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Prediction of Milk Production per Cow Lactation in the Mexican Tropics

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ABSTRACT

Objective: To evaluate non-linear and linear mathematical models used to estimate milk production per lactation, at different frequencies of milk weighing from records of Holstein (Ho), Brown Swiss (BS) cows and their crosses with Zebu (Z).

Design/Methodology/Approach: The models evaluated were: Wood, Wilmink and Linear Interpolation. Daily records of milk production from 471 lactations of 72 cows were used; 1,884 records were created with frequencies of weekly, biweekly and monthly milk production. The following were included in the statistical model: the genotype (Ho×Z and BS×Z), birth season (rainy and dry), and number of lactation (1 and 2) with double and triple interactions. The statistical analyses were performed with GLM from MINITAB v17. The means were compared with Tukey's test.

Results: No differences were found ($P \geq 0.05$) between the models for the average milk production per lactation in kg, obtained from daily measurements or estimated from weekly, biweekly and monthly data, although for the factors of birth season, number of lactation, and genotype they showed differences ($P \leq 0.05$) in milk production per lactation.

Study Limitations/Implications: Daily records of milk production are necessary to obtain production per lactation; the models applied predict milk production in a similar way in different frequencies of weighing in Holstein, Brown Swiss cows and their crosses with Zebu.

Findings/Conclusions: The models used allow predicting the milk production per cow in a similar way in different frequencies of weighing.

Keywords: Wood, Wilmink, Linear Interpolation, Prediction of milk production.

INTRODUCTION

A common characteristic of most milk production systems in Mexico, particularly in tropical zones with double-purpose cattle is the absence of production records. An adequate analysis is difficult to make without accurate information of the milk production records. Keeping track of the

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daily or weekly production in each milking per cow is tedious and costly, and for this reason, an alternative is to use production records or controls at regular intervals during the lactation, with which the total production is calculated or estimated (Van Raden *et al.*, 1999; Geary *et al.*, 2010). In Mexico there is a lack of information generated in the double-purpose systems. The mathematical models applied to the dairy industry constitute analysis tools that contribute to understanding the dynamic of the systems based on static information (Fernández and Saad de Schoos, 1999). One of the estimators to evaluate the productivity of a herd is the average of milk production per cow and lactation, which helps to establish programs of genetic and productive improvement. The implementation of a methodology that leads to monthly measurements or even less frequently would allow predicting the milk production per lactation, with the information generated through the use of non-linear and linear models (Van Raden *et al.*, 1999). This results in a more economical activity that in addition can promote the use of more productive records, with which the cattle can be evaluated and genetic and productive programs could be developed in the livestock herds.

Mechanistic models have been developed (Pollott, 2000; Wood, 1967) or polynomial empirical models (Schaeffer *et al.*, 2000) which allow predicting milk production or of its components, as function of time. The implementation of these models has allowed advances in the productivity of dairy cattle in many countries (Camerón, 1997). There is no perfect or complete model, since the behavior can depend on details of the population under study and the data used, and can vary by race, number of birth and lactation, which is why continuous or multiple ways need to be tested. The objective was to compare and evaluate different mathematical models that estimate milk production per lactation, based on different frequencies of records in the weight of milk in the Holstein (Ho), Brown Swiss (BS) breeds and their crosses with Zebu (Z), in Mexico's tropical zone.

MATERIALS AND METHODS

This study was carried out in the tropical dairy module of the "La Posta" Experimental Field of the National Institute of Forestry, Agricultural and Livestock Research (Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias), in Paso del Toro, Veracruz, Mexico (Km 22.5 Veracruz-Córdoba highway, 19° 00′ 49′′ N and 96° 08′ 19′′ W, at 12 m of altitude). The climate is tropical sub-humid Aw_2, with average relative humidity of 77.4% and annual precipitation of 1461 mm (Vidal, 2005). The module has 25.4 ha, of which 16.4 ha are pastures established with African stargrass (*Cynodon plectostachyus*); 8.0 ha were destined to sorghum (*Sorghum bicolor* L.) fodder production and 1.0 ha for the facilities of the module.

