



# Milk yield did not decrease in large herds of high-producing Holstein cows in semi-arid climate of Mexico

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## Abstract

This study aimed to determine the trends in milk production, fertility, temperature-humidity index (THI), and herd size in dairy herds from the Laguna region in northern Mexico. Records of 16 dairy herds of Holstein cows from January 2002 to December 2016 were used. Milk production was categorized in low and high levels. Milk production and fertility were analyzed using generalized equation estimation procedures by a model of repeated measures that included the effect of year, month, and productive level, an interaction for month × productive level, and herd effect was nested in productive level. For THI, a generalized linear model that included the effects of year and month was used. Dairy herds with high levels of milk production yielded more milk than those with low levels ( $P < 0.001$ ). Milk production in 2002 and 2016 was  $27.4 \pm 0.6$  and  $32.3 \pm 0.7$  L/cow/day, respectively. Fertility fluctuated throughout the study. Dairy herds with high levels of milk production recorded higher fertility than those with low levels ( $P < 0.001$ ). From October to April, THI was  $< 70$ , whereas it was  $> 73$  from May to September, indicating that cows were in heat stress (20 h/day). The median herd size was 995 and 2569 cows in 2002 and 2016, respectively. In conclusion, in large herds, milk production increased over the years of study, whereas fertility showed a wave cycle; nonetheless, when THI was  $> 73$ , both milk production and fertility decreased.

**Keywords** Dairy cattle · Milk secretion · Heat stress · Temperature-humidity index · Reproductive performance

## Introduction

In recent years, climate changes caused by anthropogenic activities are prevalent worldwide. These activities are related to economic development and population growth, which have increased greenhouse gas emissions, leading to the accumulation of carbon dioxide, methane, and nitrous oxide in the atmosphere (IPCC 2014). Variations in ambient temperature and precipitation mainly affect agriculture, including animal

production. The average global ambient temperature has been predicted to increase by 2.6 to 4.8 °C, over the current global temperature by year 2100 (IPCC 2014).

In dairy cattle, high temperature has been shown to have an adverse effect on the productive and reproductive parameters, as well as animal welfare (Polsky and von Keyserlingk 2017), especially when cows are exposed to prolonged heat stress and increased humidity. In dairy cattle, temperature-humidity index (THI) describes the effect of air temperature and relative humidity and is a measure of the level of heat stress (Hill and Wall 2015; Renaudeau et al. 2012). In fact, dairy cattle have a very well-defined thermoneutral zone; outside this zone, the animals might experience difficulty in maintaining homeostasis. Previous studies showed that cows with a THI of 70 or less are considered to be in the normal category, whereas those having THI of 71–78, 79–83, and  $> 83$  are considered to be in a state of alert, danger, and emergency, respectively (Du Preez 2000). In dairy cows, high temperatures adversely affect the neuroendocrine axis and diminish milk production and fertility (Collier et al. 2017; De Rensis et al. 2017).

Mexico have diverse ecosystems and is more vulnerable to climate change (CONABIO 2016); in some areas of the

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country, dairy cattle experiences adverse consequences of heat stress. In addition, similar to that in other countries, in Mexico, livestock production occurs under unsuitable climate conditions, where animals are more susceptible to heat stress. This study aimed to determine the trends in milk production, fertility, THI, and herd size in the dairy herds from Mexico.

## Material and methods

### Study area

The study was performed in the Laguna region located in the States of Coahuila and Durango, Chihuahuan Desert, northern Mexico (latitude 24°–26° 22′–23′ N, longitude 102°–104° 47′ W and elevation ranging between 1100 and 1200 m above the sea level). The Laguna region has a semi-arid climate, and a population of 464,086 cattle with 227,142 milking cows distributed in dairy herds (SIAP, SAGARPA 2015), over a territory of 48,000 km<sup>2</sup> (López-López and Sánchez Crispín 2010).

