Original

Assessment of Dairy Herd Productivity and Heat Stress. I. Analysis and Initial Results

Simón González Prieto *⬤, Alina Mitat Valdés **⬤, Marco A. Suárez Tronco ***⬤, Alberto Menéndez-Buxadera **⬤

*Finca Corralito, Camilo Cienfuegos Breeding Company, Consolación del Sur, Pinar del Río, Cuba.
**Independent advisor, Cuba.
***Agrarian University of Havana and Center for Tropical Animal Improvement Research (CIMAGT), Havana, Cuba

Correspondence: marcosuareztronco@gmail.com

ABSTRACT

Background: In the current conditions of Cuba, the most appropriate measure is not daily milk production per se, but the sum of all the cows present at any given time in a specific herd, i.e., the total milk production, which requires a particular analysis. **Aims.** To develop a methodology to evaluate the productivity of the total number of animals in 30 dairy herds under the conditions in the south of Pinar del Rio Province, Cuba. Methods: Several weighted mixed linear models were used to estimate the response curves of the dependent variables over time and the level of environment represented by THI. **Results:** The analyses showed that between 2018 and 2014, daily milk production (DMP) decreased by -15.9%; milk production per hectare by -39.1%, and the percentage of cows in milking (CM) by -17.5%. The total number of inseminations and monthly pregnancies decreased by -20.0% and -5.9%, respectively, and showed negative relationships with all classical variables used to measure overall productivity. At the same time, the effects of heat stress depressed DMP by -13.4%. It was found that for every 1% increase in CM, the herd's DMP increased by +2.2%. **Conclusions:** An antagonism was found between reproductive performance, milk production, and heat stress; it is suggested to apply these statistical procedures to identify limiting factors of the overall productivity of dairy herds.
Keywords: Reproductive performance, climate stress, milk production, dairy herds (Source: *AGROVOC*)

INTRODUCTION

To mitigate the issue of milk production in Cuba, it has become a common belief that increasing the daily milk production per cow (DMP) could be a way to improve the activity. However, higher DMP may be a necessary condition but not sufficient in a low-input production system, which characterizes the country's livestock activity. DMP is the result of the interaction of multiple factors related to the cow's physiology, the surrounding environment, and the human factor trying to obtain the final product. When DMP data is studied using an individual analytical approach, multiple causes affecting the results are identified, such as environmental variations (year, calving season, herd, etc.) and genetic factors (variances and covariances between traits of economic interest), which make it possible to influence those factors with positive or negative effects. However, when considering the entire herd of animals, all these effects act together and overlap, requiring other analyses to explain the results and optimize the process to increase the DMP of all cows in the herd.

In this scenario, the component cow population structure is introduced, differentiating from those that have a direct contribution to the total milk volume (TMV), i.e., the number of cows in milking (CM), total area available for the total cows in the herd (TCH), requiring a multivariate approach of the principal component type (PCA) that allows extracting the maximum of the (co)variance structure between the original variables (Hair et al., 2009). A similar procedure was applied to data from some companies under Cuban conditions, in milk production (Torres et al., 2008; Martínez-Melo et al., 2011) and reproductive performance (Bertot Valdés et al., 2008).

These investigations did not consider the impact of heat stress effects on animal production even though there is a consensus on them. In this regard, during 2022, the annual average temperature exceeded the historical average of the period 1961-1990 (25.5°C) by 0.88°C (Fonseca et al., 2023), which may induce additional depressive effects on dairy cattle, whose first evidence was published by Domínguez et al. (2015), showing a correlation of -0.72 between a combined temperature and humidity index (THI) and daily milk production in Havana province.

In this paper, an analytical procedure will be applied to the productivity of the entire dairy herd to evaluate its results in productive, reproductive performance and the effect of THI.

MATERIALS AND METHODS

The available data corresponds to 30 dairy herds from a company in the south of Pinar del Rio, with Siboney de Cuba animals between January 2014 and December 2018. The following indicators were considered:

Number of total cows (NTC) = total number of cows present in the herd each month.

Percentage of cows in milking (PCM) = (number of cows in milking/number of total cows) *100.

