Sensibility analysis and evaluation of a simulation model to estimate the caloric balance in cattle in the humid tropics

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A sensibility analysis of the model of caloric balance was performed in cattle. The factors related to the radiation (sun radiation exposure hours) were of greater influence on the estimated caloric load. The intake of energy, the liveweight, and the temperature of the humid bulb had lower effect. The rest of the variables had little effect on the outcome of the model. The estimation of the original model resulted in an excessive caloric load (from 9.8 to 16.9 Mcal/d), which was little viable biologically, thus, the model was modified in terms of sun radiation according to the day time. Once modified, the estimations were within the range from 1.3 to 4.8 Mcal/d, which was more likeable from the biological point of view.

Key words: *caloric stress, environmental effect, management strategies, heat load.*

The analysis of simulation systems and models has been used to forecast the animal behavior response (Sauvant *et al*. 1996). They both allow studying the performance of the productive systems and of the animals individually, in relation to the management practices, the use of new technologies, and the weather variations (Hirooka 2010). The simulation models are tools that facilitate the making of decisions and permit analyzing the agricultural activities and the new technological alternatives, with the object of determining their viability and defining the necessary conditions for their application (Holmann 2002).

Through the analysis of sensibility of the models, it is verified whether the estimations are adequate (Sauvant *et al*. 1996) or the influence of the different components of the model is known (Ortega *et al*. 2010). In order to know the environmental effect and establish strategies of nutritional management in cattle in heat stress conditions, Mendoza *et al*. (2003) elaborated a deterministic model, with the object of estimating the caloric balance in grazing animals in the humid tropics. This model has not been assessed, although it could have been subject to reconsideration. Thus, the aim of this study was to make a sensibility analysis of the model of caloric balance, with information from grazing cattle. Also, the necessary transformations are proposed to make an adequate biological estimation of the heat load.

Materials and Methods

The model of caloric balance for cattle was used (Mendoza *et al*. 2003), which includes the heat gain and loss (metabolic heat, nitrogen metabolism, radiation, conduction, convection and evaporation). The equations were integrated in an Excel calculation sheet (Microsoft Office 2007), available in the Bioeficiencia Network platform.

Evaluation of the original model. The model was evaluated from the information of assays performed in the humid tropics (Tabasco and Veracruz, Mexico) (tables 1 and 2) with grazing cattle without any supplement (Ramos 1994, Alarcón 1995, Cabrera 1996, Córdova 1996, Reyes 1996, Ramos *et al*. 1998, Cabrera *et al*. 2000, Aranda *et al*. 2001, and Gómez *et al*. 2003). The caloric balance was estimated in each assay to prevent confusions due to type of feed, weather conditions, and characteristics of each animal.

Modifications of the model. The model of Mendoza *et al*. (2003) was modified to incorporate the metabolic heat production associated with the protein metabolism. Thus,

Table 1. Information to estimate the caloric balance

Dried bulb temperature (DBT), °C
Humid bulb temperature (HBT), °C
Dried bulb temperature at night (DBTN), °C
Relative humidity (RH), %
Wind speed (ws), m/s
Sun exposure, h/24 h
Time without sun, h/24 h, caused by clouds
Liveweight (w), kg
Animal surface, m^2
Degradability of the protein, %
Metabolizable energy of the diet, Mcal/kg
Dry matter intake, DMI (kg/d)
Crude protein (CP) %
Total of digestible nutrients (TDN)%
Atmospheric transmitance (AT)
Absorptivity (Asr)

Table 2. Information from experiments in the humid tropics to estimate the caloric balance

