Prediction of water intake to *Bos indicus* beef cattle raised under tropical conditions¹

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ABSTRACT: Water is the most important nutrient in animal nutrition; however, water intake is rarely measured. The objective of this study was to determine whether previously published water intake (WI) equations for beef cattle would accurately predict WI from four experiments conducted under tropical conditions. The experiments were conducted from 2013 to 2015. Nellore (*Bos indicus*) growing bulls (Exps. 1, 2, and 3) and heifers (Exp. 4) were used in the feedlot trials. In all experiments, animals were fed for ad libitum DMI. The WI, animal performance, diet composition, and environmental data were collected. The prediction of WI using the current published WI equations was evaluated by regressing predicted and measured WI values. The regression was evaluated using the two-hypothesis test: H0: $\beta_0 = 0$ and H0: $\beta_1 = 1$ and Ha: not H0. If both null hypotheses were not rejected, it was concluded that the tested equation accurately

estimated WI. To develop a WI prediction equation based on the input variables, a leave-one-out cross-validation method was proposed. The proposed equation was evaluated using similar methodology described above. All previously published eight equations overestimated WI of cattle used in the four experiments conducted in southeast Brazil. A possible explanation for the overestimate of WI is that previously published WI equations were generated from data collected from predominantly *Bos taurus* cattle raised under temperate climates. From the data collected from experiments conducted with Nellore cattle in southeast Brazil, the proposed equation ($WI = 9.449 + 0.190 \times MBW + 0.271 \times T_{MAX} - 0.259 \times HU + 0.489 \times DMI$, where the MBW is the metabolic BW ($kg^{0.75}$), T_{MAX} is the maximum temperature ($^{\circ}C$), HU is the humidity (%) and DMI in kg/d), more accurately predicts WI of cattle raised under tropical conditions.

Key words: environmental parameters, feed intake, Nellore, water intake

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J. Anim. Sci. 2019.97:1364–1374

doi: 10.1093/jas/skz003

¹Financial support for this research was provided by National Council of Scientific and Technological Development (CNPq), Coordination of Superior Level Staff Improvement (CAPES), National Institute of Science and Technology in Animal Science (INCT-Ciência Animal), and Foundation for Research Support of the State of Minas Gerais (FAPEMIG).

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Received September 7, 2018.

Accepted January 11, 2019.

INTRODUCTION

Beef production systems require a considerable amount of water. Beckett and Oltjen (1993) reported an estimate of 3,682 liter/kg of boneless meat production in the USA. Mekonnen and Hoekstra (2012) reported that beef cattle demands one-third of the global water footprint of animal

production. Drinking water is an important component of total water demands, water intake (WI) ranges from 8.0% to 9.8% of BW (Ahlberg et al., 2018). However, droughts negatively impact livestock production across of the world (Ward and Michelsen, 2002; Pluske and Schlink, 2007). Research aiming to increase the efficiency of water use for livestock production has been encouraged (Tilman et al., 2002; Rijsberman, 2006); however, research evaluating the amount of free drinking water used by beef cattle remains limited (Araujo et al., 2010; Brew et al., 2011).

Accurate prediction of WI by cattle enables producers to determine water demands, and consequently, ensure water availability for animals. Several factors that affect WI are known to exist in beef cattle, such as climatic variables, type of diet, breed, BW, and physiological status. The most recent report examining factors that influence WI in feedlot cattle was published by Ahlberg et al. (2018), confirming the importance of environmental parameters and BW on WI prediction.

To our knowledge, there has not been an equation developed to predict WI of beef cattle raised under tropical conditions, where the majority of cattle are raised globally (FAS/USDA, 2017). Therefore, the hypothesis was that the current published equations to predict WI in beef cattle are not applicable to animals raised in tropical areas. Thus, the objective of this study was to evaluate the accuracy of current WI equations for beef cattle and, if needed, propose a new equation to predict WI of beef cattle raised under tropical conditions.