Stocking rate (SR) = NTC/total area of the herd. This data was grouped into three categories (low with less than 0.9 animal/ha, medium between 0.9 and 1.1 animals/ha, and high for more than 1.1

animals/ha). Total monthly milk production (TMMP) = Sum of the daily production of all cows in milking each calendar month.

Daily milk production (DMP) = TMMP/number of calendar days in the month.

Monthly milk production per hectare (MMPH) = TMMP/total area of the herd.

At the same time, to evaluate the monthly reproductive activity of each herd, the number of inseminations and gestations performed was recorded. This company is located 5 km from an official meteorological station, which provided the monthly averages of relative humidity (RH) and maximum, minimum, and mean temperature (T), combined into a THI index according to NRC (1971):

$$THI = [(1.8 \times T + 32) - (0.55 + (0.0055 \times RH) \times (1.8 \times T - 26))]$$

Where T and RH were defined previously.

For the analysis of these data, several mixed linear models were applied, weighting each record by the total number of cows and considering random effects of the dairy farm (30 classes) and the fixed effects of stocking rate (3 classes); year (5 classes); month (12 classes) and THI level (12 classes) as well as their interactions, to represent the response curves of the dependent variables over time and the environment level represented by THI.

RESULTS AND DISCUSSION

Table 1 shows the general indicators of the studied variables.

Table 1. General Information on the Structure and Productivity of 30 Dairy Herds in Pinar del Rio (indicator range in parentheses)

Indicator	Quadratic Minimum Constant
Total number of cows per dairy farm	127.1 (43 - 212)
Number of cows in milking	54.1 (13 - 118)
Percentage of cows in milking (PCM)	42.8 (13.9 - 97.5)
Number of hectares per dairy farm	125.3 (86.6 - 161.1)
Stocking rate (LLU/ha)	1.02 (0.7 - 1.8)
Total monthly milk production per dairy farm (kg)	11 985 (1 344 - 80 617)
Total monthly milk production (kg)	394 (44 - 2 650)
Daily milk production (kg)	6.8 (1.1 - 23.9)
Monthly milk production per hectare (kg)	94.6 (12.4 - 594.1)
Total number of monthly inseminations	16.2 (1 - 54)
Total number of monthly pregnancies	6.5 (1 - 29)
Average temperature (°C)	25.3 (21 - 28)
Average humidity (%)	79.9 (71 - 87)
THI	83.7 (77 - 89)

An analysis of the quadratic minimum constants of the dependent variables globally (Table 1), shows a lot of redundant information, which needs to be studied to identify the intensity and direction of some common factors describing variations in the total productivity expression of the herds.

The analyses showed highly significant differences (p<0.001) for all the studied variables. The determination coefficients of the models ranged from 79% to 83% for those events related to milk production and from 31% to 37% for reproductive events. A negative trend was evidenced in the average productivity results, as well as in the structure of the cow population and reproductive indicators (Table 2).

Table 2. Effect of the Year on the Studied Variables*

Year	Milk Production (kg)						Reproduction	
	Cow/day	Total/day	Total/month	Per ha	Total	Milking cows	AI	Pregnancies
2014	7.73^a	461.8^a	14 050^a	124.7^a	134.1^a	50.36^a	16.5^a	6.7^a
2015	6.57^b	396.5^c	12 063^b	98.5^b	134.1^a	45.60^a	14.3^b	6.2^a
2016	7.46^a	501.8^b	15 267^a	110.6^a	132.6^a	41.49^b	22.1^c	7.2^b
2017	6.75^b	380.9^c	11 589^c	92.3^b	120.1^b	43.31^c	13.6^b	4.9^c
2018	6.49^b	326.4^d	9 930^d	76.0^c	111.9^c	41.41^b	13.2^b	6.3^a
Response (%)	-15.9	-29.3	-29.3	-39.1	-17.8	-17.2	-20.0	-5.9

*Values with different subscripts differ significantly (p<0.001).

Figures 1 and 2 show the quadratic minimum constants of the THI effects on DMP and the percentage of cows in milking. Generally, these two figures represent typical seasonal curves characterizing animal production in tropical countries, with low-input production systems, where the summer's peak heat period overlaps with higher precipitation, greater availability of pastures, and increased milk production.

