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# Effects of thermal environment on dairy cattle under a grazing system in the Western Amazon, Brazil

[*Efeitos do ambiente térmico em bovinos leiteiros em sistema de pastejo na Amazônia Ocidental, Brasil*]

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## ABSTRACT

This study aimed to evaluate the thermal conditions to which animals are exposed and their effect on the comfort/discomfort of dairy herds in a grazing system in the municipality of Sena Madureira, Acre State, Brazil. Eight farms and a total of 113 lactating crossbred cows were evaluated. Dry-bulb temperature (DBT, °C), relative humidity (RH, %), black globe temperature (BGT, °C), and wind speed (v, km $h^{-1}$) were measured in January, February, and March (rainy season) to calculate temperature-humidity index (THI), black globe-humidity index (GTWBI), and radiant heat load (RHL). Moreover, the animals were measured for the physiological variables: rectal temperature (RT), heart rate (HR), and respiratory rate (RR). Significant differences (P<0.05) were observed for THI, GTWBI, and RHL. THI reached a mean value of 80 on farm G in January. Farm F had a GTWBI value of 79 in February. RHL reached the highest value (510 W $m^{-2}$). RT and HR showed no differences among the analyzed months. Thus, the environmental conditions in which dairy cows are housed at milking time rarely promoted thermal discomfort, with farm G being the most affected by THI.

Keywords: climate change, ambiance, animal welfare, heat stress, dairy cow

## RESUMO

*Objetivou-se avaliar as condições térmicas a que os animais estão submetidos, seu efeito no conforto/desconforto de rebanhos leiteiros em sistema de pastejo, no município de Sena Madureira-Acre. Foram avaliadas oito propriedades e o total de 113 vacas mestiças em lactação. As medições ocorreram nos meses: janeiro, fevereiro e março (inverno amazônico), mensurando-se: temperatura do bulbo seco (TBS, °C), umidade relativa do ar (UR, %) e temperatura de globo negro (TGN, °C), velocidade do vento (v, km/h) para cálculos dos índice da temperatura e umidade (ITU), índice da temperatura de globo e umidade (ITGU) e carga térmica radiante (CTR), além da temperatura retal (TR), frequência cardíaca (FC), frequência respiratória (FR). Entre as propriedades analisadas, houve diferenças significativas (P<0,05) para ITU, ITGU e CTR. Destaca-se que o ITU na propriedade G, em janeiro, atingiu o valor médio de 80. A propriedade F, em fevereiro, teve valor de 79 para o ITGU. A CTR apresentou carga elevada (510 W.m*$^{-2}$*). A TR e a FC não apresentaram diferença entre os meses analisados. Concluiu-se que o ambiente ao qual as vacas leiteiras estão alojadas na hora da ordenha encontraram-se poucas vezes em situação de desconforto térmico, sendo a propriedade , a mais afetada pelo ITU.*

*Palavras-chave: alterações climáticas, ambiência, bem-estar animal, estresse por calor, vaca leiteira*

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## INTRODUCTION

Brazil is one of the world's largest cow milk producers, with a production of around 35.4 million liters of milk in 2020. The State of Acre (AC) contributed with about 42,500 liters, and the municipality of Sena Madureira (AC) produced 2.6 thousand liters (Produção…, 2020). These values show the importance of dairy farming in Brazilian agribusiness and highlight the need for a product of high nutritional value for the population (Silva *et al*., 2020).

The North region of Brazil, in which AC is located, has an equatorial climate, and is subjected to wet conditions in winter and dry ones in summer, with intense solar radiation and high rainfall and relative humidity values, with the municipality of Sena Madureira located in a tropical zone where climate varies widely (Zoneamento…, 2010).

For Ferreira *et al*. (2017), air temperature, relative humidity, wind speed, and solar radiation are the main meteorological parameters to assess the thermal comfort of animals. Still, according to these authors, physiological variables such as rectal and surface coat temperature, respiratory rate, and sweating rate can be indicators of thermal comfort or discomfort of production animals.