### Data on monthly summaries for herds

Data included records from 16 dairy herds of Holstein cows (*Bos taurus*) from January 2002 to December 2016. The database included 2074 records/herd/month. Records were obtained up to the end of a month for every dairy herd. Each variable was obtained from the monthly averages in each herd by using the software DairyComp (<http://web.vas.com/updates/dairycomp>).

### Description of production systems in dairy herds

In the investigated herds, the most modern technologies were used, such as milking parlors with electronic control, fans, sprinklers, artificial shadows with adequate height, and comfortable pens (dry clean beds, with redistribution of soil surface with a disc harrow). Cows were wetted every 4 h during the day, with 1 min of water and 4 min of forced ventilation, for a total of 6 times/day (Flamenbaum and Galon 2010), from May to September. Cows were milked three times a day. Semen with + 700 Net Merit index was used for the dairy herds. The feeding system comprised total mixed ration with 18.5% crude protein and 1.8 Mcal/kg of dry matter.

### Classification of dairy herds according to productivity level

The following two types of descriptors were used: level of milk production and THI (Ismael et al. 2012). Milk production was categorized into two levels: low and high. Low-level milk producers included herds whose monthly average milk production throughout the study duration was below a general average, and

high-level milk producers were those that had milk production above this average. Milk production is the average daily production in liters produced by all cows milked in a herd. Fertility is the percentage of the total number of pregnant cows in a herd with respect to the total number of cows in the herd. The study only includes the total number of pregnant cows to calculate fertility, without considering mortality, culling, or sales.

### Temperature humidity index

The monthly averages of environmental temperature and relative humidity were obtained from the Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP 2017). The THI was calculated using the following equation (Ravagnolo et al. 2000):

$$\text{THI} = (1.8 \times T + 32) - (0.55 - \text{RH} \times 0.55) \times (1.8 \times T \times 26),$$

where T is the monthly average daily of the temperature (°C), and RH is the monthly average daily of the relative humidity (%).

### Statistical analyses

Milk production and fertility were analyzed using generalized equation estimation procedures by using a model of repeated measures that included the effect of year, month, and productive level, and an interaction for month × productive level, and herd effect was nested into productive level (e.g., a subject effect). For the selection of the best model and correlation structure with the best fit, we used an extension of the Akaike information criterion called corrected quasi-likelihood under independence model criterion. For the temperature, relative humidity, and THI, a generalized linear model (GLM) was used that included the effects of year and month. To select the best model, we used the Bayesian information criterion. In order to evaluate the effects that were significant, we used orthogonal polynomials for the effects of year and month. Contrasts for repeated measurements were obtained by comparing the data obtained in 1 month with those obtained in the next, except in December. For the interactions, multiple comparisons were performed using Bonferroni adjustment between the levels within each month. Data are expressed as the mean ± SEM, and differences were considered significant when  $P < 0.05$ .

Based on the GLM results, we used a simple linear regression model in each month of the year:  $y_{ij} = \beta_0 + \beta_1 x_{ij} + \beta_2 x_{ij}^2 + e_{ij}$ ; where  $y_{ij}$  is the value obtained from the temperature, relative humidity, or THI in the  $i$ th year;  $x_{ij}$  is the value of  $i$ th year (2002, 2003, ..., 2016);  $\beta_0$  is the intercept; and  $\beta_1$  and  $\beta_2$  are the coefficients associated with linear and quadratic effects, respectively. All procedures were performed in SPSS version 16.0 (2007).

## Results

### Milk production

The best model fit for determining milk production was achieved by specifying a normal probability distribution with an identity link function, and the matrix correlation structure was a first-order auto-regressive AR (1). Results indicated that all effects included in the model differed significantly ( $P < 0.001$ ; Table 1). Further, dairy herds with high milk production levels showed higher milk production than those with low levels ( $P < 0.001$ ; Table 1). Further, the highest and lowest milk productions were registered in March and September, respectively ( $P < 0.001$ ; Table 1). The difference in liters of milk produced was higher in March and lower in December ( $P < 0.001$ ; Table 1).

