

# Design and testing of a sweat meter for the cutaneous evaporation determination in cattle



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**Abstract** The physiological processes of adaptation respond to autonomic mechanisms. Ruminants are known to regulate heat by sweating, among other mechanisms. *Bos taurus* cattle usually do not compensate well for exposure to high temperatures. In the tropics, sweating is the most important way for ruminants to lose heat. The objective of this research was to design and validate a non-invasive external mean to determine sweat production in Colombian Creole cattle. In a research center located in the Colombian eastern plains at 4°05'N and 73°34'E, at 330 m ASL, a simple, lightweight, operational, safe, and easy-to-use device was designed to collect sweat from bovine *Planum nasolabiale* in 15 lactating cows of Colombian Creole breeds. Besides, blood samples were collected and physiological constants were determined and analyzed the relationship of this parameter with physiological measurements and heat indices. The measurement device designed and tested has proven to be efficient for sweating collection in cattle; however, the quantity of sweat collected could not reflect in a trustworthy way the overall animal response to the environmental conditions. In contrast, the heat load index was more related to evapotranspiration and sweat production than the humidity temperature index, indicating that a high heat load may lead to a major need for triggering high-level regulatory physiologic mechanisms like sweat production to compensate the rise of core temperature.

**Keywords:** Colombian Creole cattle, Colombian eastern plains, heat stress, *Planum nasolabiale*, sweat production

## Introduction

The physiological processes of adaptation respond to autonomous, highly related mechanisms associated with the principle of minimum biological effort and operational redundancy. Heat dissipation is usually an important measure

of adaptation to high temperatures. It is known that the first action that ruminants exert against heat stress is to reduce the movement and with this, they decrease food consumption; subsequently, they increase respiratory and cardiac frequencies, sweating and decrease renal filtration (Randall et al 2004; Dukes et al 1999).

All mechanisms are associated with endogenous heat loss, which is achieved mainly through the physical principles of conduction, convection, and radiation (Seebaccher et al 2015); however, some mechanisms require sophisticated endogenous processes when environmental conditions become critical, especially with increased temperature and humidity; thus endocrine control activates alternatives that reinforce homeostatic mechanisms of autonomous type (Tomasi et al 2019).

The mechanisms of genetic adaptation at high temperatures developed by cattle through thousands of years of evolution of the *Bovidae* family, which end in the emergence of *Bos indicus* as a group that defined profound physiological modifications for its adaptation to high temperatures. For their part, *Bos taurus* cattle, generally do not compensate well for exposure to high temperatures. However, in the Colombian tropics, eight cattle breeds known as Colombian Creole cattle, all originating from Spanish cattle brought to America in the 16th century can survive and reproduce under the environmental conditions of Colombian tropical lowlands (Martínez et al 2009).

To study the mechanisms of adaptation of Colombian Creole cattle, it is necessary to identify the physiological mechanisms developed in response to the environmental conditions in which they have remained. This knowledge, in turn, will allow us to understand and develop production alternatives in current climate change scenarios. In this sense, the recognition of sweating as a mechanism of heat loss, has not been studied, nor have adequate means for monitoring

over time and is evident the poor validation of statistical correlations between sweating and traditional physiological parameters (heart rate, respiratory and ruminal movements, rectal or cutaneous temperature) or with concentrations of some hormones.

Knowing that the maintenance of body temperature depends largely on sweating and respiratory exchange (Cunningham 1999), the physiological response that allows explaining and predicting the homeorhetic behavior of creole cattle, with a view to its zootechnical exploitation in pure herds or crossings with Indo-European breeds. When there is a temperature difference between the animal and its environment, a heat flow takes place, which tends to equal both temperatures (Parker 1984; Yeates 1976). Therefore, the animal can gain or lose heat according to these processes, depending on whether the ambient temperature is higher or lower than that of the animal. But the animal can also lose heat regardless of the ambient temperature, by evaporation on moist surfaces, such as the skin after sweating, evaporation of tongue and airway moisture by increasing respiratory rate and wheezing (Cunningham 1999).

