a quotient between the predicted MPC at the i-th SCMT divided by the predicted MPC at SCMT=0. The calculated projected MPC was that of the cow as if it were SCM-free. We obtained it by dividing the observed MPC on test day by the CF. The difference between the projected and observed MPC was milk loss multiplied by MX\$ 5.50 (US\$ 0.275), which gave economic loss. The model was: $MPC = [(7.60 - 4.68)e^{-0.1773SCMT} + 4.68](T^{-0.0791})(D^{-0.1701})(A^{0.1855})(Q^{0.1835})$ with an R^2 of 0.3975. The average cow had an SCMT=6, T=7, D=75, A=79, and Q=4. The predicted MPC at SCMT=0 was 9.1 kg/cow, and at SCMT=6 it was 6.8 kg/cow; the CF = $6.8/9.1 = 0.7484$. The observed MPC on test day was 5.8 kg/day; then, the projected MPC at SCMT=0 is $5.8/0.7484 = 7.7$ kg/day. Then, milk loss is $7.7 - 5.8 = 1.9$, and economic loss is MX\$ 10.72/day. It was straightforward to devise and implement this type of calculation of milk and economic losses.

Keywords: nonlinear models, subclinical mastitis, grazing cows, tropics, dairy, income.

Introduction

Subclinical mastitis (SCM) is an udder infection that does not show external signs of the disease like inflammation and is caused mainly by bacteria that negatively affect milk yield and quality (Ávila-García & Mena, 2015). The prevalence of SCM is high under the hot and humid conditions of tropical regions. For example, research conducted in the same production unit with the same type of cattle and management by González-Sedano et al. (2010) found that at the quarter level of overall

29 prevalence of SCM was between 37.9% and 59.5% for residual calf suckling once after milking and no residual calf suckling,
30 respectively. The situation prevails in most dual-purpose tropical dairies of México (Pech-Martínez et al., 2007) and other
31 countries with hot and humid environments, like India, where a meta-analysis conducted by Krishnamoorthy et al. (2017), found
32 a pooled prevalence value was 42%.

33 Most tropical dairy farmers usually do not know that subclinical mastitis presents a much higher frequency than the
34 clinical form (Mungube et al., 2005). The quarter with SCM does not show clinical signs. Therefore, the farmer assumes the
35 udder is healthy and does not take action to mend the situation by improving the milking process hygiene, which leads to
36 reductions in milk yield and quality, negatively affecting the economic income of the farm. So, specific detection methods such
37 as the California Mastitis Test must help avoid the milk yield and financial losses associated with SCM (De Graaf & Dwinger,
38 1996; Iraghva et al., 2017).

39 Schalm & Noorlander (1957) devised the California mastitis test (CMT), and it has become the "animal-aside"
40 diagnostic assay more frequently used to monitor subclinical mastitis in dairy herds. The basis for this test is the lysis of somatic
41 cells by the CMT reagent to precipitate the DNA and proteins contained in the cells. Consequently, the development of a change
42 in viscosity of the reagent when added to milk is directly related to the relative number of somatic cells. Based on the viscosity
43 change, the sample can be semiquantitatively scored to allow for sample comparison and facilitate communication of the
44 severity (Plummer & Plummer, 2012). The degree of SCM uses a five-point scale, namely, negative, traces, +, ++, and +++,
45 that correspond to original average somatic cell counts of 100,000, 320,000, 950,000, 2'900,000, and 5'000,000 cells,
46 respectively.

47 If the effects of all other factors remain constant, the SCM infected udder will produce less milk than the same udder
48 but under healthy conditions. Then, milk production decreases as the CMT score increases (Janzen, 1970). However, the
49 relationship varies from a decreasing straight line (Tesfaye et al., 2010) to a convex negative-decay (Mungube et al., 2005).
50 Both linear and nonlinear models summarize information needed to understand biological phenomena like growth or lactation.
51 Developing a model that describes the milk production response pattern to subclinical udder infections within a particular
52 environment and management system helps determine the importance of factors affecting production efficiency. The fitting of
53 a linear function to the milk production-CMT score relation has received little attention from dairy scientists. Fitting linear and
54 nonlinear functions to this relationship would help describe the course of the disease smoothly and estimate the amount and
55 rate at which losses in milk production per cow and herd occur as SCM changes. In addition, analysis of the curves helps
56 identify preventive medicine problems that lead to strategic changes to improve production efficiency.