MATERIAL AND METHODS

Current WI Predictions

Several WI prediction equations/recommendations were reported in the literature. The NRC (2000) recommended the equation proposed by Hicks et al. (1988) for WI prediction. The model proposed by Hicks et al. (1988) was developed from two studies, the first one with three dietary salt (DS) levels (0%, 0.25%, and 0.50%) and the other one with rotational feeding of lasalocid and monensin. Both trials were conducted during summer, at Oklahoma, using crossbred yearling steers. Daily WI was recorded by group. On the proposed equation, WI (L/d) is a function of maximum temperature (T_{MAX} , °F), DMI (kg/d), precipitation (PP, mm), and DS (%), as follows:

$$WI = -18.67 + 0.3937 \times T_{MAX} + 2.432 \times DMI + 3.87 \times PP - 4.437 \times DS \quad (1)$$

In addition to the equation proposed by Hicks et al. (1988), the National Academies of Sciences, Engineering, and Medicine (NASEM, 2016) reports two equations (eqs. 2 and 3) proposed by Arias and Mader (2011), as follows:

$$WI_{AM[1]} = 5.92 + 1.03 \times DMI + 0.04 \times SR + 0.45 \times T_{MIN} \quad (2)$$

$$WI_{AM[2]} = -7.31 + 1.00 \times DMI + 0.04 \times SR + 0.30 \times THI \quad (3)$$

where $WI_{AM[1]}$ and $WI_{AM[2]}$ are the water intake in L/d, predicted by eqs. 2 and 3, respectively, SR is the solar radiation (W/m²), T_{MIN} is the minimum temperature in °C; and THI is the temperature humidity index. THI is calculated using the equation adapted from Thom (1959) that utilized the percentage of relative humidity (HU) and the average temperature (T_{AVG} , °C), as follows: $THI = 46.4 + 0.8 \times T_{AVG} + (HU \times (T_{AVG} - 14.4) / 100)$.

Both equations proposed by Arias and Mader (2011) were developed from data collected in seven experiments conducted at Nebraska. These experiments utilized predominantly Angus or Angus crossbreed steers and heifers. Daily WI was obtained by the quotient between total WI and the number of animals who have access to the waterer.

For moderate climates, Meyer et al. (2006) measured WI of German Holstein bulls over 282 d in an experiment, conducted at Germany. Experimental diets were based on CP content (i.e., 102, 117, and 135 g CP/kg DM) and type of supplement (i.e., soybean or peas-based supplements). Individual WI was recorded from the difference between the mass of the waterer before and after each drinking. In the equation reported by Meyer et al. (2006), WI is a function of T_{AVG} (°C), DMI (kg/d), dietary forage content (DF, %), percentage of DM of forage (DMF), and BW (kg), as described on the following model:

$$WI = -3.85 + 0.507 \times T_{AVG} + 1.494 \times DMI - 0.141 \times DF + 0.248 \times DMF + 0.014 \times BW \quad (4)$$

CSIRO (2007) recommended WI prediction according to DMI and TAVG. Estimates of WI for cattle at lower than 15, equal to 20, 25, and 30,

and $>35^{\circ}\text{C}$, expressed as L/kg of DMI, are, respectively, 3.0, 3.5, 4.5, 6.0, and 8.0 for *Bos indicus*. These estimates were based on water turnover by cattle and the report of Winchester and Morris (1956), who measured WI of cattle over a range of 4 to 38°C in Australia.

Sexson et al. (2012) proposed an equation to predict WI based on average, maximum, and minimum relative humidity (HU, HU_{MAX} , and HU_{MIN} , respectively, %), T_{MAX} ($^{\circ}\text{C}$), minimum temperature (T_{MIN} , $^{\circ}\text{C}$), average, maximum and minimum sea level pressure (SLP, SLP_{MAX} , and SLP_{MIN} , respectively, mmHg), wind speed (WS, m/s), maximum temperature on the previous day ($T_{\text{MAX.PREV}}$, $^{\circ}\text{C}$), and metabolic BW (MBW, $\text{kg}^{0.75}$) parameters, as follows:

$$\begin{aligned} \text{WI} = & -14.07 + 0.163 \times \text{HU} - 0.0017 \times \text{HU}^2 \\ & + 0.0096 \times T_{\text{MAX}}^2 - 0.00032 \times \text{HU}_{\text{MAX}}^2 \\ & + 1.01 \times T_{\text{MIN}} - 0.026 \times T_{\text{MIN}}^2 + 0.038 \\ & \times \text{HU}_{\text{MIN}} + 0.396 \times \text{SLP} - 0.055 \times \text{WS} \\ & - 1.395 \times \text{BW} - 0.249 \times \text{SLP}_{\text{MAX}} - 0.411 \\ & \times \text{SLP}_{\text{MIN}} + 0.0012 \times T_{\text{MAX.PREV}}^2 \\ & + 8.79 \times \text{MBW} \end{aligned} \quad (5)$$