Cattle have fewer sweat glands than horses. The type of gland in ruminants is mainly apocrine (Mader 2003). Nerve mechanisms are controlled by sweating centers located in the central nervous system that can be activated by external heat stimuli, afraid or fear; or by action derived from self-balancing mechanisms associated with pH regulation (Collier et al 2019).

Evaporation efficiency is conditioned by low ambient humidity and rapid air movement (Yeates 1976). Sweating is the most important route for heat loss in ruminants in the tropics (Kennedy 1995). Well-adapted animals can increase sweating rapidly as soon as body temperature begins to increase; in *Bos indicus* cattle sweating increases exponentially in response to the increase in body temperature while in *Bos taurus* cattle it is peaked shortly after the onset of the increase in body temperature (Ferreira et al 2009).

The complete stability of body temperature would only be possible if there was no heat exchange between the body and the environment. The constant production of heat and its loss towards the environment determines, in homeothermic animals, a thermal gradient that goes from the hot interior to the less hot surface. In the extremities, a thermal gradient is formed in the longitudinal (axial) direction and there is also a temperature gradient in the radial direction so it is perpendicular to the surface, which due to the irregular geometric conformation of the body determines a complicated thermal picture (Collier and Gebremedhin 2015).

Several methods have been used to calculate the sweating of cattle (Ferreira et al 2009). One of them is the vapormeter, developed in Finland by Dolphin Technologies Ltd, which calculates air temperature and humidity without the effect of airflow. It is placed between 10 and 20 seconds

on one square centimeter of skin and determines the loss of trans-epidermal water. The instrument delivers the results in grams per square meter hour.

Until now, it is the only method used in Colombian Creole cattle, finding for the Romosinuano breed a production of 175 g/m<sup>2</sup>/h of sweat (Scharf et al 2010). Other methodologies start from the use of predictive equations (Thompson et al 2011) to calculate the sweating rate (SR) in grams/square meter/hour and respiratory rate per minute (RR), based on skin temperature (Ts) and body temperature (Tb) measured in degrees Celsius (Ts and Tb, °C), with which they have also calculated sweat production for *Bos indicus*, *Bos taurus* cattle, and their crosses. However, these measurements are not considered reliable, nor sufficiently validated.

Thus, the objective of this paper was to design and validate a non-invasive external device to determine sweating in Colombian Creole cattle and to analyze the relationship of this parameter with physiological constants.

## Materials and Methods

The experiment was carried out at a research center in the Colombian eastern plains, at 4°05'N and 73°34'E, at 330 m ASL. The average annual temperature of the center is 26 °C, with a relative humidity of 80% and the average annual rainfall of the last 28 years has been 2932.6 mm. Precipitation in this geographical area exceeds 300 mm/month between April and November, followed by a dry period between December and March (IDEAM 2005) Table 1.

Blood samples were collected and physiological constants were determined in 15 cows of Colombian Creole breeds that corresponded to four cows of the Sanmartinero breed, six of the Blanco Orejinegro breed and five cows of the Hartón del Valle breed; with a range of ages between three and twelve years, and between one and five births, all cows grazed on meadows of *Brachiaria decumbens* with access to mineralized salt and water *ad libitum*. These animals underwent sanitary prevention and control programs by the regular schedules and plans provided by the research center. The project was approved by the animal ethics and experimentation committee of the research center.

Sampling was performed between April and September within seven evaluation periods, with an interval of 15 to 30 days. On the day for registration of information, experimental cows were taken to the working yard at 8:30 a.m. for milking, weighing their calves, and recording milk production. After 60 minutes of rest, they entered in the squeeze chute under the artificial shade where they were allowed to recognize the environment and calm for 15 minutes before starting the measurement of the physiological parameters and blood samples, taken between 11:30 and 13:00 hours. Heart beats was determined by auscultation for one-minute, respiratory movements by observation for one-minute

of the lateral flank of the animal, ruminal motility by observation of movements the left paralumbar fossa for two minutes, and the rectal temperature with mercury thermometer for three minutes.

The weather data of the observation period were obtained from the IDEAM weather station N° 70 "La Libertad"

located in the Research Center at a latitude 4°04'N and longitude 73°28'W. The information evaluated included records of ambient temperature in the dry bulb (°C), relative humidity (%), wind speed (m/sec), and solar radiation (hours).