Throughout the study duration, milk production showed a positive, linearly increasing trend (Fig. 1); however, between the two levels, the difference in liters differed significantly (Table 1). Milk production increased in 2009 by almost 1.0 L/cow/day (Fig. 1). In contrast, during the following 2 years (2010–2011), this increase was the highest at 4.0 L/cow/day. Finally, milk production reached 4.9 L/cow/day in 2016 with respect to that in 2002 (Fig. 1).

### Fertility

The best model fit for fertility was achieved with a gamma probability distribution and a log link function, and the correlation matrix was a first-order auto-regressive AR (1). Fertility at the beginning and end of the study were similar, and large fluctuations were detected throughout the study duration (2002–2016;  $P < 0.001$ ; Fig. 1). Likewise, fertility showed a cyclical fluctuation for all months of the year (Table 2 and Fig. 2). In addition, fertility was the highest in January and the lowest in September ( $P < 0.001$ ; Table 2). In addition, from September to July, the difference in fertility percentage differed significantly ( $P < 0.05$ ; Table 2). Further, it was similar between the two production levels ( $P > 0.05$ ; Table 2).

### Temperature humidity index

The THI showed a quadratic trend throughout the year (Fig. 2). In fact, the minimum and maximum values of THI coincided with the data of temperature. The values highest for temperature and THI were recorded in June ( $75.2 \pm 1.6$  and  $28.7 \pm 1.3$  °C, respectively), while the values lowest for the same variables were in January ( $13.7 \pm 1.6$  °C and  $57.1 \pm 2.1$ , respectively). Similarly, the values lowest for relative humidity were in April ( $28.2 \pm 7.6\%$ ), and it reached the maximum values in September ( $52.3 \pm 8.9\%$ ). In addition, from May to September, the THI was  $> 72$  (Fig. 2). Unexpectedly, throughout the study duration (2002–2016), the averages of

temperature, relative humidity, and THI decreased ( $1.9$  °C,  $3.9\%$ , and  $2.6$ , respectively). Nevertheless, when each month was analyzed, the average for regression coefficient was  $0.10 \pm 0.11$  °C by year. In January, March, April, and May, the change was  $b_1 = -0.21$  °C to  $b_1 = -0.3$  °C ( $P < 0.03$ ); however, in February, and from June to December, the change was  $< 0.1$  °C ( $P > 0.15$ ). In contrast, the slopes were negative ( $-0.62 \pm 0.33\%$ ) for the percentages of relative humidity by year, and when the analysis was conducted by month, from May to December, the slopes were negative ( $-0.55$  to  $-1.07\%$ ). Therefore, the THI decreased on average:  $b_1 \pm s = -0.18 \pm 0.12$  by year, although in February, November, and December, the slopes did not differ from zero ( $P > 0.05$ ). April showed the lowest decrease ( $b_1 = -0.40$ ;  $P < 0.01$ ).

In addition, the Spearman correlation ( $R_s$ ) between temperature and THI was  $0.98$  ( $P < 0.001$ ). In contrast, THI was not related with relative humidity ( $P > 0.05$ ); however, temperature and relative humidity were negatively related ( $R_s = -0.154$ ;  $P = 0.038$ ). The simple linear regression coefficients were negative for temperature, relative humidity, and THI, that is, for each unit of increase in temperature, relative humidity, or THI; milk production decreased  $0.10$  L/cow/day ( $P < 0.001$ ), while for fertility, the lowest decrease was for temperature ( $0.83\%$ ;  $P < 0.001$ ) and THI ( $0.7\%$ ;  $P < 0.001$ ), and low for relative humidity ( $0.14\%$ ;  $P < 0.001$ ).

### Herd size

The median herd size changed from 995 cows in 2002 to 2569 cows in 2016 (Fig. 3).