The cows were managed in nocturnal rotational grazing and daytime stabling. They were milked mechanically twice per day, at 6:00 and at 16:00 h. In each milking the dairy production was measured and recorded daily. During milking, the cows were complemented with 2 kg of a concentrate elaborated in the La Posta Experimental Field, with 16% of Raw Protein and 70% of Total Digestible Nutrients. Sorghum ensilage was offered in the pens (20 to 25 kg in Humid Base), mineral salts, and free access to fresh and clean water every day during the research period.

The variables of study were the following:

- Milk production per lactation (kg days^{-1} in lactation).
- Milk production per lactation, obtained from daily measurements.
- Milk production per lactation, estimated taking weekly data.
- Milk production per lactation, estimated taking biweekly data.
- Milk production per lactation, estimated taking monthly data.

The evaluation of the different prediction models of milk per lactation was made by comparing their estimations with those obtained from the daily milk production records from 1998 to 2004 of Ho, BS cows and their crosses with Z. The records were refined by eliminating cows of unknown genotype and incomplete lactations. The database finally included 471 lactations of 72 cows and a total of 1,884 records.

The explanatory factors included were: genotype, birth season, number of lactation, mathematical model and frequency of data recording. The effect of the genotype had two levels: Level 1 of Ho×Z bred cows, and level 2 of BS×Z bred cows. The birth date was classified into two seasons: dry season and rainy season; the lactations were grouped into first and second or more lactations; the models included were Wood (1976), Wilmink (1987) and linear interpolation (Sargent *et al.*, 1968).

The Wood model is described with the following equation:

$$y = ax^{b} e^{-cx}$$

where y = daily milk production; x = days in lactation; a = production at the beginning of the lactation; b = parameter that explains the rate of increase before the peak of lactation; c = parameter that explains the rate of decrease after the peak of lactation; e = base of natural logarithm.

In the model proposed by Wilmink, the milk production estimated was calculated as:

$$y = a_o + a_1 t = a_2 e^{(-0.05t)}$$

where y = milk production in a time interval; a = coefficients (parameters) to be estimated; t = time.

In the Linear Interpolation Model (Sargent *et al.*, 1968), milk productions per lactation were calculated through the formula:

$$y = \sum_{i=1}^{n} \left[\left(INT_i - 1 \right) * y_i + \left(INT_i + 1 \right) * y_{i+1} \right] / 2$$

where: y = milk production; y_i = i-th production (daily, weekly, biweekly or monthly); INT_i = interval in days between productions (daily, weekly, biweekly or monthly) y_i and $y_i + 1$; n = total number of productions (daily, weekly, biweekly or monthly).

The weekly, biweekly and monthly milk production records were obtained from daily weighing. The total milk production of each cow per lactation (average of 300 d) was obtained from daily weighing. For the models by Wood and Wilmink, the intermediate days between measurements were simulated, to add and obtain the results from the estimations of the total milk productions per lactation. These were run with the Scientist® software, using the Powell algorithm and for the linear method the Excel software was used. The parameters were determined by cow, and this way equations were obtained with their respective coefficients and later the milk production was estimated per lactation per cow for both models proposed, using the simulation module of the software. The statistical parameters were obtained, such as the Model Selection Criterion (MSC) and the coefficient of determination (R) of the statistical model of the same software.