**Table 1** Climatic variables, ITH, and heat load index (HLI) associated with seven moments between April and September in the Experimental Center (Foothills region of the Colombian eastern plains).

	Sampling dates						
*	1	2	3	4	5	6	7
Maximum temperature (°C)	32,0 <sup>c</sup>	31,0 <sup>bc</sup>	31,6 <sup>bc</sup>	32,4 <sup>c</sup>	29,6 <sup>b</sup>	26,0 <sup>d</sup>	33,4 <sup>a</sup>
Minimum temperature (°C)	22,2 <sup>b</sup>	22,0 <sup>b</sup>	21,6 <sup>c</sup>	23,4 <sup>a</sup>	22,2 <sup>b</sup>	22,0 <sup>b</sup>	23,2 <sup>a</sup>
Relative humidity (%)	82 <sup>b</sup>	86 <sup>b</sup>	87,3 <sup>a</sup>	69,5 <sup>d</sup>	67,5 <sup>d</sup>	89 <sup>a</sup>	75 <sup>c</sup>
Wind speed m/sec	6,12 <sup>c</sup>	6,75 <sup>bc</sup>	7,28 <sup>bc</sup>	7,86 <sup>bc</sup>	11,07 <sup>a</sup>	2,57 <sup>e</sup>	4,68 <sup>d</sup>
Solar radiation (hours)	6,6 <sup>b</sup>	9,4 <sup>a</sup>	4,1 <sup>c</sup>	6,5 <sup>b</sup>	3,7 <sup>c</sup>	1,1 <sup>e</sup>	2,6 <sup>d</sup>
HLI	57.92 <sup>c</sup>	66.34 <sup>a</sup>	61.26 <sup>b</sup>	62.09 <sup>b</sup>	60.41 <sup>b</sup>	58.11 <sup>c</sup>	59.48 <sup>b</sup>
ITH	78,5 <sup>b</sup>	78,9 <sup>b</sup>	78,3 <sup>b</sup>	78,2 <sup>b</sup>	75,9 <sup>c</sup>	74,2 <sup>c</sup>	81,2 <sup>a</sup>

\*Sampling dates: 1 = 08/04; 2 = 22/04; 3 = 06/05; 4 = 20/05; 5 = 08/07; 6 = 12/08 and, 7 = 30/09  
Duncan test for the variables studied. Different letter subtitles on each line indicate a significant difference ( $P < 0.05$ ).

To evaluate the sweating produced per unit of time and area, a sweat meter was designed and constructed, which consists of a metalhead, with two pieces that move on the same axis, which allows adjustment to the different sizes of bovine head and fixed with canvas straps. On the front is a platen that covers the nose and on which an adherent absorbent pad composed of non-woven transfer fabric that has an absorbent gel mixed with cellulose is placed. Given the method used, the device was called "Nasolabial plane Sweat meter" (Figure 1).



**Figure 1** Image of the device designed for the collection of sweat in cattle.

The experimental design and statistical analysis included analysis of variance for three treatments (cattle breeds) with different numbers of repetitions. For all variables, measures of central tendency (mean, median), variance, and standard deviation were calculated as dispersion measures.

The existence of possible associations between the variables studied was analyzed using Pearson's moment correlation coefficient with a simple linear regression model; the statistical program IBM-SPSS (2015) was used for these analyzes. Due to the homogeneity of the environment and the possibility of a different number of repetitions for each treatment, the data were arranged in a completely random arrangement (Petrie and Watson 2013). The test was assumed to be significant if the probability associated with it was less than or equal to 5%. The Duncan test was used as a means comparison test.

**Results and Discussion**

*Design of the sweat meter*

Due to the need to determine the amount of sweat produced by a bovine, it was decided to value the sweat produced in the *Planum nasolabiale*, since this anatomical point has the highest concentration of sweat glands (Mader 2003). Besides, the *Planum nasolabiale* is easier to access

because of its position, in relation to other areas of sweating like the hock or the fetlock regions.