The results indicated that the highest THI values, between May and August, correspond to the highest daily milk productions.
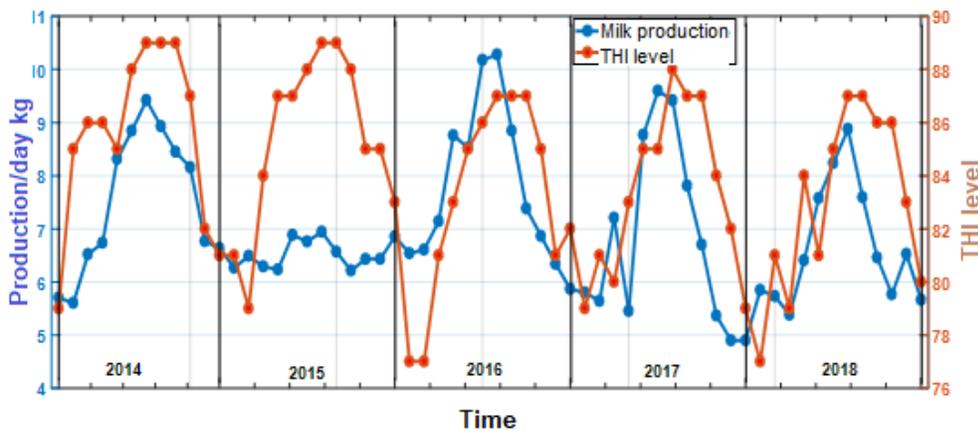

Figure 1. Effects of THI Level on Daily Milk Production

The relationships between the percentage of cows in milking and THI level show a marked deterioration throughout the time period, although the response pattern is very similar to DMP.
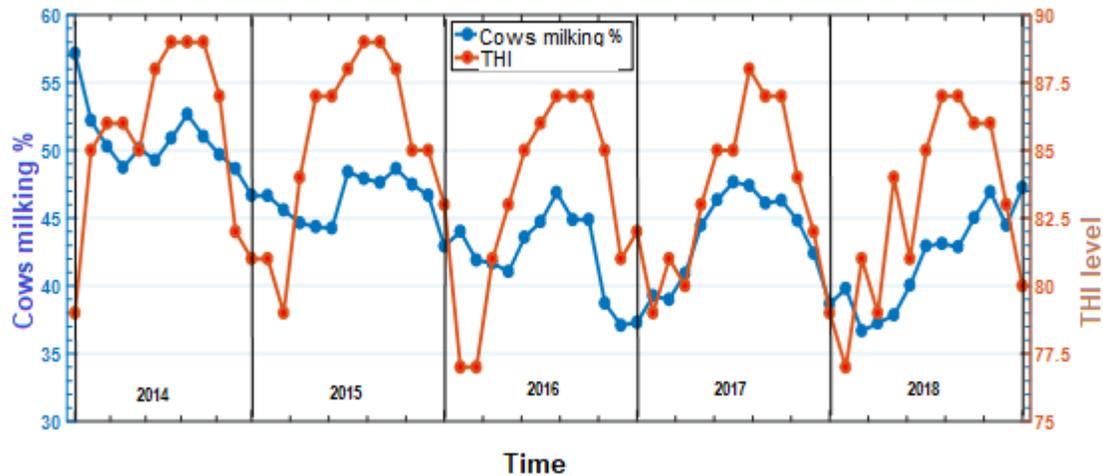
González Prieto, S., Mitat Valdés, A., Suárez Tronco, M.A., Menéndez-Buxadera, A.

Figure 2. THI Values and Percentage of Cows in Milking

It is obvious that this reality should be taken advantage of, and in this sense, there are studies recommending the use of a calving season system, whose benefits will be reflected in productivity increases in dairy herds in Cuba (Soto Senra et al., 2020; Horrach Junco et al., 2020). Although this alternative can produce significant productive and economic benefits, it is not without some medium-term risks that it should be considered, especially during the summer season due to heat stress (Valdivia-Cruz et al., 2021; Enríquez and Álvarez, 2020). The impacts on milk production due to heat stress are consistent with evidence in other regions of Latin America, in Holstein herds in Brazil (Menéndez-Buxadera et al., 2020), Panama (Guerra et al., 2019), and Peru (Menéndez-Buxadera et al., 2022; Galván et al., 2023). Regarding the effects of heat stress on the reproductive activity of cattle, similar trends have been indicated by Silva et al. (2023); Stefanska *et al*. (2024).