High air temperatures associated with high humidity and direct solar radiation are the main stressors that cause low performance in dairy cattle due to their specialized production function and high nutritional requirements and heat production (Rosanova *et al*., 2020). Cows with high genetic and production indices may not be able to express their full productive potential when subjected to heat stress and may spend part of the consumed energy maintaining body temperature (Nascimento *et al*., 2013).

Milk productivity is directly related to the time animals are under thermal comfort, that is, homeostasis (Bertoncelli *et al*., 2013). Animals raised outside their thermal comfort zone do not reach maximum production potential, with production, reproduction, and welfare being affected (Urbano *et al*., 2019).

Heat stress is a major challenge for sustainable livestock production, compromising animal welfare and performance during the hot summer months (Osei-Amponsah *et al*., 2020). In this context, this study aimed to evaluate the thermal conditions to which animals are subjected and their effects on the comfort/discomfort of dairy herds in a grazing system in the municipality of Sena Madureira, Acre State, Western Amazon, Brazil.

## MATERIAL AND METHODS

All management practices involving animals were approved by the Ethics Committee on the Use of Animals at UFAC (CEUA) (Process No. 23107.016410/2019-06).

The study was carried out on eight farms (classified from A to H) during the Amazonian winter or rainy season (January to March) of 2020 in the municipality of Sena Madureira, Acre State, in the Western Amazon. The site is located at latitude 09°03′57″ S, longitude 68°39′25″ W, and an altitude of 150 m above sea level.

This region has a tropical climate according to Köppen's classification. According to Weather Spark (2019), this region is characterized by temperatures between 20 and 33 °C throughout the year and rarely below 13 °C or above 37 °C, with a mean annual rainfall of 2,017 mm mainly between November and April. All farms assessed in the experiment were similar to each other and characterized by family production and low technological level; however, milking systems and facilities distinguished them from each other.

Milking is carried out manually on seven farms (87.5%) and mechanically with hired labor on only one (12.5%). Regarding facilities, one farm (12.5%) has a milking parlor with a concrete floor, while the others (87.5%) with an earthen floor. Moreover, only one farm (12.5%) has open-air milking. Milking time varied among farms and occurs from 2:00 am to 6:00 am. All farms (100%) perform only one milking daily and have a calf at foot model. Milking management was not changed to avoid stress conditions. In the eight farms, 113 lactating crossbred cows with the following genetic profile were evaluated: Holstein x Girolando, Holstein x Nellore, and Holstein x Zebu, with a mean daily production of 4.8 L/day.

Livestock production system is extensive grazing, and forages fed to animals include *Brachiaria humidicola*, *Brachiaria decumbens*, *Brachiaria brizantha* cv. Marandu, *Brachiaria brizantha* cv. MG-5, and *Paspalum conspersum*. Animals had access to mineral supplementation and water *ad libitum* throughout the experiment.

All parameters were evaluated for three days during the morning in the corral at milking time (between 2:00 am and 6:00 am, according to each farm routine) and once a month (January, February, and March), with an interval of 30 days between them.

Heat stress was measured by a WBGT-8758 portable digital monitor (globe thermometer). Resolutions and accuracies were 0.1°C and ±1°C for temperature, 0.1% and ±5% for relative humidity, and ±2 °C (IN) and ±3 °C (OUT) for globe temperature. Finally, the globe thermometer wet-bulb index (GTWBI) presented a resolution of 0.1°C.

The parameters evaluated were dry-bulb temperature (DBT, °C), wet-bulb temperature (WBT, °C), relative humidity (RH, %), and black globe temperature (BGT, °C), while wind speed (v, km $h^{-1}$) was obtained from a climate and weather forecast platform (Climatempo, 2020). Then, the temperature-humidity index (THI) in the milking parlor was calculated using the formula recommended by Mader *et al*. (2006):

$$THI = (0.8 \times DBT + (RH/100) \times (DBT - 14.4) + 46.4$$

Wherein: DBT is the dry bulb temperature (°C), and RH is the relative humidity (%).