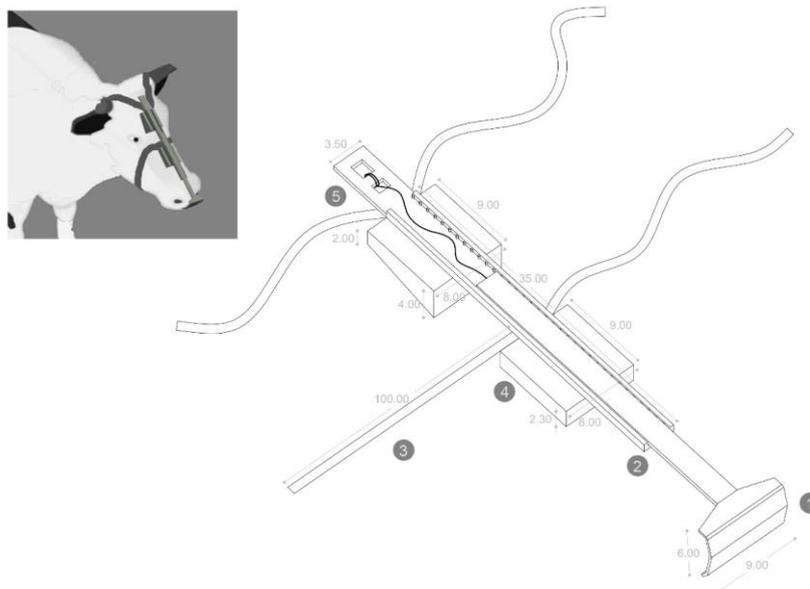
The selected anatomical area presents some limitations for humidity record. Firstly, the possible licking of the animal, since it can pass the tongue on the nose and collect sweating or impregnate the area with saliva; secondly, nasal secretions that could descend from the nostrils. To avoid these inconveniences, a simple, lightweight, operational, safe, and easy-to-use device was designed to collect sweat from bovine *Planum nasolabiale* (Figure 1).

The design included: a) an adjustable leather harness support with step closure, b) an aluminum rail system with one-way travel through sliding by mechanical bearing and spring adjustment at the top, and c) located at the base or distal end an adhesive pad consisting of nonwoven transfer fabric coated with absorbent gel mixed with cellulose.

To avoid traumatic friction for the animal due to the metal parts supporting and sliding, they were protected with synthetic foam which provided a cushioning, support, and point of contact with the cow's head.

The mechanical system allowed the animal to move the head together, without affecting the capture of sweat, since the device allowed the bearing to move the outer portion that carries the terminal for the pad without causing discomfort to the animal, likewise, the adjustment of the upper spring prevented the device from being altered by the animal's licks, by preventing it from giving in and getting wet by saliva in case the animal passed the tongue through the nose.

Figure 2 describes a three-dimensional diagram with the support and adjustment structures that allow to directly determine the amount of sweat produced in the *Planum nasolabiale* of the bovine, the main anatomical point of sweating.



**Figure 2** Axonometric graphic, for three-dimensional diagram of the sweat meter designed to capture sweat in the bovine nose. 1) Support of the pad that contacts the *Planum nasolabiale*; 2) Sliding rail system; 3) Adjustment straps; 4) Foam cushions; 5) Spring for longitudinal size adjustment.

The presented scheme is axonometric and isometric and represents the object three-dimensional image, maintaining the proportions in their true magnitude, that is, without distorting any of the three dimensions. Unlike cut or plant, which are two-dimensional representations, in the axonometric, the understanding of the entire represented object is not lost and facilitates the understanding of the designed sweat meter.

*Determination of physiological and hormonal constants*

Once the sweat meter was designed and tested, physiological measurements were performed on the fifteen cows. On the same day of the sweat measurement, the

physiological variables rectal temperature, heart rate, respiratory and ruminal movements were directly determined. Likewise, the climatic variables were recorded including maximum and minimum temperature, solar radiation, wind speed, and relative humidity. With the values of the climatic variables and the animal response, the heat load (HLI) and humidity temperature (ITH) indices were calculated (Hahn et al 2009; Gaughan et al 2008), as presented in Table 2, together with the values of the physiological constants determined in the study.