Data to build the model proposed by Sexson et al. (2012) were compiled from four experiments conducted in Colorado. Data collection was performed from April to October depending on the study in the years of 2001, 2003, 2004, and 2007. In both experiments, cattle from two pens used each waterer. Daily WI was calculated by the quotient between daily water flowing into each waterer and the number of steers who had access to the waterer.

Recently, Ahlberg et al. (2018) proposed five equations to predict WI, based on season (winter and summer) and bunk management protocols. Crossbreed and Angus steers were divided into five groups, which allowed data collection during winter and summer. Each group was fed ad libitum or slick bunk management. Both equations are using DMI, MBW, T_{AVG} , HU, WS, and SR. The equation chooses were made according to the tropical climate and usual bunk management in Brazil (ad libitum, Oliveira and Millen, 2014), as follows:

$$\begin{aligned} \text{WI}_{\text{ad libitum}} = & 0.71 + 2.63 \times \text{DMI} - 0.009 \\ & \times \text{MBW} + 0.76 \times T_{\text{AVG}} - 0.06 \\ & \times \text{HU} + 0.23 \times \text{SR} - 0.11\text{WS} \end{aligned} \quad (6)$$

$$\begin{aligned} \text{WI}_{\text{summer}} = & -9.74 + 2.32 \times \text{DMI} + 0.11 \\ & \times \text{MBW} + 1.31 \times T_{\text{AVG}} - 0.17 \\ & \times \text{HU} - 0.03 \times \text{SR} - 0.27\text{WS} \end{aligned} \quad (7)$$

WI Measurement

WI data were collected from four experiments using Nellore cattle (Prados et al., 2017, Zanetti et al., 2017, and two unpublished experiments). All experiments were performed in Southeast Brazil and followed the recommendations of the Ethics Committee for Animal Use and Care of Federal University of Viçosa (protocol numbers CEUAP/DZO/UFV 20/2013, 17/2015, 59/2016, and 15/2017).

In Exp. 1 (from July to December 2013; Prados et al., 2017), 32 bulls (274 ± 34 kg, 8 mo) were randomly divided into four groups of eight animals. Each group was fed sugarcane-based diets, with 600 g/kg concentrate on a DM basis. The concentrate composition and dietary nutrients of the diets are given in Supplementary Table 1. The treatments were based on the supplementation or not of inorganic sources of calcium (Ca) and phosphorus (P), and MM further to the basal diet. In Exp. 2 (from July to November 2014; Zanetti et al., 2017), 42 Nellore bulls (270 ± 36 kg, 8 mo) were randomly assigned to one of six treatments in a 3×2 factorial design, with three types of diets and supplementation or not of Ca, P, and MM. The three types of diets were: (i) sugarcane (400 g/kg) as roughage source with a soybean meal–soybean hull concentrate mix, (ii) sugarcane (400 g/kg) as roughage source with a soybean meal–ground corn-based concentrate mix, and (iii) corn silage (600 g/kg) as roughage source with a soybean meal–ground corn-based concentrate mix. The concentrate composition and dietary nutrients of the diets are given in Supplementary Table 2. In Exp. 3, 42 Nellore bulls (260 ± 8 kg, 8 mo) were randomly divided into six groups of seven animals. Each group was fed corn silage-based diets, with inclusion of 500 g/kg concentrate on DM basis. Each group was randomly assigned to one of the following treatments, 105, 125, or 145 g CP/kg DM at static or oscillating levels. The concentrate composition and dietary nutrients of the diets are given in Supplementary Table 3. In Exp. 4, 16 Nellore heifers (377 ± 49 kg, 16 mo) were randomly divided into four groups of four animals. Each group was fed sugarcane or elephant grass for 77 d (from February to April 2015), with or without 400 g/kg DM concentrate consisting of

450 g/kg soybean hulls, 462 g/kg corn grounded, 68 g/kg soybean meal, 10 g/kg commercial premix mineral, 10 g/kg salt on DM basis. The dietary nutrients of the diets are given in [Supplementary Table 4](#).