Reference	Initial weight	DMI kg	Climate	Latitude	Longitude	Altitude msnm
Ramos (1994)	211	8.10	RH 80 % T 26° Am (f) w (i) g	19º 15'	93º 00'	10
Alarcón (1995)	319	8.20	RH 80 % T 26° Am (f) w (i) g	19° 23’	98° 39’	10
Cabrera (1996)	185	8.54	RH 80 % T 26° Am (f) w (i) g	19° 23’	98° 39’	10
Córdova (1996)	295	6.01	RH 80 % T 25.9° Am (f) w (i) g	19º 15'	93º 00'	10
Reyes (1996)	250	8.62	RH 80 % T 25.9° Am (f) w (i) g	19° 23’	98° 39’	10
Ramos (1998)	211	7.66	RH 80 % T 26.25° Am (f) w (i) g	19º 15'	91º 59'	30
Cabrera (2000)	190	8.20	RH 80 % T 25.9° Am (f) w (i) g	18º 00'	93º 30'	9
Aranda *et al*. (2001)	242	9.13	RH 80 % T 25.9° Am (f) w (i) g	18º 00'	93º 30'	12
Gómez *et al*. (2003)	270	8.80	RH 80 % T 26.2° Am (f) w (i) g	17º 15'	99º 24'	20

DMI: dry matter intake
RH: relative humidity
T: temperature °C
m.a.s.l. above the sea level

the potential weight gain was estimated as based on the protein and energy intake. The second modification was performed to fit the heat load by radiation.

Weight gain by means of the protein. In order to calculate the weight gain by means of the protein, it was obtained first the potential microbial protein synthesis (g/kg DM) based on the energy (PMSe), and, later, the protein (PMSp) through the NRC equations (2000):

PMSe=1.044*TDN*0.92 (1)

PMSp= DEG*CP*0.1 (2)

Where,

DEG = ruminal degradability of the protein, as crude protein percentage

CP = crude protein, %

TDN = total of digestible nutrients, %

The metabolizable protein (MP, g/kg DM) and its total intake (MPI kg/d) were calculated through the dry matter intake (DMI kg/d):

MP = [CP*0.1 (100-DEG)*0.9] + [(PMSp-15)*0.8] (3)

MPI = MP*DMI (4)

The requirement of the metabolizable protein for maintenance (MPm) was estimated based on the liveweight (w) and the metabolizable protein for the gain (MPg). The estimation was made by difference. Then, the daily weight gain was calculated by means of the protein intake (WGp) (Fernández-Rivera *et al*. 1989):

$\text{MPm} = [0.0125*(70.4*w^{0.734})]/0.47$ (5)

MPg = MPI-MPm (6)

WGp = 0.00137*MPg (7)

Weight gain by energy. If the weight gain estimated by intake of protein (WGp) is higher than that calculated by intake of energy (WGe), the protein is not deposited. It is excreted or it is deaminated, which would generate energy cost. On the contrary, the animal obtains gains according to the intake of energy.

The intake of energy was estimated from the equations of NRC (1996). The gross energy for maintenance was calculated (GEm, Mcal/d), as well as the gross energy for gain (GEg, Mcal/d), the intake of dry matter for weight gain (DMIg, kg/d) and the retained energy (RE, Mcal/d) in respect to the metabolizable energy (ME).

$\text{GEm} =1.37\ \text{EM}- 0.138\ \text{EM}^2 + 0.0105\ \text{EM}^3 – 1.12$ (8)

$\text{GEg} = 1.42\ \text{EM} – 0.174\ \text{EM}^2 + 0.0122\ \text{EM}^3 – 1.65$ (9)

The intake of dry matter for maintenance (DMIm) was obtained by dividing the demand of GEm of the animal between the dietary concentration of the ration (GEm). Then, the feed for gain (DMIg) was calculated by difefrence between the feed consumed by day (DMI) and the DMIm:

DMIm kg/d = (GEm Mcal/d) / (GEm ration) (10)

DMIg = DMI-DMIm (11) Fernández-Rivera *et al*. (1989)

RE = DMIg*GEg (12) Fernández-Rivera *et al*. (1989)

The gain estimated by energy intake was calculated in respect to the sweight in kg (w) and of the retained energy (RE):

$\text{WGe} =13.91*w^{-0.6837}*\text{RE}^{0.9116}$ (13)