57 We proposed that a mathematical relationship between subclinical mastitis, measured by the California mastitis test,
58 and milk production could be the basis for milk production loss computation. Therefore, the objective of the present study was
59 to determine the fit of the monophasic exponential decay function to the CMT score-milk production per cow data as a part of
60 a protocol for milk loss evaluations due to SCM in this herd.

61 **Materials and methods**

62 **Location**

63 The study took place at the Centro de Enseñanza, Investigación y Extensión en Ganadería Tropical (Center for
64 Education, Research, and Extension in Tropical Animal Science - CEIEGT in Spanish), Facultad de Medicina, Veterinaria y
65 Zootecnia, Universidad Nacional Autónoma de México, from 26 May to 19 August 2017 (84 days). Its location on the Gulf of
66 México coastal plains lies about 40 km west of the coastline. Its geographical coordinates are 20° 02' of northern latitude, 97°
67 06' of western longitude, and 112 masl of altitude. The climate is hot and humid without a defined dry season. Minimum and
68 maximum average temperatures are 18.6 ± 3.9 °C, and 29.2 ± 3.3 °C, respectively. The yearly rainfall mean is 1931 mm with
69 a standard deviation of 334 mm. Three climatic seasons occur: rainy from July to October, with high precipitation and
70 temperature; winter or "norther-wind" from November to February, with lower rainfall and temperatures; and dry from March
71 to June (Castillo et al., 2005). The high temperature and the increased air and soil moisture that prevails throughout the year
72 favor mastitis-causing bacteria growth.

73 **Cattle management**

74 The present investigation used eighty-four lactating cows of different ages and lactation days. The animals grazed
75 rotationally, pastures composed of a mixture of exotic (*Urochloa brizantha*, *Urochloa arrecta*, *Cynodon nlmefuensis*), and native
76 grasses (*Axonopus* spp, *Paspalum* spp). The cows were machine milked once a day between 8:00 and 10:00 AM, and milk
77 production registered in kg/cow/day. The supplement was one kilogram of commercial concentrate (88% dry matter, 18%
78 crude protein) and a mineral mixture fed ad libitum at milking time. The calves did not suckle; thus, the cows received an
79 intradermic oxytocin injection of 10 IU within a minute and a half before milking to facilitate milk let-down.

80 **Description of data**

81 The application of the CMT to the milking herd took place on twelve occasions from 26 may to august 19 of 2017.
82 We changed the original CMT scale from negative, traces, +, ++, and +++ to 0, 1, 2, 3 and 4. The sum of the CMT scores
83 (SCMT) of the four quarters was the independent variable. The number of quarters with CMT score evaluations was 2748. Of
84 those, 2076 were from 63 cows with their four quarters intact, 568 corresponded to 17 cows with three functional quarters, and

104 evaluations belonged to four cows with only two-quarters available. The distribution numbers of CMT scores were 1183, 586, 409, 379, and 184 for 0, 1, 2, 3, and 4, respectively. There were twelve test days (T). At the trial start, the cows were from 2 to 196 days in milk (D), their ages (A) varied from 25 to 209 months, and 2, 3, or 4 functional quarters (Q).

Statistical analysis

We used a multiplicative model to control a one-phase exponential decay curve to study the relationship between daily milk production per cow (MPC) and the SCMT score. Multiplicative models are repeated measures designs in which milk production is represented as any relationship, linear or nonlinear. Its effects, the error term included, are multiplicative, proportional to the magnitude of MPC. The models may consist of longitudinal factors, those that act over the entire curve, like the cow, and perpendicular effects, which change the curve pattern at a particular time, like a month, season, etc. (Menchaca et al., 1996).