THI data were analyzed and interpreted according to the classification proposed by Hahn (1985) for dairy cows. It considers values lower than or equal to 74 as a normal condition, between 75 and 78 as heat stress warning, between 79 and 83 as a dangerous situation in which animals are under stress, and higher than 83 as emergency condition (hence urgent measures must be provided).

The black globe-humidity index (GTWBI) was calculated according to the formula proposed by Buffington *et al*. (1981):

$$GTWBI = BGT + 0.36\ WBT + 41.5$$

Wherein: BGT is the black globe temperature (°C), and WBT is the wet-bulb temperature (°C).

GTWBI results were interpreted according to Buffington *et al*. (1981), in which values up to 74 are defined as comfort, from 74 to 78 as a warning condition, from 79 to 84 as a dangerous condition, and higher than 84 as an emergency condition.

Radiant heat load (RHL) was calculated as proposed by Esmay (1982), using the Stefan-Boltzmann equation:

$$RHL = \sigma(TMR)^4$$

Wherein: RHL is the radiant heat load (W $m^{-2}$), σ is the Stefan-Boltzmann constant ($5.67 \times 10^{-8}$ W $m^{-2}$ $K^{-4}$), and MRT is the mean radiant temperature (K), as follows:

$$MRT = 100 \cdot \sqrt[4]{2.51 \cdot \sqrt{V} \cdot (BGT - DBT) + (BGT/100)^4}$$

Wherein: MRT is the mean radiant temperature (K), and v is the wind speed (m $s^{-1}$).

The physiological parameters heart rate (HR, beats per minute), respiratory rate (RR, movements per minute), and rectal temperature (RT) were measured by the method recommended by Santos *et al*. (2018). HR was determined by auscultation, using a stethoscope on the left side of the animal between the 3rd and 5th intercostal spaces. The auscultation was performed for 15 seconds, and the result was multiplied by four to determine HR per minute. RR was performed through visual assessment, observing the flank movements for 15 seconds, also multiplied by four to determine RR per minute. RT was recorded using a digital clinical thermometer inserted directly into the animal's rectum.

Statistical analysis was performed using the R programming language (R Core Team, 2019), in which the parameters were evaluated by generalized linear models (GLM) with Gaussian distribution. For this purpose, the *gamlss* package was used (Rigby; Stasinopoulos, 2005).

The parameters influenced by months and farms were evaluated by Tukey's test at a 5% significance level, using the *agricolae* package (Mendiburu, 2019). Moreover, the parameters that showed influence by months were evaluated individually on each farm.

## RESULT AND DISCUSSION

During this study, mean DBT and RH ranged from 20.2 to 27.8°C and 71 to 86%, respectively, when crossbred cows (*Bos taurus taurus* x *Bos taurus indicus*) were milked. Cattle under thermal comfort are recommended to remain in an environment with temperatures between 4 and 24°C and RH lower than 75%, and this range can be restricted to limits between 7 and 21°C, depending on the relative humidity and solar radiation (Antunes *et al*., 2009).

THI results in the study period (January, February, and March 2020) and on the evaluated farms (A, B, D, E, F, G, and H) were significantly different (P<0.05) by the Tukey's test (Table 1). Only farm C showed no difference between the three analyzed months, and THI remained at 77 throughout the period. The lowest THI was found in March on farms A, D, E, F, and H, ranging from 70 to 75 on farms H and F, respectively.

According to classification by Rosenberg *et al.* (1983), THI values at milking time were equal to or greater than 72 (Table 1). Therefore, from this point forward, attention to animal thermal comfort should be given since those values may increase throughout the day, thus making cows more prone to thermal stress.