For all experiments, each treatment was housed in a feedlot pen (48 m²), with one electronic feeder (Model AF-1000 Master, Intergado Ltd, Contagem, Minas Gerais, Brazil) and one waterer (Model WD-1000 Master, Intergado Ltd, Contagem, Minas Gerais, Brazil) per pen. Prior to the beginning the experiments, each animal was fitted with an ear tag containing a unique passive transponder (FDX-ISO 11784/11785; Allflex, Joinville, Santa Catarina, Brazil) in the left ear. The Intergado monitoring system was used to evaluate individual feed and WI. For each visit to the feed bunk or waterer, the system recorded the animal ID, and initial and final weights, from which the Intergado system (Intergado Ltd., Contagem, Minas Gerais, Brazil) calculate the weight of the feed or water consumed. These data were continuously recorded and transferred via a network cable to the Intergado web software for data capture and storage ([Chizzotti et al., 2015](#)).

The waterers were manually cleaned once a week, by scrubbing them with a brush and then replacing the water. Water level was automatically filled by the equipment. All the waterers (Model WD-1000 Master, Intergado Ltd., Contagem, Minas Gerais, Brazil) are connected to a scale, allowing the voluntary weighing of the animals at each drinking event. The electronic system generates the average BW per animal per day, and this value of daily BW was used to calculate MBW.

Total mixed ration was provided twice a day, at 0700 and 1600 hours. The feeders were managed to provide ad libitum intake. All feedstuffs were sampled daily. The samples were oven-dried at 55 °C for 72 h, ground in a knife mill with a 1-mm screen and were analyzed for DM content (method 934.01; [AOAC, 2012](#)). Environmental variables were collected in an automatic weather station (model MAWS301, Brand Vaisala) of National Institute of Meteorology installed 700 m from the experimental feedlot (latitude: -20.7626°, longitude: -42.8640°, and elevation from sea: 698 m). All data were organized by animal and by day on a spreadsheet (Microsoft Excel, Microsoft, Inc., Seattle, WA), and WI was calculated by equation. At the end, the number of predicted WI equals the number of animals multiplied by the number of days of each experiment.

WIs, estimated by the equations proposed in the literature, were compared with the actual WI values collected in the four experiments conducted south-east Brazil using the following regression model: $Y = \beta_0 + \beta_1 \times X$, where Y was the observed value; β_0 and β_1 were the intercept and slope of regression, respectively; and X was the predicted value. The regression was evaluated using the two hypothesis test: $H_0: \beta_0 = 0$ and $H_0: \beta_1 = 1$ and H_a : not H_0 . If both null hypotheses were not rejected, it was concluded that the tested equation accurately estimated WI. Moreover, the mean square error of prediction (MSEP; [Bibby and Toutenburg, 1977](#)) was also computed to assess the accuracy of the WI prediction equations. These analyses were performed using the MES (Model Evaluation System Software, version 3.1.13; [Tedeschi, 2006](#)).

Predictor Variables and WI Prediction from Data Collected in Southeast Brazil

All variables used in eqs. 1 to 7 to predict WI were adopted as possible predictor variables of the proposed equation. The correlation between measured WI and each variable, and among variables were determined. The correlation between variables and WI was used to determine if the variable was to be included in the prediction equation. Once the correlation between two variables was significant, only the variable with strongest correlation with WI was utilized as a predictor variable.

To develop a WI prediction equation based on the input variables, a leave-one-out cross-validation method was proposed. Without loss of generality for each variable, the dataset with 132 individuals was divided into 132 new data sets (D_k) with 131 individuals, $D_1, D_2, \dots, D_{132}$. Each index k in this data set notation indicates that the k th observation was removed. Linear regression models were fitted separately for each D_k , which represents the estimated intercept and slope from each model. Thus, at the end of this process, empirical distributions and coefficients of determination containing 132 values were obtained for these parameters. The means of the parameter distributions were assumed as the coefficients of the prediction equations. A linear regression analysis was performed using the REG procedure in the SAS software (SAS Inst. Inc., Cary, NC).