The monophasic exponential decay function was the primary term (in bold) in the following model:

$$y = \left((a - b)e^{-c1 \cdot SCMT} + b \right) (T^{c2}) (D^{c3}) (A^{c4}) (Q^{c5}).$$

Where y is the average milk production per cow on the week previous to the test, test day included. Parameters a and b are the amounts of milk produced by a cow with an SCMT score of 0 and a cow scored 16, respectively. The (a – b) component is the extent of milk loss. The parameter c1 is a relative decay rate expressed as kg of milk loss per kg produced per unit increase in SCMT. Parameters c2, c3, c4, and c5, were power coefficients for the remaining variables T, D, A, and Q, respectively. The model was solved by the iterative procedure of Marquardt using PROC NLIN (SAS, 2013). The extra sum of squares F-ratio test helped identify non-significant terms (Motulsky and Christopolous, 2003), except the primary function.

Economic losses

The estimated milk loss (ML) was the difference between y_{xpct} or expected milk production at $x = 0$, and y_{obs} or the observed milk production on the test week. In turn, the y_{xpct} value came from the product of y_{obs} and a theoretical conversion factor ($0 \leq CF \leq 1$, unitless), calculated from the monophasic exponential decay parameters as $CF = \hat{y}_{(0)} / \hat{y}_{(0 \leq x \leq 16)}$, where the numerator is the predicted milk production at SCMT score of zero ($\hat{y}_{(0)}$) and the denominator is the predicted milk production at each x value ($\hat{y}_{(4 \leq x \leq 365.2)}$). The economic loss was the milk loss multiplied by the price per kg of milk at the farm's gate, currently 5.50 pesos or 0.275 dollars per kilo of milk, given an exchange rate of 20.00 Mexican pesos per US dollar.

Results

Table 1 shows the descriptive statistics for milk production per cow, according to the value of SCMT. The means of MPC declined as SCMT increased. The MPC data was highly variable since CV ranged from 29% to 54%, with an overall value of 51%.

Table 2 presents the analysis of variance for the decay function alone or the complete model that included the multiplicative terms. Both models were highly significant ($P < 0.0001$). Figure 1 shows that the coefficient of determination of the decay function alone was low because of the high variability of the milk production data and other factors. The inclusion of the multiplicative terms improved fit 3.5 times compared to the decay function (adjusted coefficients of determination of 0.3975 vs. 0.1150).

Table 3 shows the extra-sum-of-squares F ratio test. The test day and the number of productive quarters increased significantly ($P=0.0310$ and $P=0.0436$, respectively), while the days in milk and age of cow increased highly significantly ($P<<0.0001$), the sum of squares of the model. Even though T and Q were significant, they only contributed to the overall adjusted coefficient of determination (0.3975) with 0.0038 and 0.0034 fraction units, respectively, that is, less than 1% in either case. The cause of their significance was, no doubt, the large number of degrees of freedom for the residual variation.

Table 4 presents the parameters of the decay function without the control multiplicative variables (second column) and that of the model with all four control variables included (last column). The values of parameter a differed significantly between both models (11.6342 vs. 7.6043, $P=0.0127$). On the other hand, the b parameters difference showed a tendency to be significant (7.0261 vs. 4.6823, $P=0.0733$). Even though the c1 parameter difference among both models appeared noticeable (0.2924 vs. 0.1773), it was not significant ($P=0.3123$). On the other hand, the parameters c2 and c3 were negative, so milk production per cow decreased as the test days advanced and the days in milk increased. On the contrary, c4 and c5 were positive, so milk production increased with age and number of quarters.

Table 5 presents the computation of the factors used to convert the observed y_i to the expected maximum $y_{\max}$. The decay function extracted from the multiplicative model served to compute a predicted y per each x value. The conversion factor increased with SCMT, e. g. for SCMT = 0, $\hat{y} = 7.60$, the conversion factor was $7.60/7.60 = 1$. For SCMT = 8, $\hat{y} = 5.39$, and the CF = $5.39/7.60 = 0.7088$.