The linear model for the statistical analysis was the following:

$$Y_{ijklmo} = \mu + G_i + L_j + E_k + M_l + F_m + G_iM_l + G_iF_m + E_kM_l + E_kF_m + L_jM_l + L_jF_m + M_lF_m + G_iM_lF_m + E_kM_lF_m + L_jM_lF_m + \xi_{(ijklmo)}$$

Y_{ijklm} = o-th observation of the milk weighing; μ = population mean; G_i = effect of the i-th genotype (i = 1 and 2); L_j = effect of the j-th number of lactation (j = 1 and 2); E_k = effect of the k-th birth season (k = 1 and 2); M_l = effect of the l-th estimation method (l = 1, 2 and 3); F_m = effect of the m-th frequency (m = 1, 2, 3 and 4); GM_{il} = interaction between the genotype and the estimation method; GF_{im} = interaction between genotype and frequency of milk weighing ; EM_{kl} = interaction between birth season and estimation method; EF_{km} = interaction between season and frequency of weighing; ML_{lj} = interaction between estimation method and number of lactation; LF_{jm} = interaction between number of lactation and frequency of weighing; MF_{lm} = interaction between estimation method and frequency of weighing; GMF, EMF and LMF are triple interactions; and $\xi_{(ijklm)}$ = experimental error $N(0,\sigma 2)$.

The data were analyzed with the statistical package MINITAB version 17, with the GLM routine (General Linear Model). The means comparison was performed with Tukey's test, with α of 0.05.

RESULTS AND DISCUSSION

Milk production per lactation of Ho×Z cows, fed in a tropical dairy system, was 3,130 kg, which was higher in 26% ($P \leq 0.05$) than BS×Z cows with 2,489 kg. Likewise, in milk production starting with the second lactation (2,967 kg), they showed higher production, outperforming the cows from the first lactation in 12% (2,652 kg; $P<0.05$), and these values agree with what was reported by Cañas *et al*. (2011) and Carvajal-Hernández *et al*. (2002), who reported that first birth cows are less productive than cows with 2 to 5 births. During the rainy season, the highest milk production per lactation was found, of 2,951 kg *versus* 2,268 kg, which was the production of cows during the dry season, this being a significant difference ($P \leq 0.05$). A higher milk production is favored during the rainy season, which is related to the absence of heat stress, an increase of food consumption and an increase of blood flow toward the gastrointestinal tract that increased the nutrient flow toward the mammary gland and therefore increases the quality of milk (Ponce, 2009; West, 2003).

Table 1 shows the milk production means per lactation of Ho and BS cows crossed with Z, for simple purposes, prediction model and recording frequency or milk weight. A difference was not observed (P≥0.05) in the prediction of milk production per lactation, between the Wood, Wilmink and Linear models, which agrees with what was reported by Stanton *et al*. (1992) and Silvestre *et al*. (2009) who used the Wood model to predict milk, fat and protein production per lactation of the cows. Regarding the effect of frequencies of milk weighing, it was observed that there is no difference (P≥0.05), which is why weighing the milk monthly during the whole lactation and covering the entire curve, that is, from the first month until the end of the lactation, would be enough, assuming this does not include incomplete lactations. Therefore, the prediction of milk production per lactation of Ho×Z and BS×Z cows would have reliability higher than or equal to 95% with the three models studied. This agrees with what was reported by López *et al*. (1991), where they conclude that the Wood model predicts milk production per lactation reliably in pure Holstein cows, in a monthly frequency of weighing.

The results (Figure 1a) with the prediction models in genotypes (Ho×Z and BS×Z) and the birth season (rainy and dry) evidenced how the three models estimate the milk production per lactation similarly (P≥0.05) in cows

Table 1. Effect of the model and frequency of milk weighing (kg) in the prediction of milk production per lactation, of Holstein and Brown Swiss cows crossed with Zebu, in a Tropical Dairy system.

Milk Prediction Models				
Wood	Wilmink		Linear Interpolation	SEM
2806.6[a]	2804.7[a]		2818.5[a]	59.3
628	628		628	N
Milk Weighing Frequency				
Daily	Weekly	Biweekly	Monthly	SEM
2814.7[a]	2811.9[a]	2792[a]	2820.7[a]	68.5
471	471	471	471	N

SEM = Standard Error of the Mean; N = observations. Different literals in the same column indicate significant difference, Tukey (P≤0.05).

with genotype of the Ho×Z crosses and productions higher than 3,000 kg and similar behavior with cows of the BS×Z genotype, with productions close to 2,500 kg. Although there is a statistical difference (P≤0.05) between the genotypes for each model, it was because of the genotype effect and not the model; that is, the models predict the milk production independently of the genotype. Figure 1b shows the same behavior, without difference (P≥0.05) in the milk production by birth season, and the three models predict the milk production, although there is statistical difference from the effect of the birth season.