To validate the proposed equation, new data were collected from 42 Nellore young bulls (10 mo, initial BW = 299 ± 32 kg) from August to October 2017. The experiment was performed following the recommendations of the Ethics

Committee for Animal Use and Care of Federal University of Viçosa (protocol number 23/2017). On this experiment, the inclusion of additives (sodium bicarbonate + magnesium oxide, monensin, virginiamycin, virginiamycin + monensin, lasalocid, and Crina RumiStar) to diet was evaluated. Each group was fed corn silage-based diets, with 70% of concentrate on a DM basis. The concentrate composition is given in [Supplementary Table 5](#). Animal and environmental variables (WI, BW, DMI, T_{MAX} , and HU) were collected with aid of electronic feeders and waterers, and automatic weather station, respectively, in the same way as previously described for Exp. 1 to Exp. 4. Similarly, the comparison between predict and measured values was performed using the MES (Model Evaluation System Software, version 3.1.13), and adopting H0 previously described.

RESULTS AND DISCUSSION

Evaluation of Current Equations to Predict WI in Cattle Raised Under Tropical Conditions

WI was overestimated ([Table 1](#), [Figures 1](#) and [2](#)) by the previously published WI equations (eqs. 1 to 7) when compared to the actual WI observed in Nellore cattle raised under tropical conditions. The climate conditions of where these equations were developed may help to explain why the prediction

is not accurate. In general, beef production on tropics is conditioned to high temperatures, with small daily oscillation, and elevated humidity and precipitation.

Differences between predicted and observed values may be, also, explained by cattle genetics. Equations 1 to 7 were built from databases with predominantly *Bos taurus* cattle, while *Bos indicus* cattle, such as Nellore, are predominant under tropical conditions ([Oliveira and Millen, 2014](#)). Some studies ([Ittner et al., 1951](#); [Winchester and Morris, 1956](#); [Valente et al., 2015](#)) have reported greater WI for *Bos taurus* cattle than for *Bos indicus* cattle raised in similar conditions. This may be one reason why WI was overestimated: data collected to build the evaluated models were collected from *Bos taurus* cattle, except the equation proposed by [CSIRO \(2007\)](#). Furthermore, [Sexson et al. \(2012\)](#) reported a contribution of Brahman, in the genetic composition of the animals used in their experiment. However, their equation overestimated WI by 253% in cattle raised under tropical conditions ([Table 1](#)). Several factors may help to explain the greater WI for *Bos taurus*. These factors mainly related to body thermal homeostasis. [Hansen \(2004\)](#) reported a greater level of acclimation to heat stress for *Bos indicus*, which is probably related to the distinct climates where these species were developed. This indicates that during genetic adaptations, *Bos indicus* may have acquired thermoregulatory

Table 1. Parameters of regression and accuracy between the estimates of water intake from equations in the literature and observed values of water intake for Nellore cattle in feedlot under tropical conditions

Item	Observed	Estimated according to ¹							
		A	B	C	D	E	F	G	H
Average, kg	16.7	36.2	23.7	27.3	36.6	35.1	44.6	31.3	31.4
Standard deviation	6.49	27.52	3.50	6.36	6.39	6.27	6.89	4.42	6.02
Minimum, kg	0.6	13.9	4.1	5.3	16.9	16.3	4.4	12.7	7.6
Maximum, kg	55.6	396.4	41.7	79.4	53.1	51.7	58.8	61.7	60.0
<i>Regression parameters</i>									
Intercept	—	17.65	−1.45	5.78	−1.08	−1.16	−0.62	−2.73	−0.24
P-value	—	<0.001	0.394	<0.001	0.860	0.306	0.510	<0.001	0.554
Slope	—	−0.03	0.76	0.40	0.49	0.51	0.39	0.62	0.54
P-value	—	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
MSEP ²	—	1,471.8	71.4	161.9	378.0	379.8	732.7	251.2	255.7
Mean bias	—	464.9 (31.6%)	37.2 (52.1%)	99.4 (61.4%)	335.6 (88.8%)	335.7 (88.4%)	670.1 (91.5%)	213.8 (85.1%)	216.4 (84.6%)
Systematic bias	—	968.5 (65.8%)	2.1 (2.9%)	29.6 (18.3%)	11.6 (3.1%)	13.3 (3.5%)	31.9 (4.3%)	4.3 (1.7%)	7.7 (3.0%)
Random error	—	38.4 (2.6%)	32.1 (45.0%)	32.9 (20.3%)	30.8 (8.1%)	30.8 (8.1%)	30.7 (4.2%)	33.1 (13.2%)	31.6 (12.6%)