## Discussion

Our study results showed that, in large dairy herds, milk production did not decrease drastically, but fertility changed during the study. We observed a positive correlation between milk production and fertility. Dairy herds with high levels of milk production did not show a decrease in milk secretion from May to July, whereas it decreased from August to October. Dairy herds with low levels of milk production showed a similar pattern. These results show that high milk-producing cows maintain their milk production even under unfavorable environmental conditions. Further, fertility was found to be similar in both types of dairy herds; however, all dairy herds documented the lowest fertility in August and September. In addition, our results are consistent with those studies that show the negative effects between milk production and fertility associated with warming environment and a cyclical trend (Hill and Wall 2015; Key et al. 2014). For example, in the investigated herds, from June to August, the THI was 75, and cows registered lower milk production and fertility. In fact, in the same months, dairy cows were under heat stress for almost

**Table 1** Means  $\pm$  standard errors (SEM) for milk production by productivity level in Holstein cows throughout the study duration (2002–2016)

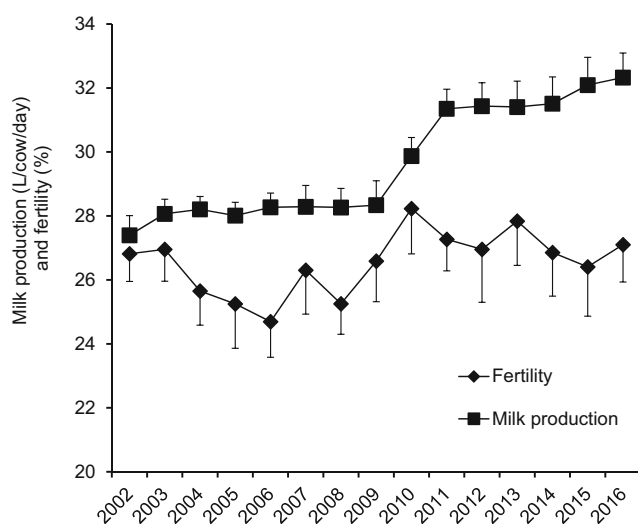
	Milk production (L/cow/day) (mean $\pm$ SEM)		Difference High levels–low levels <sup>a</sup>	Milk production (L/cow/day) (mean $\pm$ SEM) <sup>b</sup>
	High levels	Low levels		
January	31.8 $\pm$ 0.2	29.2 $\pm$ 0.1	2.6**	30.5 $\pm$ 0.1**
February	32.5 $\pm$ 0.2	29.6 $\pm$ 0.1	2.8**	31.0 $\pm$ 0.1**
March	33.1 $\pm$ 0.2	30.1 $\pm$ 0.1	3.0**	31.6 $\pm$ 0.1**
April	32.9 $\pm$ 0.2	29.9 $\pm$ 0.1	2.9**	31.4 $\pm$ 0.1**
May	32.0 $\pm$ 0.2	29.3 $\pm$ 0.2	2.7**	30.7 $\pm$ 0.1**
June	30.8 $\pm$ 0.2	28.3 $\pm$ 0.1	2.5**	29.6 $\pm$ 0.1**
July	30.0 $\pm$ 0.2	27.5 $\pm$ 0.1	2.5**	28.8 $\pm$ 0.1**
August	29.0 $\pm$ 0.3	26.6 $\pm$ 0.2	2.4**	27.8 $\pm$ 0.2**
September	28.7 $\pm$ 0.3	26.2 $\pm$ 0.1	2.5**	27.5 $\pm$ 0.2**
October	29.2 $\pm$ 0.3	26.8 $\pm$ 0.1	2.4**	28.0 $\pm$ 0.2**
November	30.3 $\pm$ 0.2	27.7 $\pm$ 0.1	2.6**	29.0 $\pm$ 0.1**
December	31.1 $\pm$ 0.2	28.9 $\pm$ 0.1	2.2**	30.1 $\pm$ 0.1
Total	31.0 $\pm$ 0.2	28.4 $\pm$ 0.1	2.6**	29.7 $\pm$ 0.1 <sup>c</sup>

<sup>a</sup> All test of differences between the mean and the next are different (\*\* $P < 0.001$ )