There are reasonable arguments suggesting confusion in interpreting this environmental relationship of higher DMP levels and the hottest summer months, due to some compensatory behavior partially expressed in milk production levels. To have a preliminary and very partial view of this question, based on the available data, the quadratic minimum constants of the interaction effects stocking rate-THI on DMP were estimated, adjusted for dairy farm effects (random) and year-month effects (coefficient of determination of the model $R^2=75.4\%$), the results are shown in Figure 3.
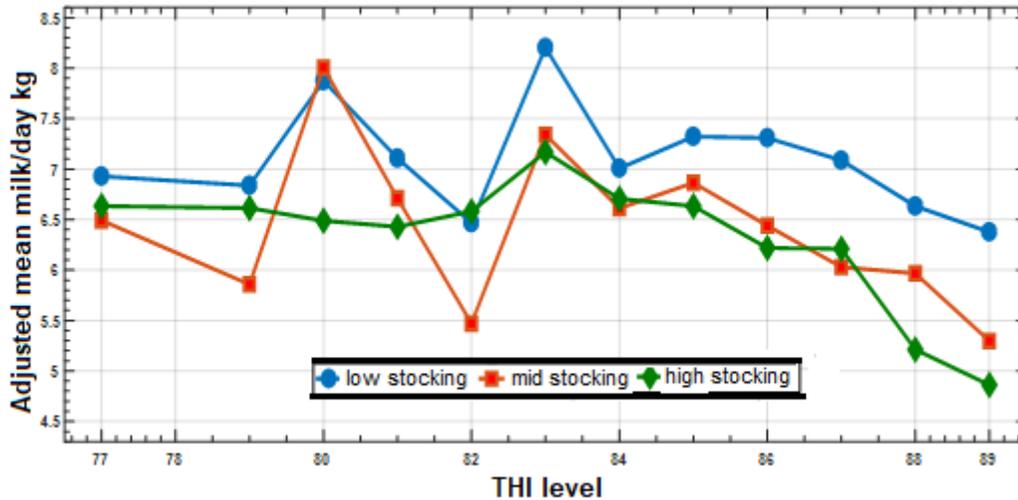
Figure 3. Effect of stocking rate-THI Interaction on Daily Milk Production

These results indicated that there is a comfort zone at THI≤83 within which DMP shows some highs and lows, although the overall response is quite stable, so the effects of THI can be considered practically null. However, from THI=83 there is a sharp change in trend in the three stocking rates, starting a heat stress zone where the response curve was frankly negative up to THI≤89. The potential losses in milk production of each dairy farm can be estimated using the same approach originally developed by Ravagnolo and Misztal (2000) with the so-called broken line model. These authors suggested expressing the results as deviation (d) from the level at the point of trend change, in our case at THI=83:

d = 0 for THI<=83 comfort zone.
d =THI - 83 heat stress zone.

In this study, d takes values between 0 and 6, and the regression analysis showed that d = -0.152±0.027/kg for each level of THI (R^2 of the model=87.2%), estimated very close to the -0.2kg/THI published by Ravagnolo et al. (2000) with a large database of individual Holstein animals in the United States. This negative effect must be considered multiplicative, so the overall losses related to heat stress can be inferred if it is considered that, in the database, 56.1% of the results are obtained during this heat stress zone. At the dairy farm level, the total impact equals 6 x -0.152 = -0.912 kg, representing a loss of -13.4% of the daily milk production per cow (Table 1).