Figure 2 presents the graphs of the prediction models in the number of lactation (a) and the frequency of milk weighing (b). Figure 2a indicates how the three models similarly predict milk production in lactation one and two

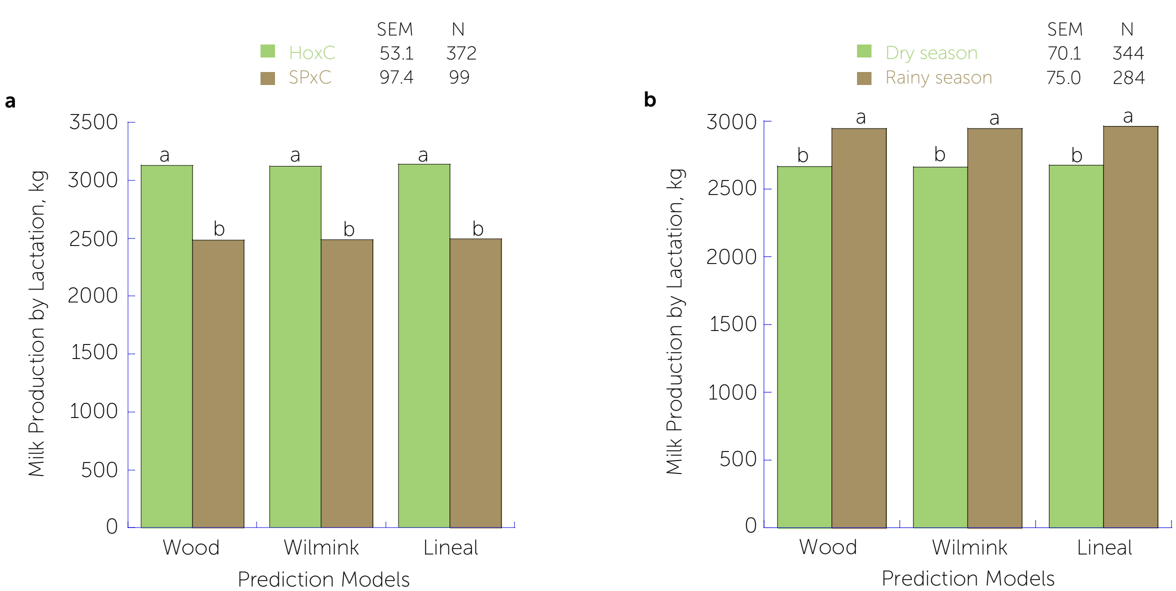

Figure 1. a) Prediction models in the Ho×Z and BS×Z genotypes, b) Prediction models in the birth season (rainy and dry).