<sup>b</sup> All tests of differences between the mean of *i*th month and the next are different (\*\* $P < 0.001$ )

<sup>c</sup> Great mean

the entire day (20 h/day), whereas in September, the THI was 73, and cows showed the lowest level of milk production and fertility. Although in May the THI was 73, cows registered an acceptable level of milk production. Perhaps, in May, cows were not subjected to the chronic thermal load as in September. In addition, in this region, historical records indicate that the temperature increases in May. As mentioned earlier, the THI of 73–75 indicated that the cows were in a state of alert (Du Preez 2000). Further, in May, probably the cows did not receive high thermal load (Collier et al. 2017). The THI of



**Fig. 1** Changes throughout the study duration (2002–2016) for milk production (squares, L/cow/day, means  $\pm$  SEM), and fertility (diamonds, %, means  $\pm$  SEM) in Holstein cows

< 70 in April indicates that the cows were in the normal category (Du Preez 2000). From May to September, the percentages of fertility also were lower compared to those in October–April. The present findings show that dairy herds in Mexico have well-defined fertility throughout the year; in other words, seasonality of reproductive activity (De Rensis et al. 2015) in Holstein cows adapted to subtropical latitudes. In fact, in this region, most births are known to occur from August to December owing to the low fertility registered from May to September. In addition, the results showed that THI is more affected by relative humidity than by temperature. For example, from October to April, the averages of temperature and relative humidity were 14–25 °C and 28–49%, respectively, and dairy cows did not experience heat stress. In contrast, from May to September, the averages for the same variables were 28–29 °C and 32–52%, respectively, and the THI was 73–75. Furthermore, heat stress decreased fertility owing to the harmful effects on follicular development, apart from inadequate development of corpus luteum, and insufficient progesterone luteal support or poor embryonic development (De Rensis et al. 2017). In addition, a good management exerts a positive effect on high-producing dairy cows (Flamenbaum and Galon 2010). Similarly, in these types of herds, the genetic antagonism between milk production and fertility is reduced owing to the superior management practices (Castillo-Juarez et al. 2000). Throughout the study years, milk production indicated a positive trend, whereas the fertility measures fluctuated, as mentioned above. In addition, milk production increased by 5.0 L/cow/day from 2002 to 2016; this change was

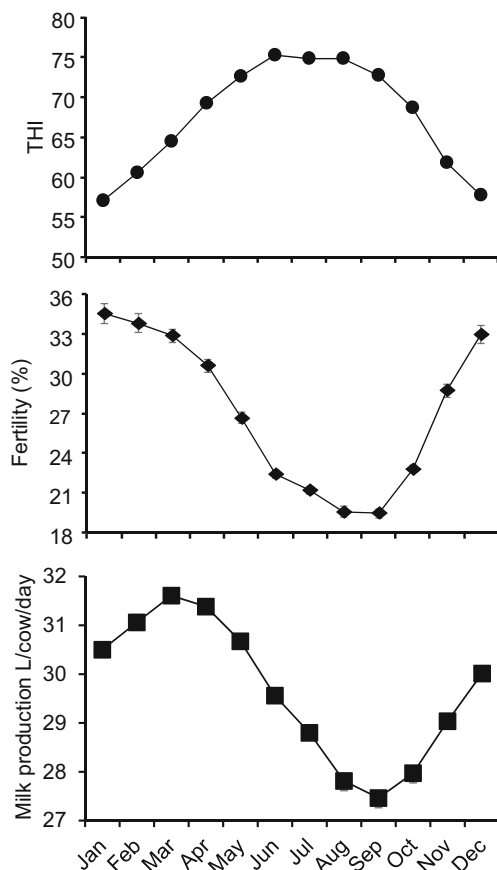
**Table 2** Percentage of fertility (mean ± SEM) by month and productivity level in herds of Holstein cows throughout the study duration (2002–2016)