¹/ A: values predicted by [Hicks et al. \(1988\)](#); B: values predicted by [Meyer et al. \(2006\)](#); C: values predicted by [CSIRO \(2007\)](#); D: values predicted by [Arias and Mader \(2011\)](#)—eq. 1; E: values predicted by [Arias and Mader \(2011\)](#)—eq. 2; F: values predicted by [Sexson et al. \(2012\)](#); G: values predicted by [Ahlberg et al. \(2018\)](#) for ad libitum; H: values predicted by [Ahlberg et al. \(2018\)](#) for summer.

²/MSEP = mean square error of prediction.

Figure 1. Comparisons between predicted and observed water intake for Nellore cattle in tropical conditions. The dotted line represents the equality line, a point in this line represents similar values to predicted and observed water intakes. A: values predicted by eq. 1; B: values predicted by eq. 2; C: values predicted by CSIRO (2007); D: values predicted by eq. 3.

characteristics, reducing the dependence on mechanisms involving water to alleviate heat stress, such as lower basal metabolism rates and skin properties (Hansen, 2004).

Additionally, the negative coefficient to dietary salt in relation to WI prediction on the equation proposed by Hicks et al. (1988) may help to explain the reason for the observed overestimation of WI by this equation. For dairy cattle, WI is positively related with dietary sodium composition (Murphy et al., 1983), dietary potassium (Fraley et al., 2015), and dietary ash (Appuhamy et al., 2014), all of which, may be correlated to increased osmotic pressure in the rumen by dietary salt (Rogers et al., 1979). Similarly, the concentration of total dissolved salts in water has been reported to increase WI by cattle (Alves et al., 2017). A second factor may contribute

to the overestimate WI from the equation proposed by Hicks et al. (1988): for each millimeter of rain, WI increases in 3.84 L. Under tropical conditions, high volume of rain is common, which contributes to overestimate WI (Figure 1A).

In addition to the factors cited, the influence of cattle's individual metabolism and behavior are not well known. As an example, Table 2 reports minimum WI for Exp. 1 to Exp. 5 to be 0.6 kg/d, which appears low. Similarly, Meyer et al. (2006) and Ahlberg et al. (2018) reported minimum WI to be zero, or close to that, respectively. Meyer et al. (2006) reported low minimal values of WI in consequence of temporary health problems. However, health disorders were not verified in any of the experiments utilized in this study. Consequently, NASEM (2016) reported that its impossible to list

Figure 2. Comparisons between predicted and observed water intake for Nellore cattle in tropical conditions. The dotted line represents the equality line, a point in this line represents similar values to predicted and observed water intakes. E: values predicted by eq. 4; F: values predicted by eq. 5. G: values predicted by eq. 6; H: values predicted by eq. 7.

water requirements accurately due the number of factors affecting WI.

Prediction of WI

Among all measured variables in the current experiment, those related to BW, DMI, temperature, and humidity present greater correlation with WI, and were selected to predict WI to cattle raised under tropical conditions, using the following equation:

$$\begin{aligned} \text{WI} = & 9.449 + 0.190 \times \text{MBW} + 0.271 \\ & \times T_{\text{MAX}} - 0.259 \times \text{HU} + 0.489 \times \text{DMI} \end{aligned} \quad (8)$$

where the MBW is the metabolic BW in $\text{kg}^{0.75}$, T_{MAX} is the maximum temperature in $^{\circ}\text{C}$, HU is the humidity in %, and DMI in kg/d . The correlation

between WI and MBW, T_{MAX} , HU, and DMI were 0.25, 0.51, -0.41 , and 0.14, respectively. The summary descriptive statistics of these parameters for each experiment is shown in Table 2.