Table 1. Means of the temperature-humidity index (THI) in January, February, and March 2020 during the collection of physiological data from lactating crossbred cows (*Bos taurus taurus* x *Bos taurus indicus*) on eight dairy farms

| Period | Farm | | | | | | | | Mean |
|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | H | |
| January | $74^{b}$ | $73^{c}$ | $77^{a}$ | $77^{a}$ | $73^{a}$ | $76^{c}$ | $80^{a}$ | $77^{a}$ | $76^{a}$ |
| February | $73^{c}$ | $77^{a}$ | $77^{a}$ | $73^{b}$ | $76^{b}$ | $77^{a}$ | $77^{c}$ | $72^{b}$ | $75^{b}$ |
| March | $72^{a}$ | $74^{b}$ | $77^{a}$ | $72^{c}$ | $72^{c}$ | $75^{b}$ | $79^{b}$ | $70^{c}$ | $73^{c}$ |
| Mean | $74^{DE}$ | $75^{CD}$ | $77^{AB}$ | $74^{D}$ | $75^{D}$ | $76^{BC}$ | $79^{A}$ | $73^{E}$ | |

Adapted from Hahn (1985).
Means followed by different lowercase letters in the column differ statistically by Tukey's test at a 5% probability (P<0.05).
Means followed by different uppercase letters in the row differ statistically by Tukey's test at a 5% probability (P<0.05).
THI ≤ 74 Normal; 75 to 78 Warning; 79 to 83 Danger; > 83 Emergency

Importantly, only farm G presented THI values in a dangerous situation in January (80) and March (79), according to the classification of Hahn (1985). These high THI values may indicate that dairy cows were in discomfort, thus welfare and hence dairy productivity may be compromised (Lima *et al*., 2019).

Rosanova *et al*. (2020) evaluated dairy cattle welfare under high and stressful THI conditions in northern Tocantins State (Brazil) and found that values ranged from 72.41 to 77.66, with a mean of 75.70. In addition, the authors observed that even in months with milder temperatures, the region presented unfavorable climate conditions for animal thermal comfort and milk production.

According to the recorded data, GTWBI showed significant differences (P<0.05) among the analyzed months (January, February, and March) and farms (Table 2). The values found in January ranged from 75 to 76 on farms C, D, E, F, G, and H, which are considered under stress warning for less favorable environmental conditions; therefore, safety measures must be implemented to avoid losses. According to Buffington *et al.* (1981), values up to 74 define comfort, from 74 to 78 a warning condition of stress, from 79 to 84 a dangerous condition, and above 84 an emergency condition for cattle.

Farm F presented a mean GTWBI of 79 in February, indicating a risk of thermal discomfort for cows at milking time (Buffington *et al.*, 1981). These conditions, above the thermoneutral zone, suggest that animals are likely to experience heat stress.

In contrast, Moreira *et al.* (2017) characterized the thermal comfort condition and physiological and behavioral parameters of 3/4 Holstein-Zebu cows maintained on pasture during the summer and winter in the municipality of Verdelândia, Minas Gerais State (MG), Brazil, and found that the mean GTWBI values during milking at 6:00 am were 72.49 and 60.78 when animals were under thermal comfort conditions.

According to Valentim *et al.* (2018), heat stress is an important source of economic loss in livestock production, with an adverse effect on milk production, production physiology, reproduction, and udder health, with a consequent reduction in reproductive performance of dairy cows (Soares *et al*., 2021).

Table 2. Means of the black globe-humidity index (GTWBI) in January, February, and March 2020 during physiological data collection from lactating crossbred cows (*Bos taurus taurus* x *Bos taurus indicus*) on eight dairy farms

| Period | Farm | | | | | | | | Mean |
|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | H | |
| January | $73^{c}$ | $73^{c}$ | $75^{a}$ | $76^{a}$ | $76^{a}$ | $75^{b}$ | $77^{b}$ | $76^{a}$ | $75^{a}$ |
| February | $75^{a}$ | $76^{a}$ | $71^{c}$ | $72^{b}$ | $74^{c}$ | $79^{a}$ | $76^{c}$ | $75^{b}$ | $74^{b}$ |
| March | $74^{b}$ | $75^{b}$ | $73^{b}$ | $72^{b}$ | $75^{b}$ | $74^{c}$ | $78^{a}$ | $72^{c}$ | $73^{c}$ |
| Mean | $74^{CDE}$ | $74^{CD}$ | $72^{F}$ | $73^{EF}$ | $75^{BC}$ | $76^{AB}$ | $77^{A}$ | $74^{DE}$ | |