	Fertility % (mean ± SEM)		Difference High levels–low levels <sup>a</sup>	Fertility % (mean ± SEM) <sup>b</sup>
	High levels	Low levels		
January	35.5 ± 1.3	33.7 ± 0.5	1.8	34.6 ± 0.7**
February	34.3 ± 1.2	33.4 ± 0.5	0.9	33.8 ± 0.7**
March	33.2 ± 0.9	32.6 ± 0.4	0.6	32.9 ± 0.5**
April	30.9 ± 0.8	30.3 ± 0.6	0.5	30.6 ± 0.5**
May	26.4 ± 0.5	26.8 ± 0.5	−0.4	26.6 ± 0.4**
June	22.2 ± 0.4	22.6 ± 0.4	−0.4	22.4 ± 0.3**
July	21.2 ± 0.5	21.2 ± 0.3	0.0	21.2 ± 0.3**
August	19.8 ± 0.8	19.3 ± 0.3	0.6	19.6 ± 0.4
September	19.4 ± 0.6	19.5 ± 0.4	−0.2	19.4 ± 0.3**
October	22.9 ± 0.6	22.8 ± 0.2	0.1	22.8 ± 0.3**
November	29.2 ± 0.6	28.2 ± 0.7	1.0	28.7 ± 0.5**
December	33.7 ± 0.9	32.2 ± 0.8	1.5	32.9 ± 0.7
Total	26.7 ± 0.4	26.3 ± 0.1	0.4	26.7 ± 0.5 <sup>c</sup>

<sup>a</sup> All test of differences between the productive levels did not differ ( $P > 0.05$ )

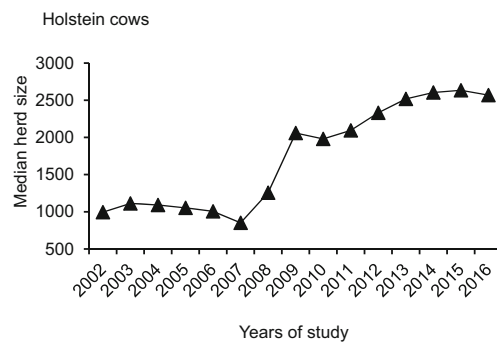
<sup>b</sup> All tests of differences between the mean of *i*th month and the next are different (\*\* $P < 0.001$ ) except August vs September ( $P > 0.05$ )

<sup>c</sup> Great mean



**Fig. 2** Cyclical trend throughout the study duration (2002–2016) for THI (circles, top), fertility (diamonds, %, means ± SEM, middle), and milk production (squares, L/cow/day, means ± SEM, bottom) in Holstein cows

probably because of the improvement in the management of the herds; in addition, the dairy herds used the semen of bulls with positive Net Merit index. In this study, the median number of cows in dairy herds studied was higher than that located in Mississippi State and UK, which were from 318 to 586 cows (Hill and Wall 2015; Smith et al. 2013). Hence, dairy herds between 600 to 1000 cows also showed lower fertility (Lozano-Domínguez et al. 2005). The high productivity of local dairy herds from the Laguna region despite the high number of cows in herds in the semi-arid climate can be attributed to the good management practices implemented by farmers, such as good feeding system, stall design, tall shadow, artificial shadow, and comfortable pens that allow the cows to lie down and ruminate, which improve the welfare of dairy cows (Polsky and von Keyserlingk 2017). Further, farmers implemented activities for wet dairy cows that contributed to the amelioration of the negative effects of heat



**Fig. 3** Median herd size in Holstein cows throughout the study duration (2002–2016)

stress (Chen et al. 2015). Finally, acceptable reproductive parameters under adverse natural conditions in dairy herds imply good management that involves the combination of multiple daily practices in a herd.

## Conclusion

We conclude that dairy cows in large herds under high stress did not show remarkable reduction in milk production, whereas fertility showed a wave cycle. However, when dairy cows experienced heat stress, with THI > 73, milk production and fertility decreased.

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## Compliance with ethical standards

**Statement of animal rights** This article does not contain any studies with animals performed by any of the authors.

**Conflict of interest** The authors declare that they have no conflict of interest.

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