The aforementioned implies that even when considering a global analysis, the antagonism between heat stress and milk production is a real effect and should be taken into account. To identify the importance of PCM (Percentage of Cows in Milking) on milk production levels, a mixed linear model similar to the previously described one was used, incorporating this variable

as a fixed covariable. The determination coefficients of these models ranged from 79% for DMP to nearly 82% for MPH and TCP. The results indicated that for every 1% increase in cows in milking, milk production per cow increases by +4.6%, and total milk production increases by +2.2%, values very similar to those obtained two decades ago in 19 dairy units in Havana province (Menéndez-Buxadera et al., 2004).

CONCLUSIONS

An antagonism was found between reproductive performance, milk production, and heat stress. It is suggested to apply these statistical procedures to identify the limiting factors of the overall productivity of dairy herds.

REFERENCIAS

Bertot Valdés, J. A., Vázquez Montes de Oca, R., de Armas de la Rosa, R., Garay Durba, M., Avilés Balmaseda, R., Tejeda del Risco, E., Loyola Oriyés, C., & Honrach Junco, M. (2008). Determinación de las variables más representativas para la organización y el control de la reproducción en sistemas vacunos lecheros. *Revista de Producción Animal*, *20*(1). 65-71. https://www.academia.edu/download/46365941/Variables_mas_representativas_para_la_o rganizacion__y_el_control_de_la_reproduccion.pdf

Domínguez, A. M., Morales, Y., & Sánchez, J. A. (2015). Influencia del índice temperatura-humedad sobre la producción de leche por época del año en vacas. En Memorias de V Congreso de Producción Animal Tropical. Mayabeque, Cuba: Instituto de Ciencia Animal. https://www.engormix.com/ganaderia-leche/articulos 7 de Mayo 2020

Enríquez, A. V. & Álvarez, A. (2020). Caracterización del índice de temperatura y humedad y el estrés calórico en el ganado bovino de leche en dos lecherías en la provincia Mayabeque, Cuba. *Cuban Journal of Agricultural Science*, *54*(1). http://cjascience.com/index.php/CJAS/article/view/942Adan/publication/346938753. f

Fonseca Rivera, C., Martínez Alvarez, M., González, M. H., Pérez Suárez, R., Velazquez Saldívar, B., Valderá Figueredo, N., González García, I., Cutié Cancino, V., Vázquez Montenegro, R., Cruz Estopiñan, E. V., Mitrani Arenal, I., Hidalgo Mayo, A., Cabrales Infante. J., Lapinel Pedroso, B., Marzo Lobaina, O., & Ríos Ortega, Y. (2023). Estado del Clima en Cuba 2022. Resumen ampliado. *Revista Cubana de Meteorología*, 29. http://scielo.sld.cu/scielo.php?pid=S2664-08802023000100010&script=sci_abstract

Galván Cavero, G. A., Menendez-Buxadera, A., More Montoya, M. J., & Gutiérrez Reynoso, G. A. (2023). Impacto de los efectos climáticos sobre la producción de leche de ganado Holstein en Lima, Perú. *Revista de Investigaciones Veterinarias del Perú*, *34*(5), e23388. https://doi.org/10.15381/rivep.v34i5.23388

Guerra Montenegro, R., Hernández Rodríguez, A., & Menéndez-Buxadera, A. (2019). Componentes de varianza genética para producción de leche y tolerancia a cambios de temperatura ambiental en vacas Holstein en Chiriquí, Panamá. *Livestock Research for Rural Development. 30*(12). https://www.researchgate.net/publication/329451337.

Hair, J. F., Black, W. C., Babin, B. J., Anderson, R. E., & Tatham, R. L. (2009). Multivariate data analysis. 7th edition, Prentice Hall, Upper Sadde River, NJ, USA.

Horrach Junco, M. N., Bertot Valdés, J. A., Vázquez Montes de Oca, R., & Garay Durba, M. (2020). Eficiencia reproductiva de sistemas vacunos en inseminación artificial. Tendencias actuales y perspectivas. *Revista de Producción Animal, 32*(3), 70-78. https://revistas.reduc.edu.cu/index.php/rpa/article/view/e3592

Martínez-Melo, J., Jordán, H., Torres, V., Guevara, G., Hernández, N, Brunett, L. Fontes, D., Mazorra, C., Lezcano, Y & Cubillas, N. (2011). Classification of dairy units belonging to the Basic Units of Cooperative Production in Ciego de Avila, Cuba. *Cuban Journal of Agricultural Science*, *45*(4). 373-377. http://cjascience.com/index.php/CJAS/article/view/96