Adapted from Buffington *et al*. (1981).
Means followed by different lowercase letters in the column differ statistically by Tukey's test at a 5% probability (P<0.05).
Means followed by different uppercase letters in the row differ statistically by Tukey's test at a 5% probability (P<0.05).
GTWBI ≤ 74 Normal; 74 to 78 Warning; 79 to 84 Danger; > 84 Emergency

Analysis of variance showed a significant difference (P<0.05) for the interaction between treatments (months and farms) and farms for months of the year regarding RHL (Table 3), even when milking was performed at times of the day with the mildest temperatures.

Table 3. Means of radiant heat load (RHL) in January, February, and March 2020 during physiological data collection from lactating crossbred cows (*Bos taurus taurus* x *Bos taurus indicus*) in eight dairy farms

| Period | Farm | | | | | | | | Mean |
|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | H | |
| January | $434^{c}$ | $454^{c}$ | $470^{b}$ | $477^{a}$ | $451^{b}$ | $459^{c}$ | $516^{b}$ | $490^{b}$ | $506^{a}$ |
| February | $477^{a}$ | $482^{b}$ | $459^{c}$ | $459^{b}$ | $477^{a}$ | $522^{a}$ | $474^{c}$ | $565^{a}$ | $473^{b}$ |
| March | $445^{b}$ | $510^{a}$ | $496^{a}$ | $459^{b}$ | $477^{a}$ | $479^{b}$ | $523^{a}$ | $441^{c}$ | $470^{b}$ |
| Mean | $453^{C}$ | $482^{AB}$ | $475^{BC}$ | $465^{BC}$ | $468^{BC}$ | $487^{AB}$ | $504^{A}$ | $499^{A}$ | |

Means followed by different lowercase letters in the column differ statistically by the Tukey test at a 5% probability (P<0.05).
Means followed by different uppercase letters in the row differ statistically by the Tukey test at a 5% probability (P<0.05).

The environment on farms B in March (510 W $m^{-2}$), F in February (522 W $m^{-2}$), G in January (516 W $m^{-2}$) and March (523 W $m^{-2}$), and H in February (565 W $m^{-2}$) had high heat loads. This fact can be attributed to external climate conditions. On the contrary, Moreira *et al.* (2017) observed radiant heat loads of 389.13 and 345.81 W $m^{-2}$, with the animals being under thermal comfort conditions. The farms were measured in the aforementioned months, and the environment corral showed an increase in heat load, which is unfavorable to cow comfort during milking.

According to Silva (2000), the radiant heat load (RHL) is the amount of thermal energy exchanged by an individual through radiation with the environment. This value is ideally as small as possible.

Environmental temperatures higher than those of animal bodies and animals exposed to radiating heat sources (i.e., sunlight) cause animals to lose heat to the environment through body surface radiation by convection, evaporation, and conduction, in addition to small part eliminated via urine and feces (Klein, 2014).

Physiological parameters, such as rectal temperature, heart rate, and respiratory rate, are influenced by extrinsic variables such as air temperature and humidity, solar radiation, wind speed, the season of the year, time of the day, and shading (Paula *et al*., 2017).

Although cows were often subjected to warning and sometimes dangerous situations in terms of thermal environment (Tables 1, 2, and 3), the physiological variables of these animals were not changed (Table 4). This can be stated since the physiological analysis of crossbred cows (*Bos taurus taurus* x *Bos taurus indicus*) showed no sign of heat stress, with these values being within the normal range even when temperature and humidity values were not ideal.