Table 6 presents the milk and money loss for the cow 201-4 on test weeks 4, 8, and 12. That cow started the present study with 130 days in milk and 36 months of age. The daily milk loss varied from 1.2 to 2.1 kg/day, equivalent to MX\$ 6.60 to MX\$ 11.55. During the study, subclinical mastitis of cow 201-4 was responsible for 134.1 kg of milk losses and MX\$ 737.30 (about US\$ 36.87).

Discussion

Some published papers present plots of the CMT score vs. milk yield. Still, so far, we found only one in which the researchers used a simple linear regression to relate milk production to the degree of subclinical mastitis, assessed with electrical conductivity (Oshima et al., 1990). In our case, we selected the monophasic exponential decay function because the original relationship between somatic cell counts (SCC) and CMT scores (Schalm & Noorlander, 1957) has the shape of an exponential growth equation. If the relationship between SCC and milk production is negative, then the relationship among SCMT scores and MPC had to be a negative exponential decay function. Furthermore, the decay function presented the best fit over simple linear regression and the Cobb-Douglass power function (data not shown).

Figure 1 shows a wide amplitude of the standard deviations, which led to a low coefficient of determination (0.11), considered inadequate for prediction purposes. Nevertheless, the 95% confidence bands of the fitted function indicate that the likely location of the fitted line is pretty narrow, suggesting that it is the more likely model. The multiplicative terms inclusion improved the fit (Table 2), modifying the magnitude of the response of milk production to the SCMT scores per cow (Figure 2). The extra sum-of-squares F-ratio test analysis indicated a significant effect of the control factors added to the model, and for this reason, the final model included them (Table 4).

The exponential decay curve convexity depended on parameter c_1 , an instantaneous relative rate of decrease of milk production as SCMT scores increase. So if c_1 changes for any reason, so does convexity. The c_1 parameter is a relative rate that indicates the kg of milk loss per kg of milk produced as the SCMT score changes one unit. Figure 2 demonstrates that the multiplying factors increased the curve's height when averages and medians were used to predict the MPC of the average cow for this herd.

Our data showed an increasing milk production curve in response to age. The many old cows in our herd remained in it because of their well above average milk production and reproduction performance, increasing the milk production values for advanced ages. On the other hand, the daily milk production response to advancing age or parity of Holstein cows under intensive management is parabolic (Yoon et al., 2004). The animals of the present study did not show the typical milk production-age relationship because we only collected partial lactation data. Nonetheless, the age effect was highly significant ($P < 0.0001$), and its inclusion improved model fit, so it fulfilled its purpose.

Menchaca (1970) developed and applied multiplicative models to describe biological processes like cattle and pasture growth and lactation curves. The model consists of a primary function, preferable an exponential for ease of linearization adjusted ("controlled") for by the power-effect of different factors known to modify the behavior of the biological process

described by the chosen function. The logarithmic conversion of the multiplicative model into its additive form allows applying formal analysis of variance procedures for parameter estimation. We used an iterative approach to estimate the parameters of nonlinear regression functions because it was not necessary to comply with unusual assumptions like the side conditions mentioned by (Menchaca et al., 1996). Besides, the decay function is easy to fit by conventional software (SAS, 2013), and its parameters have practical meaning.

The literature presents various ways to calculate milk loss from raw data. Almost all use as reference values, the milk production of quarters scored negative in the CMT or a very low SCC. After that, the expression of milk loss is a fraction or percentage that increases with the CMT score (Janzen, 1970).