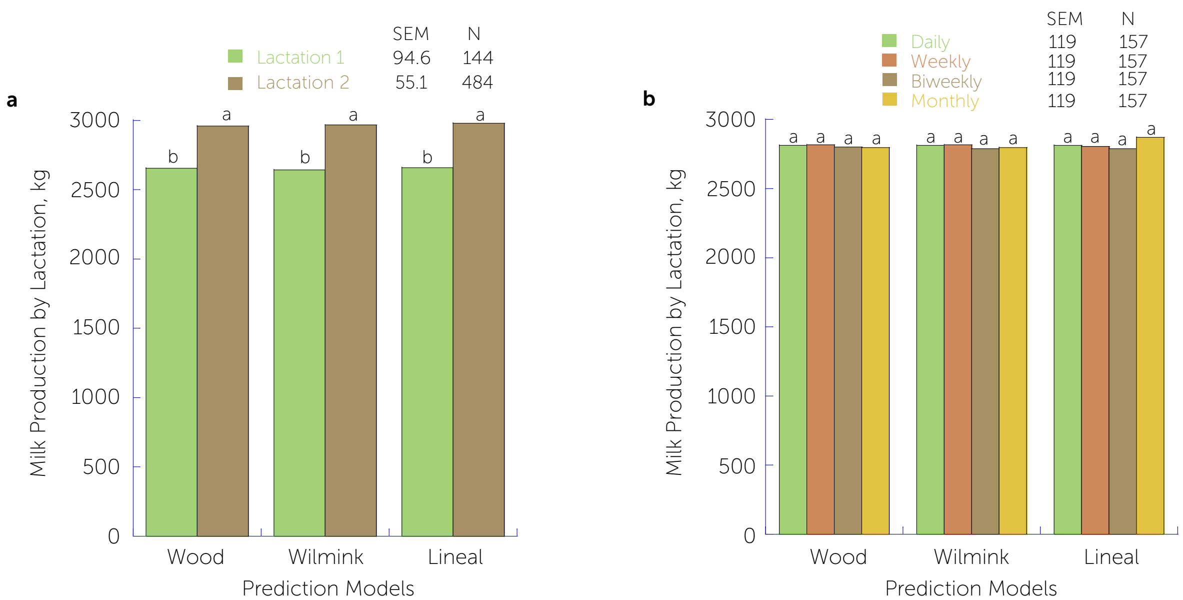

Figure 2. a) Prediction models in the number of lactations, b) Prediction models in the frequencies of weighing.

(P≥0.05). Figure 2b shows that the frequency of milk weighing does not have a significant effect on the three models or between them (P≥0.05), which confirms what was found when the simple effects were analyzed both by model or by frequency; that is, the three models can be used to predict the milk production per lactation of Ho×Z and BS×Z bred cows in a tropical dairy system, weighing the milk monthly.

Table 2 shows the comparison of the Wood, Wilmink and Linear Interpolation models in the milk production per number of lactation in the different frequencies of weighing of the milk of bred cows, highlighting that there is no significant difference (P≥0.05); that is, the non-linear (Wood and Wilming) and linear (Linear Interpolation) models predict the milk production of Ho×Z and BS×Z bred cows in the tropical dairy system with a certainty of 95%, regardless of the number of lactation and frequency of weighing.

Table 3 shows the comparison of the Wood, Wilmink and Linear Interpolation models in milk production per genotype in different frequencies of milk weighing from bred cows, highlighting that there is no significant difference (P≥0.05); that is, the non-linear (Wood and Wilming) and linear (Linear Interpolation) models predict the milk production of Ho×Z and BS×Z bred cows in the tropical dairy system with an accuracy of 95%, regardless of the number of genotype and frequency of weighing.

Table 4 shows the comparison of the Wood, Wilmink and Linear Interpolation models in the milk production per birth season (rainy and dry) in the different frequencies of milk weighing of the bred cows, highlighting that there is no significant difference (P≥0.05); that is, the non-linear (Wood and Wilmink) and linear (Linear Interpolation) models predict the milk production of Ho×Z and BS×Z bred cows in the tropical dairy system with certainty of 95%, regardless of the birth season and frequency of weighing.

One of the important criteria to define whether a model adjusts well to the data, allowing with this to make a good prediction, is the Model Selection Criterion (MSC), which is none other than a modification to the Akaike

Table 2. Milk production (kg) per lactation of Ho×Z and BS×Z bred cows, with different prediction models, number of lactation and frequencies of milk weighing.

Frequency	Milk Prediction Models					
	Wood		Wilmink		Linear Interpolation	
	Lactation		Lactation		Lactation	
	1	2	1	2	1	2
Daily	2657[a]	2972[a]	2657[a]	2972[a]	2657[a]	2972[a]
Weekly	2659[a]	2974[a]	2665[a]	2968[a]	2650[a]	2955[a]
Biweekly	2649[a]	2953[a]	2601[a]	2977[a]	2621[a]	2954[a]
Monthly	2655[a]	2933[a]	2645[a]	2951[a]	2707[a]	3032[a]
N	121	36	121	36	121	36
SEM	189	110	189	110	189	110

SEM = Standard Error of the Mean; N = observations. Equal literals in the same column indicate that there is not significant difference, Tukey (P≤0.05).