Table 4. Means of the physiological parameters of crossbred cows (*Bos taurus taurus* x *Bos taurus indicus*) rectal temperature (RT), heart rate (HR), and respiratory rate (RR) raised on pasture at milking time in Sena Madureira, State of Acre, Brazil

| Physiological variable | Farm | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | H |
| RT (°C) | 37.3[ab] | 37.3[ab] | 37.3[ab] | 37.3[ab] | 37.6[a] | 36.4[b] | 37.5[a] | 37.8[a] |
| HR (beats per minute) | 72.1[a] | 71.9[a] | 73.0[a] | 74.0[a] | 77.3[a] | 74.7[a] | 72.7[a] | 74.7[a] |
| RR (movements per minute) | 22.9[ab] | 22.1[b] | 22.3[b] | 25.3[ab] | 25.7[a] | 23.5[ab] | 22.0[b] | 23.6[ab] |

Means followed by different lowercase letters in the row differ statistically by Tukey's test at a 5% probability ($P<0.05$).

The means of the physiological parameters observed experimentally indicated the absence of heat stress, not exceeding the range considered as comfortable, with the reference value for cattle being between 36.7 and 39.1°C (Reece *et al*., 2015).

THI and GTWBI results in February indicated a dangerous climate environment for farms G and F, respectively. This result may have occurred because the cows could maintain body temperature in the morning due to a relative comfort generated by lower temperatures the previous night, thus remaining closer to the thermoneutral zone (Marins *et al*., 2020).

Similarly, Castro *et al*. (2018) carried out a study in Montes Claros, MG, Brazil, where the mean annual temperature is 22.6°C, to characterize the effect of the microclimate in two different environments. The authors found that mean rectal temperature (38.4°C) both in the morning and afternoon did not exceed normal values even when GTWBI (87.7) classified the climate environment as dangerous.

Tukey's test (Table 5) shows significant differences ($P<0.05$) for RR among the months of the year evaluated. RT and HR showed no differences among the three months analyzed, with RT ranging from 37.3 to 37.5 °C and HR from 73.2 to 75.5 beats per minute. These results may be due to high temperatures associated with increased relative humidity in the rainy season of the region.

The animals in the present study might be more resistant to heat due to breed since Zebu animals are more easily adapted to environments with warmer temperatures (Cardoso *et al*., 2015). When evaluating the effect of the climate environment on the physiological responses of the Zebu breed, Santos *et al*. (2018) found a mean RR of 32.5 movements per minute, HR of 75 beats per minute, and TR of 38.1°C.

Table 5. Means of physiological parameters of crossbred cows (*Bos taurus taurus* x *Bos taurus indicus*) raised on pasture at milking time in Sena Madureira, State of Acre, Brazil, in January, February, and March 2020

| Physiological variable | Jan. | Feb. | Mar. |
|---|---|---|---|
| | Mean | | |
| Rectal temperature (°C) | 37.3[a] | 37.4[a] | 37.5[a] |
| Heart rate (beats per minute) | 73.4[a] | 73.2[a] | 75.5[a] |
| Respiratory rate (movements per minute) | 23.9[a] | 21.6[b] | 25.0[a] |

Means followed by different lowercase letters in the row differ statistically by the Tukey test at a 5% probability (P<0.05).

## CONCLUSION

During the experiment, temperature-humidity indexes ranged from 70 to 80, with only farm G presenting the most critical value (THI = 80) in January. Black globe-humidity indexes ranged from 71 to 79, with farm F achieving the highest discomfort condition (GTWBI = 79) in February. Regarding radiant heat load, values ranged from 434 to 565 W.m-², with farm H being the most affected by external weather conditions. Farms B, F, G, and H were the ones that showed the greatest variations in terms of environmental variables. Moreover, crossbred cows showed no changes in physiological variables (rectal temperature, heart rate, and respiratory rate) at milking time, not differing from normal values when challenged by heat stress.

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