De Graaf and Dwinger (1996), in five farms situated on the cloud forest ecological zone of Alajuela and Heredia provinces of Costa Rica, paired 200 cows with subclinical mastitis with another 200 healthy cows based on breed, lactation number, and days in milk. The loss in milk production was the difference between the milk produced by the healthy cow minus the milk produced by the cow with SCM. The unadjusted production loss of a cow with SCM was 1.56 kg/cow/day, equivalent to 17.6% of the milk produced by healthy cows. This case-control study allowed these researchers a great control of residual variation. However, pairing needs numerous cows, a resource not readily available if the research occurs in small farms. Otherwise, these types of experiments would need more extended periods.

Romero et al. (2018) estimated milk loss due to subclinical mastitis as $DPMQ = DRMQ \cdot (TQ / (TQ - UQE))$, where: DPQM is daily potential milk production per quarter, DRMQ is daily actual milk production per quarter, TQ is the total number of quarters, and UQE is the unproductive quarter equivalence. The same authors estimated the UQE as follows: $UQE = TQ \cdot ((1 \cdot PLQ) + (0.02 \cdot PLSQ) + (0.33 \cdot PHSQ))$, where: PLQ is the prevalence of lost quarters per farm, PLSQ is the prevalence of low SCC quarters ($250-1000 \times 10^3$ cells per ml), PHSQ is the prevalence of high SCC ($> 1000 \times 10^3$ cells per ml). The advantage of using this formula is that it takes into account production losses due to unproductive quarters. But on the other hand, the coefficients 1.00, 0.02, and 0.33 came from animals managed in different environments and management conditions (Mungube et al., 2005), so its use may not be appropriate because it may lead to biased estimation of milk loss.

We fitted a nonlinear regression function to predict the effect of subclinical mastitis on individual milk production and compute milk loss factors from it (Table 5). Our fractional conversion factors (CF) were divisors that converted the observed milk production of a cow into expected milk production as if the quarter or udder were SCM-free (Table 6). Our

computation approach was different. However, it is the same basis: the difference between the milk produced by an SCM-free quarter minus the milk produced by an SCM-affected quart.

Shaw and Beam (1935) were probably the first to refer to the opposite quart procedure to study milk loss due to SCM, and after them and up to the present time, several authors followed (Forster et al., 1967; Janzen, 1970; Romero et al., 2018). Most studies measure and express milk loss on a per quarter basis because in the same udder, a quarter may be healthy while others may present SCM. The opposite quarter measurement technique obeys the purpose of having a case (the quarter with SCM) and control (the quart without SCM) within the same animal, improving error control. Individual quarters produce different amounts of milk when healthy and react differently to SCM (Jansen, 1970). Another reason for using opposite quarters is to consider the negative influence of non-functional quarters on milk production. The trends of SCM incidence obtained in some studies point out that the incidence rate of SCM in different quarters is not similar, being higher in hindquarters (Pranay et al., 2017). However, when the milk production recording is on a per cow basis, it is not easy to justify the division by four to calculate milk production per quarter; because the differences between the front and rear quarters are unaccounted for in the computation. Estimating total herd milk yield loss varies with cow-level SCC and parity distribution within the herd, so it is necessary to calculate milk loss per cow basis (Chen et al., 2020). These were the reasons behind our use of the sum of all CMT scores as an explanatory variable when registered milk per cow is the response variable.

Conclusions

It was feasible to fit a negative exponential decay function to describe the milk production-CMT score relationship and calculate conversion factors to project test-day milk production of a cow with SCM into milk production of a healthy cow. Then, to estimate milk loss by difference. There are many variations in the environmental landscape of the tropics that would lead to differences in the milk loss in response to differences in the CMT scores, so it is advisable to use local nonlinear regression functions to avoid biased evaluations. Incorporating the calculation procedure into an electronic worksheet is pretty straightforward, making possible a timely and on-site estimation of milk loss.

The somatic cell counts must be more accurate than the CMT score to predict milk losses because its basis is quantitative and objective. At the same time, that of the CMT is qualitative and subjective, thus prone to biases and significant variations. Nevertheless, in some situations like in tropical México, measuring the SCC is expensive, and there is a lack of adequately trained personnel to perform this task. So, the CMT must be the procedure of choice to test for subclinical mastitis for the time being. Besides, considering the economic losses generated by subclinical mastitis in the herd, extension agents and practitioners must constantly alert dairy farmers about the negative consequences of not testing cows for subclinical mastitis.