The climatic variables did not present severe variations, nor were extreme for the zone of study (Table 1). The sampling period was carried out in a rainy season and this

could have affected that the physiological responses did not indicate high degrees of stress associated with the animal response to environmental conditions. None of the sweat collection dates coincided with values associated with alerts or danger (ITH index values higher than 79), which agrees with other authors that have described that high humidity in the presence of temperatures above 30 °C, lead animals to comfort loss or minor productive dynamics (Polsky and Von Keyserlingk 2017; Lenis et al 2016)

The weight values of sweat collected during one hour of the *Planum nasolabiale* were on average 7.994 grams with a standard deviation of 7.044. The lowest value was 0 grams and the maximum was 17.44 grams. A significant difference was found as the heat load index increased, and there was also an increase in the weight of sweat produced at a higher heat load. A significant correlation was observed with ruminal frequency, but not with respiratory or cardiac rates (Table 2).

**Table 2.** Heat load Index (HLI) and physiological parameters of experimental cows of creole Colombian breeds in seven study periods.

Sample date	Heat load index (HLI)	Sweat weight (g/h)	Cardiac beats (heartbeats/min)	Respiratory movements (breaths/min)	Ruminal frequency (movements/2 min)	Rectal temperature (°C)
08/04	57.92 <sup>c</sup>	4.76 <sup>b</sup>	63.73 <sup>c</sup>	52.36 <sup>cd</sup>	3.00 <sup>a</sup>	39.66 <sup>a</sup>
22/04	66.34 <sup>a</sup>	6.217 <sup>ab</sup>	72.67 <sup>b</sup>	65.67 <sup>a</sup>	2.67 <sup>cd</sup>	39.75 <sup>a</sup>
06/05	61.26 <sup>b</sup>	11.30 <sup>a</sup>	72.09 <sup>b</sup>	51.00 <sup>de</sup>	2.73 <sup>cd</sup>	39.54 <sup>a</sup>
20/05	62.09 <sup>b</sup>	8.25 <sup>ab</sup>	74.00 <sup>b</sup>	61.08 <sup>ab</sup>	2.83 <sup>cd</sup>	39.81 <sup>a</sup>
08/07	60.41 <sup>b</sup>	6.83 <sup>ab</sup>	56.11 <sup>d</sup>	42.22 <sup>de</sup>	2.66 <sup>cd</sup>	39.50 <sup>a</sup>
12/08	58.11 <sup>c</sup>	4.50 <sup>b</sup>	43.13 <sup>e</sup>	33.13 <sup>ef</sup>	2.38 <sup>de</sup>	39.41 <sup>a</sup>
30/09	59.48 <sup>d</sup>	2.78 <sup>b</sup>	87.25 <sup>a</sup>	29.88 <sup>f</sup>	1.88 <sup>e</sup>	39.35 <sup>a</sup>

Duncan test or multiple amplitude test for the comparison of means of the variables studied. Different letters subscripts indicate a significant difference ( $P < 0.05$ ).

There were no significant differences between cattle breeds on sweat production, this finding, as well as the relatively low amount of sweat registered, leads us to consider that Creole cattle due to their centennial adaptation to the ecological conditions of the Colombian tropics, do not produce sweating in excessive quantities.

Cattle production systems in the tropics due to global warming can face severe unfavorable conditions (Da Silva et al 2015), depending on the influence of the animal type and environmental conditions, since bovines in tropical regions depend on grazing, generally of low nutritional quality forage (Amézquita et al 2013). Thus, having *Bos taurus* cattle breeds that have already demonstrated physiological mechanisms, through which respond to the conditions that the environment imposes, represents an advance in the proposals for production alternatives with profitability in tropical lowlands.

## Conclusions

The measurement device designed and tested has proven to be efficient for sweating collection in cattle. However, the amount of sweat collected could not reflect in a trustworthy way the overall animal response to the environmental conditions. The heat load index is more related

to the cutaneous evaporations and sweat production than the humidity temperature index, thus a high heat load may lead to a major need for triggering high level regulatory physiologic mechanisms like sweat production to compensate the rise of core temperature.

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## Conflict of Interest

The authors declare no conflict of interest.

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