Based on the calculations of weight gain by intake of protein and energy, the equivalent of metabolizable protein of the tissue (MPd, kg/d) was estimated. With it, the gross energy required for the protein synthesis (GEd Mcal/d) in the model of caloric balance was calculated to determine the caloric heat:

MPd = ((WGe-WGp)/0.00137)/1000 (14)

GEd = 0.72*0.454*MPd (15)

Fit of radiation. The original model was applied to calculate the surface area of the animals. The exponent 0.75 was respected. It was assumed that when the animal is standing, it has 50 % of its surface exposed to the radiation (A). Nevertheless, it occurs differently when lying down, because the surface area of exposure is reduced. Therefore, the gain of radiant heat (Sr) changes and it can be estimated with the following equation:

Sr=(SR*0.5A*Asr*Gt)+(SR*(0.5A*0.5)*Asr*TD*0.26) (16)

Where,

SR = sun radiation

Asr = animal absorptivity for the solar infrared radiation (0.5, 0.8 or 0.9 for white, red and black)

Gt = grazing time, h

RT = resting time, h

The factor of 0.26 corresponds to a fit of 26 % of radiation reduced by shade effect.

The model also establishes a constant of 1200 kcal/h of sun radiation. However, this datum is variable due to the weather changes during the day time. If the solar angle is considered according to the time, the azimuth is presented at 12:00 p.m., when this angle is equivalent to zero (Jaramillo 1998) and the sun rays are direct. At this time, the radiation is of 1200 kcal/h and it is modified at 15° per hour, being positive to the West and negative to the East (Jaramillo 1998). The formula for the solar radiation was added to the calculation, according to the day hour (SRH):

SRH = 1200-(H°(1200/A°)) (17)

Where,

H° = angle hour.

A° = degrees needed to obtain an exchange value, since 1200 up to zero radiation, which corresponds to the solar azimuth when the solar angle is 0, and it is the database of the model that in conjunction fits the radiation.

The calculation of solar radiation is estimated as:

SR = SRH•AT (18)

Where,

AT = atmospheric transmittance (0.7 to 0.35 for clear sky or cloudy conditions, respectively). The modified model is available in the platform of the Bioeficiencia Network.

Analysis of sensibility. The analysis of sensibility was performed according to the procedures of Ortega *et al*. (2010) from a group of simulations. The environmental variables were modified (temperature of the dried and humid bulb, relative humidity, wind speed, sun exposure and not sun) and animals (liveweight, intake of dry matter, protein and total of digestible nutrients). The ranges were from five to five, for the temperature of the humid bulb (HBT), dried (DBT) and relative humidity (RH). For the sun exposure they were 0.3 in 0.3; 1 in 1 clear time; 50 in 50 for liveweight (LW). For the intake of dry matter (DMI) and protein, of 1 in 1, and of 5 in 5 for TDN. For each variable, between seven and ten simulations were conducted permitting to evaluate the adequate range of biological values. Constant intervals, from low to high values, were used. For each rise in the input value, a change in the output value of the response variables was obtained dividing by the constant value. The change can be negative, zero, or positive (Δ CB).

Results

Evaluation of the original model. The estimations of the caloric balance (table 3) evidenced that the animals had heat stress in all the experiments. This was reflected in the caloric load estimated during them. The highest value was of 19.06 Mcal/d, affected mainly by the radiation, 17.75 Mcal/d for the heat gain, and

Table 3. Daily heat balance average calculated with the original model, from experimets performed in the humid tropics