Menéndez-Buxadera A., Caunedo Sibori, J., & Fernández Santibáñez, M. (2004). Relación entre el por ciento de vacas en ordeño y la producción láctea total del rebaño. *Revista Cubana de Ciencia Agrícola*, *38*(4), 361-367. http://www.redalyc.org/articulo.oa?id=193017793003

Menéndez-Buxadera, A., Montoya, M. M., Gutiérrez-Reynoso, G., & Cavero, G. G. (2022). Interacción genotipo ambiente en estrés térmico y producción de leche en vacas Holstein en la región de Lima, Perú. En *Anales Científicos*, *83*(2), 160-174. https://revistas.lamolina.edu.pe/index.php/acu/article/view/1902

Menéndez-Buxadera, A., Pereira, R. J., El Faro, L., & Santana Jr, M. L. (2020). Genotype by environment interaction due to heat stress during gestation and postpartum for milk production of Holstein cattle. *Animal*, *14*(10), 2014-2022. https://doi.org/10.1017/S1751731120001068

National Research Council (NRC) 1971. A guide to environmental research on animals. National Academy Press, Washington, DC, USA.

Ravagnolo, O., & Misztal, I., (2000). Genetic component of heat stress in dairy cattle, parameter estimation. *Journal of Dairy Science*, *83*, 2126– 2130. https://doi.org/10.3168/jds.S0022-0302(00)75095-8

Ravagnolo O., Misztal, I., & Hoogenboom, G. (2000). Genetic component of heat stress in dairy cattle, development of heat index function. *Journal of Dairy Science, 83*, 2120– 2125. https://doi.org/10.3168/jds.S0022-0302(00)75094-6

Silva, W. C. D., Silva, J. A. R. D., Camargo-Júnior, R. N. C., Silva, É. B. R. D., Santos, M. R. P. D., Viana, R. B., Silva, A. G. M. Silva, C. M. G., & Lourenço-Júnior, J. D. B. (2023). Animal welfare and effects of per-female stress on male and cattle reproduction-A review. *Frontiers in Veterinary Science*, *10*, 1083469. https://doi.org/10.3389/fvets.2023.1083469

Soto Senra, S. A., Guevara Viera, R. V., & Guevara Viera, G. E. (2020). Uso estratégico de la base forrajera en la producción estacional de leche bovina en la zona centro-oriental de Cuba. *Revista de Producción Animal, 32*(3), 120-132. https://revistas.reduc.edu.cu/index.php/rpa/article/view/e3668

Stefanska, B., Sobolewska, P., Fievez, V., Pruszynska-Oszmałek, E., Purwin, C., & Nowak, W. (2024). The effect of heat stress on performance, fertility, and adipokines involved in regulating systemic immune response during lipolysis of early lactating dairy cows. *Journal of Dairy Science*, *107*(4), 2111-2128. https://doi.org/10.3168/jds.2023-23804

Torres, V., Ramos, N., Lizazo, D., Monteagudo, F., & Noda, A. (2008). Statistical model for measuring the impact of innovation or technology transfer in agriculture. *Cuban Journal of Agricultural Science*, *42*(2), 131-137. http://www.ciencia-animal.org/cuban-journal-of-agricultural-science/articles/V42-N2-Y2008-P131-V-Torres.pdf 9

Valdivia-Cruz, J. C., Reyes-González, J. J., & Valdés-Paneque, G. R. (2021). Effect of temperature and humidity index (THI) on the physiological responses of grazing dairy cows. *Cuban Journal of Agricultural Science*, *5*(1), 21. https://www.academia.edu/download/87564461/2079-3480-cjas-55-01-21.pdf

AUTHOR CONTRIBUTION STATEMENT

Research conception and design: SGP, AMB; data analysis and interpretation: SGP, AM, MST, AMB; REDACTION OF THE MANUSCRIPT: SGP, AMB, AM, MST.

CONFLICT OF INTEREST STATEMENT

The authors declar there are no conflicts of interests whatsoever.

,