222 **Supplementary information** We do not provide supplemental information.

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226 **Author contribution** Epigmenio Castillo-Gallegos conceived the study, did the statistical analysis and interpretation and wrote
227 the draft. Miguel Cordero-Montoya did the CMT and milk production measurements and reviewed the document as well.
228 Miguel Angel Alonso-Díaz conceived and designed the study and reviewed the draft.

229 **Data availability** Databases are available upon reasonable request.

230 **Code availability** SAS codes are available upon reasonable request.

231 **Declarations**

232 **Ethics approval** The management of cattle followed applicable national and international guidelines for the care, use, and
233 production.

234 **Consent to participate** All authors agreed on their roles and participation tasks and also on the authorship.

235 **Consent for publication** All authors agreed on the publication of the manuscript.

236 **Conflict of interest** The authors declare not to have any conflict of interest.

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Table 1. Descriptive statistics for milk production of grazing F1 Holstein-Zebu cows according to the sum CMT scores from the four quarters (SCMT).

SCMT	Statistics of daily milk production per cow						
	n	Mean	Std. Dev.	Std. Error	C. V.	LB95	UB95
0	146	11.68	5.11	0.42	43.78	10.84	12.52
1	59	10.05	5.27	0.69	52.41	8.68	11.43
2	82	10.11	5.11	0.56	50.49	8.99	11.24
3	85	8.75	4.39	0.48	50.15	7.81	9.70
4	72	7.78	4.01	0.47	51.53	6.84	8.72
5	53	8.74	3.83	0.53	43.75	7.69	9.80
6	48	7.70	4.19	0.61	54.45	6.48	8.92
7	33	8.03	3.95	0.69	49.24	6.63	9.43
8	44	7.78	3.48	0.52	44.70	6.72	8.83
9	30	7.21	2.72	0.50	37.66	6.20	8.23
10	27	7.06	3.31	0.64	46.85	5.75	8.37
11	18	7.96	3.92	0.92	49.23	6.01	9.91
12	10	7.79	2.25	0.71	28.88	6.18	9.40
13	21	6.10	2.69	0.59	44.07	4.88	7.33
14	8	6.20	3.97	1.41	64.10	2.88	9.52
15	1	8.00	-----	-----	-----	-----	-----
16	3	7.93	3.05	1.76	38.45	0.36	15.51
Overall	740	9.07	4.64	0.17	51.22	8.73	9.40

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298 Table 2. Analysis of variance of the multiplicative model with the control of the one-phase exponential decay curve. Both
 299 models described the relationship between the California mastitis test score upon milk production of F1 Holstein-Zebu cows.
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Source	DF ¹	SS	MS	F value	Pr > F	R ² _{adj.}	RSD
<i>Monophasic exponential decay function (primary function)</i>							
Model	3	1832.40	610.80	31.87	2.2560E-19	0.1150	4.38
Residual	736	14107.39	19.17				
Total	739	15939.79	21.57				
<i>Multiplicative with control of the primary function</i>							
Model	7	6336.18	905.17	68.99	2.2779E-76	0.3975	3.62
Residual	732	9603.61	13.12				
Total	739	15939.79	21.57				

301 ¹ The headings meaning are DF, degrees of freedom; SS, sums of squares; MS, mean square; R²_{adj.}, coefficient of
 302 determination adjusted by parameter number, and RSD, residual standard deviation.
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307 Table 3. An extra sum of squares F ratio test was used to identify non-significant factors in the multiplicative model.
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Source of variation ¹	Degrees of freedom	SS of the model	Extra SS ²	MS of the model	Extra MS	F ratio	Pr > F	Partial R ²
SCMT	3	1832.40		610.80		46.56	<0.0001	0.1150
SCMT, T	1	1893.69	61.29		61.29	4.67	0.0310	0.0038
SCMT, T, D	1	5870.01	3976.32		3976.32	303.08	<0.0001	0.2495
SCMT, T, D, A	1	6282.58	412.57		412.57	31.45	<0.0001	0.0259
SCMT, T, D, A, Q	1	6336.18	53.60		53.60	4.09	0.0436	0.0034
Error	732	9603.61		13.12	13.12			
Corrected total	739	15939.79						0.3975 ²