	Heat gains Mcal/d			Heat losses Mcal/d				CB Mcal/d
	MH	NM	Radiation	Radiation	Conduction	Convection	EV	
Ramos (1994)	5.42	0.26	13.02	-2.22	-0.17	-0.02	-5.2	11.09
Alarcón (1995)	9.7	0.06	17.75	-3.03	-0.22	-0.01	-5.2	19.06
Cabrera (1996)	5.34	0.05	11.80	-2.01	-0.15	-0.02	-5.2	9.80
Córdova (1996)	9.23	0.24	16.74	-2.86	-0.21	-0.01	-5.2	17.93
Reyes (1996)	7.53	0.06	14.78	-2.52	-0.18	-0.01	-5.2	14.44
Ramos (1998)	7.63	0.56	13.02	-2.22	-0.17	-0.02	-5.2	13.59
Cabrera (2000)	6.05	0.24	16.74	-2.86	-0.15	-0.02	-5.2	10.99
Aranda *et al*. (2001)	8.24	0.02	12.03	-2.46	-0.18	-0.01	-5.2	14.83
Gómez *et al*. (2003)	8.61	0.06	15.66	-2.67	-0.19	-0.01	-5.2	16.95

MH: metabolic heat

NM: nitrogen metabolism

EV: evaporation

CB: caloric balance

Table 4. Caloric balance through the original model in respect to the modified

	Original model			Modified model		
	Alarcón 1995	Cabrera 1996	Córdova 1996	Alarcón 1995	Cabrera 1996	Córdova 1996
	Mcal/d	Mcal/d	Mcal/d	Mcal/d	Mcal/d	Mcal/d
Heat gains						
MH	9.70	5.34	9.23	5.82	3.73	5.75
NM	0.06	0.05	0.24	0.06	0.05	0.24
Radiation +	17.75	11.80	16.74	7.02	4.67	6.62
Heat losses						
Radiation -	-3.03	-2.01	-2.86	-2.71	-1.80	-2.56
Conduction	-0.22	-0.15	-0.21	-0.38	-0.27	-0.36
Convection	-0.01	-0.02	-0.01	-0.01	-0.02	-0.01
EV	-5.20	-5.20	-5.20	-5.01	-5.01	-5.01
CB	19.06	9.80	17.93	4.80	1.36	4.68

MH: metabolic heat
NM: nitrogen metabolism
EV: evaporation
CB: caloric balance

Table 5. Analysis of sensibility of the variables modifying the caloric balance

Variable	Unit	Increment units[1]	Δ CB
DBT	°C	5.0	-0.2679
HBT	°C	5.0	0.1769
DBTN	°C	5.0	0.0169
RH	%	5.0	0.0118
WS	m/s	0.3	-0.0489
SE	h/24 h	1.0	1.4913
TWS	h/24 h	1.0	-1.4913
LW	kg	50.0	0.1169
DMI	kg	1.0	0.0454
CP	%	1.0	0.0874
TDN	%	5.0	0.1581

DBT: dried bulb temperature
HBT: humid bulb temperature
DBTN: dried bulb temperature at night
RH: relative humidity
Ws: wind speed
SE: sun exposure
TWS: time without sun
LW: liveweight
DMI: dry matter intake
Δ CB: change of caloric balance

[1] The criterion used in the increment range was established until obtaining a sufficient number of simulations to evaluate the range of adequate biological values

-3.03 Mcal/d for the losses.

Modifications of the model. The caloric balance estimated with the model of Mendoza *et al*. (2003) showed values keeping the cattle in severe heat stress, which could compromise the homeostasis. When considering the analysis of sensibility and revising the equations of the model, it was modified to obtain closer estimations from the biological point of view, which could occur in reality. The greatest limitation of the model was in respect to the estimation of the caloric load by radiation.

Table 4 shows the estimation of the caloric balance of the modified and the non-modified model. There was change in the estimation of values such as the radiation

(17.75 to 7.02 Mcal/d) and the metabolic heat (9.70 to 5.82 Mcal/d). The maximum point of radiation was attained at 12:00 p.m. There were longer days, with higher radiation during the spring and the summer.