Table 3. Milk production (kg) per lactation, of crossed cows with different prediction models, genotypes and frequencies of milk weighing.

Frequency	Milk Prediction Models					
	Wood		Wilmink		Linear Interpolation	
	Genotype		Genotype		Genotype	
	Ho×Z	Bs×Z	Ho×Z	Bs×Z	Ho×Z	Bs×Z
Daily	3135[a]	2494[a]	3135[a]	2494[a]	3135[a]	2494[a]
Weekly	3158[a]	2475[a]	3146[a]	2488[a]	3136[a]	2469[a]
Biweekly	3115[a]	2487[a]	3082[a]	2496[a]	3114[a]	2461[a]
Monthly	3105[a]	2484[a]	3124[a]	2472[a]	3177[a]	2561[a]
N	124	33	124	33	124	33
SEM	106	195	106	195	106	195

SEM = Standard Error of the Mean; N = observations. Equal literals in the same column indicate that there is not significant difference, Tukey (P≤0.05).

Table 4. Milk production (kg) per lactation, of Ho×Z and BS×Z bred cows with different prediction models, birth season (rainy and dry) and frequencies of milk weighing.

Frequency	Milk Prediction Models					
	Wood		Wilmink		Linear Interpolation	
	Dry	Rainy	Dry	Rainy	Dry	Rainy
Daily	2677[a]	2952[a]	2677[a]	2952[a]	2677[a]	2952[a]
Weekly	2691[a]	2942[a]	2683[a]	2951[a]	2668[a]	2937[a]
Biweekly	2659[a]	2943[a]	2639[a]	2939[a]	2631[a]	2944[a]
Monthly	2637[a]	2951[a]	2658[a]	2939[a]	2727[a]	3012[a]
N	71	86	71	86	71	86
SEM	140	150	140	150	140	150

SEM = Standard Error of the Mean; N = Observations. The same letters in the same column indicate that there are no significant differences, Tukey (P≤0.05).

Table 5. Model Selection Criterion (MSC) and coefficient of determination (R) in the Wood and Wilmink models, in weekly, biweekly, and monthly frequency.

Milk Prediction Models	MSC	R	SEM
Wood	0.9364[a]	0.6632[a]	0.02286
Wilmink	0.8972[a]	0.6478[a]	0.02286
Milk Weighing Frequency			
Weekly	0.9546[a]	0.6280[a]	0.02802
Biweekly	0.8819[a]	0.6611[a]	0.02802
Monthly	0.9139[a]	0.6774[a]	0.02793

The same letters in the same column indicate that there is no significant statistical difference. Tukey's means test (P≥0.05). SEM = Standard Error of the Mean.

criterion. It is observed that there is no statistical difference (P≥0.05), on the Wood model (0.93) and the Wilmink model (0.90) in the different intervals of weekly, biweekly and monthly intervals, which indicates that both models are adjusted similarly to the data and help describe the lactation curve of Ho×Z and BS×Z bred cows in a tropical dairy system with reliability higher than or equal to 95% (Table 5). In the coefficient of determination R, it is an estimator that helps us establish together with the MSC the adjustment of the data to the models. The results did not indicate difference (P≥0.05) between the Wood and Wilmink models. Regarding the frequencies of milk weighing, no significant difference was found (P≥0.05) (Table 5).

CONCLUSIONS

The Wood, Wilmink and Linear Interpolation models can estimate similarly the milk production per lactation, in Holstein and Brown Swiss cows and their crosses with Zebu, whether during rainy season or dry season, and in different frequencies of milk weighing. The frequency of milk weighing from the cows analyzed can be carried out weekly, biweekly, or monthly, using any of the models: Wood, Wilmink and Linear Interpolation.

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