309 ¹ SCMT, sum of the four quarters CMT scores; T, mean test days; D, days in milk at start; A, age of cows at start in months; Q, number of functional quarters.

310 ² Extra SS is the marginal increase in the model resulting from the sequential addition of another variable to the model.

311 ³ It is the coefficient of determination of the full model (SCMT, T, D, A, Q).
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¹ SCMT, sum of the four quarters CMT scores; T, mean number of test days; D, days in milk at start; A, age of cows at start in months; Q, number of functional quarters.

336 Table 5. Conversion factor computed from the monophasic exponential decay function:
 337 $\widehat{MPC}_i = (7.60 - 4.68)e^{-0.1773 \cdot SCMT_i} + 4.68$.
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SCMT ¹	$\widehat{MPC}_i$	$\widehat{MPC}_0$	Conversion factor $\widehat{MPC}_i/\widehat{MPC}_0$
0	7.60	7.60	1.0000
1	7.13	-----	0.9376
2	6.73	-----	0.8853
3	6.40	-----	0.8415
4	6.12	-----	0.8048
5	5.88	-----	0.7741
6	5.69	-----	0.7484
7	5.52	-----	0.7269
8	5.39	-----	0.7088
9	5.27	-----	0.6937
10	5.18	-----	0.6810
11	5.10	-----	0.6704
12	5.03	-----	0.6616
13	4.97	-----	0.6541
14	4.92	-----	0.6479
15	4.88	-----	0.6427
16	4.85	-----	0.6383

339 ¹ SCMT is the sum of CMT scores of the productive quarters of the udder.
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Table 6. Estimated milk production and economic losses due to the subclinical mastitis of the cow 201-4 on test days 4, 8, and 12. The y variable is the average daily milk production of the cow on the week preceding the test, test day included.

Test day	SCMT ¹	CF	Observed MPC ²	Expected MPC at SCMT=0 ³	Milk Loss per day ⁴	MX\$ loss per day ⁵
4	8	0.7088	5.0	7.1	2.1	11.55
8	5	0.7741	4.1	5.3	1.2	6.60
12	7	0.7269	3.9	5.4	1.5	8.25

¹ SCMT is the sum of the CMT scores from all productive quarters.

² The observed MPC is the average milk production on the week previous to the test.

³ The expected MPC at SCMT=0 is equal to the observed test day MPC divided by the conversion factor (CF).

⁴ Milk loss is the difference between the expected MPC at SCMT=0 and observed MPC on the test day.

⁵ The price of milk at the farm's gate was MX\$ 5.50 (US\$ 0.275. MX\$ 20.00 per US dollar.

Figures

Figure 1

Monophasic exponential decay relationship between observed daily milk production per cow (MPC, kg/cow/day) and the sum of the CMT scores of the four quarters (SCMT) of grazing F1 Holstein-Zebu cows. The solid line is the fitted function, and the dotted lines are the 95% confidence bands showing the likely location of the actual curve. $R^2_{\text{adj.}}$ is the coefficient of determination adjusted for the number of parameters in the model; RMSR is the square root of the mean square of the residual, and DF is degrees of freedom.

Figure 2

Effect of the sum of the CMT (SCMT) scores of the productive quarters on milk production per cow (MPC; kg/day). The primary function does not have any of the control factors and gives unadjusted milk production values. The equation for the average cow had as control factors that modify the height of the curve, the averages for days in milk (D, 75) and age of cow (A, 79 months), and the medians for test day (T, 7) and the number of productive quarters (Q, four).