Analysis of sensibility. Table 5 presents the results of the analysis of sensibility, the units in which each variable was expressed, as well as the common value, which is the change of the variable. The values of zero, or next to it, show that the variables have null or low effect for the estimations. The positive or negative show that the variables respond in direct or inversely proportional manner, in respect to the rise of the value, respectively. The factors related to the radiation (exposure to the sun or time without exposure to the radiation) had higher effect on the sensibility of the model and generated modifications in the caloric balance, but with the same intensity.

If the animal receives the solar radiation from certain angle, the amount that can receive or not is the same. The variables liveweight of the animal and the total of digestible nutrients have greater effect on the model in respect to the intake of dry matter and crude protein. This is possibly due to the fat that at larger size of the animals, the intake of dry matter per kilogram of metabolic weight is lower. In the heat generation, the digestibility of the nutrients was important.

Discussion

The use of the model demonstrates that the metabolic heat is the second most important factor that produces caloric gains. This is due to the feeding processes, where the nutritional factor seems to be that of greatest importance for the productivity, thereby demanding an adequate and strategic utilization of the nutrients (Mills *et al*. 2001, and Williams and Jenkins 2003). This response is manifested in changes in the water and energy allowances, which modify the feed intake (Beatty *et al*. 2006) because they are related to the caloric balance in the animal (Foster *et al*. 2009). If a balance is attained between these factors, the caloric stress associated with the digestive processes can be reduced.

In the heat losses, the values of conduction and convection are lower than those of radiation and evaporation for all the experiments, due to the thermoregulation is determined by factors such as the absorption (solar radiation or metabolic heat) and heat loss (Brosh 2007). These factors require the existence of thermal gradients that are not always present, and that modify the animal behavior with the aim of reducing the heat capture. Therefore, when the animal temperature increases, it avoids the absorption of heat by effect of the solar radiation (Mader *et al*. 2002). Thus, the sun exposure is evaded, that is, the exposed surface is reduced and its orientation is modified in respect to the wind direction. At the same time, mechanisms of heat dissipation are activated, such as the rise in the respiratory frequency to release larger amount of hot air (Brosh *et al*. 1998).

The evaporation was the highest factor in the heat losses, which agreed with De Dios (2001), who noted that it represents 84 % of the total heat losses. However, there were not differences of evaporation between the experiments. This could be, possibly, due to the combination of the climatic and dietary conditions to which the animals were exposed and to their characteristics, which provoked a similar evaporation response. In this instance, the response of the organism to the

The radiation tends to increase the caloric load in large proportion, as a consequence from the overestimation of this factor. Maquivar *et al*. (2006) noted that by using any model of simulation, the lack of accuracy in the forecast can be associated with the information input, the equations incorporated to the model and the design for the adequate climate.

The fits resulted in lower estimated caloric load, whether from the metabolic heat or from the radiation. Brosh *et al*. (1998) proved that the metabolic heat can be more important than that provoking the radiation; thus, the fit of the model represents better the conditions that can occur naturally. In tropical conditions, for an organism keeps its homeostasis at the end of a 24-h period, it has to end up with a low caloric load to survive. Therefore, it is considered that the fits of Mendoza *et al*. (2003) permitted improving the model, because the one that was not modified obtained biologically incorrect values. The analysis of sensibility showed overestimation of the absorbed heat by sun exposure, which was evidenced in the application of the model. Nevertheless, by making the previous modifications, the estimation of the radiation was reduced, which provided better estimation of the caloric balance of the animal.

In respect to the sensibility analysis (table 5), for the negative values such as the temperature of the dried bulb (DBT), wind speed (ws) and time without sun (TWS), there was decline in the value, indicating that there is reduction of the heat production. For instance, by increasing the TWS, the solar radiation that reaches the animals is lower. West *et al*. (2003) mentioned that factors such as the environmental temperature, the radiant energy, the relative humidity, and the wind speed contribute to the drop or rise of the caloric stress.

The modified model evidenced that the SE, TWS, DBT and TDN are the factors affecting the most the caloric balance in cattle in tropical conditions. They permit a more exact and accurate estimation from the biological point of view in respect to the original model that overestimates the impact of the climatic values.

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