The proposed equation predicted WI accurately ($P \geq 0.577$, Table 3 and Figure 3). Estimated average WI was 18.2 kg/d vs. an observed WI of 17.9 kg/d . Regarding the mean square error of prediction, 99.6% was involved to the random error, showing the accuracy of prediction.

The effects of the selected variables in the changes of WI have been well described in the literature. Furthermore, all previously published WI prediction equations use DMI or BW as a predictor of WI (Bond et al., 1976; Kramer et al., 2009). Moreover, all equations included temperature, or parameters derived from temperature, as a partial component of an equation to predict WI. The

Table 2. Summary descriptive statistical of animal's and environmental parameters for each experiment

Variables	Exp. ¹	Mean	Standard deviation	Maximum	Minimum
Water intake, kg/d	1	17.0	7.86	55.6	2.0
	2	17.2	5.94	39.7	0.6
	3	12.4	7.28	47.9	2.0
	4	16.7	6.14	45.0	3.0
	5	17.9	6.31	43.7	0.8
DMI, kg/d	1	7.5	1.67	16.3	1.5
	2	7.0	1.68	17.6	1.8
	3	6.5	2.45	14.5	2.0
	4	7.6	1.02	10.0	5.0
	5	7.5	1.35	10.9	3.8
Metabolic BW, kg ^{0.75}	1	80.9	9.25	106.3	56.1
	2	83.5	11.90	111.3	55.2
	3	76.1	5.46	90.0	66.9
	4	89.9	8.69	113.5	46.6
	5	82.3	8.50	106.9	56.5
Maximum temperature, °C	1	27.0	3.74	35.9	17.5
	2	26.0	3.37	34.6	17.6
	3	26.6	2.68	31.3	19.4
	4	21.2	2.51	26.9	16.2
	5	27.3	3.33	34.2	19.6
Relative humidity, %	1	70.4	10.12	95.0	48.3
	2	76.5	8.36	95.3	36.8
	3	82.8	4.79	94.4	73.1
	4	74.0	8.07	92.2	53.4
	5	68.8	7.74	88.0	43.4

Exp. 1 ($n = 32$): [Prados et al., 2017](#); Exp. 2 ($n = 42$): [Zanetti et al., 2017](#); Exp. 3 ($n = 42$), 4 ($n = 16$), and 5 ($n = 42$): unpublished.

Table 3. Parameters of regression and accuracy between the estimates of water intake from proposed equation and observed values of water intake for Nellore cattle in feedlot

Item	Observed	Estimated
Average, kg	17.9	18.2
Standard deviation	6.31	4.01
Minimum, kg	0.8	8.9
Maximum, kg	43.7	31.7
<i>Regression parameters</i>		
Intercept	—	-0.23
P-value	—	0.577
Slope	—	0.99
P-value	—	0.835
MSEP ¹	—	23.5990
Mean bias	—	0.0992 (0.4%)
Systematic bias	—	0.0003 (<0.1%)
Random error	—	23.5 (99.6%)

¹/MSEP = mean square error of prediction.

relationship between temperature and WI is based on the function of water being used for body temperature homeostasis ([Cunningham et al., 1964](#); [Purwanto et al., 1996](#); [Bewley et al., 2008](#)).

The relationship between body thermal control and WI is attributed to temporary reduction of rumen temperature immediately after WI ([Blackshaw and Blackshaw, 1994](#); [Bewley et al., 2008](#)) and the direct effect of evaporative cooling in the reduction of a thermal load ([Bernabucci et al., 2010](#); [Arias and Mader, 2011](#)). Consequently, reductions in overall heat stress, respiration rate, and skin and rectal temperatures are reported after WI ([Purwanto et al., 1996](#)).

In the current equation, DMI was the predictor with the greatest contribution to increasing WI, which agrees with the equations proposed by [Arias and Mader \(2011\)](#) and [Meyer et al. \(2006\)](#). The reduction of DMI is followed by a reduction in WI ([Bond et al., 1976](#); [Cardot et al., 2008](#); [Kramer et al., 2009](#)). This behavior could be explained by either the ruminal liquid dilution rate ([Adams et al., 1981](#); [Adams and Kartchner, 1984](#)) or the heat increment caused by heat from fermentation and digestion ([Finch, 1986](#)). The rumen is a fermentation and digestion site, and it depends on regular entry of feed and the movement of digesta and microbes to the omasum. The digesta consists of insoluble particles and soluble fractions. However,

Figure 3. Comparison between predicted by the proposed equation and observed water intake for Nellore cattle in tropical conditions. The dotted line represents the equality line, a point in this line represents similar values to predicted and observed water intakes.

the liquid fraction passes into the omasum two to four times faster than insoluble particles (Russel and Hespell, 1981). An increase in the liquid dilution rate is generally followed by an increase in bacterial growth and the flow of nutrients through the gastrointestinal tract. Nevertheless, microbial metabolic activity dissipates free energy as heat during fermentation in the digestive tract, mainly in the rumen (Czerkaski, 1980; Russel, 1981). Bergen and Yokoyama (1977) reported that the loss of heat during the fermentation process varies from 3.0% to 12.0% of the gross energy from feed in ruminants vs. ~1.0% for nonruminants.

Apparently, DMI influences WI as well as WI influences DMI. Cattle fed ad libitum drink more water than slick bunk managed cattle, without effect of climate parameters (Ahlberg et al., 2018). On other hand, when steers have access to water restricted by 80% and 60%, DMI decreased 5% and 23%, respectively (Utley et al., 1970). However, this relation is not consistent and is influenced by several factors, such as ambient temperature, which greater temperature may reduce DMI and increase WI (Kreikemeier and Mader, 2004; NASEM, 2016).

Regarding MBW, BW is initially related to WI due to the relationship between BW and DMI. Thereby, a larger animal consumes more DM and a

greater DMI produces a greater WI, as previously discussed. Furthermore, basal metabolism is nearly proportional to animal BW (Kleiber, 1932), and basal metabolism generates ~33% of heat generated by an animal (Finch, 1986). Consequentially, a larger animal generates more heat from basal metabolism than a smaller animal. Also, within a given physiological maturity, a large animal tends to be fatter than a smaller animal. Body fat acts as insulation and makes it more difficult for a fatter animal to dissipate heat (Finch, 1986; Gaughan et al., 2010). Moreover, peripheral vasodilatation helps to dissipate heat from the core region of the body. However, vasodilatation becomes more difficult with greater BW (Finch, 1986; Silanikove, 2000). Finally, sweat is an important pathway for heat loss in cattle (Ferguson and Dowling, 1955), and the rate of heat loss via sweating depends on the skin surface area for water evaporation (Hansen, 2004). Thus, the relationship between surface area and BW decreases as the animal grows.

Among the environmental variables, HU and T_{MAX} were included in the equation. Berman (2003) reported that heat exchange between the environment and the animal is the main component for body temperature regulation. A high correlation is observed between daily T_{AVG} and T_{MAX} (1.00). The

T_{MAX} was included in the model due this greater correlation with WI than T_{AVG} (0.51 vs. 0.48, respectively). Arias and Mader (2011) also report T_{MAX} as a primary factor which influence WI. These variables have strong interactions with the previous variables described (Bernabucci et al., 2010). Regarding temperature, non-evaporative mechanisms of heat loss decline with the increase of environmental temperature and the animal is dependent on evaporative mechanisms (Silanikove, 2000).

The HU was reported by Blackshaw and Blackshaw (1994) as the major contributor to heat stress in hot climates. At a high HU, water vapor is trapped in the air space between hair and skin and reduces water evaporation, where water diffusion depends on a water pressure gradient (Allen et al., 1970; Renaudeau et al., 2012). In consequence, in an analysis of HU separate from other aspects, in greater HU conditions, water loss via evaporation is reduced and therefore WI is reduced.

In conclusion, current published equations do not accurately predict WI of *Bos indicus* cattle raised under tropical conditions. In this situation, the proposed equation $WI = 9.449 + 0.190 \times MBW + 0.271 \times T_{MAX} - 0.259 \times HU + 0.489 \times DMI$ should be used to more accurately predict WI and improve sustainable usage of water in the tropical production systems.

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