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Prediction of water intake for beef cattle

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INTRODUCTION

The availability of water resources fluctuates globally across regions, and an increasing number of countries, or parts of countries are reaching critical levels of water scarcity (FAO, 2012). In some parts of the world, including Brazil, the effects of water scarcity have already impacted livestock production (Pluske and Schlink, 2007; Ward and Michelsen, 2002). Having Brazil in this reality is alarming, since the country holds the largest reserve of fresh water in the world. It is worth mentioning that this position of Brazil is pointed out as a determining factor for the competitiveness of Brazilian agribusiness (Palhares et al., 2021). Reports from the *Agência Nacional de Águas* (ANA, 2019) indicate that the Brazilian agriculture was responsible for 79.2% of the total water intake, with irrigation responsible for 68.4% and animal production for 10.8%, of which the bovine herd represents 88%. In this scenario, planning an adequate supply of water for cattle becomes even more important, in addition to the drop in animal performance without sufficient water.

This makes research aimed at increasing the efficiency of water use for livestock production to be encouraged (Rijsberman, 2006; Tilman et al., 2002). At the same time, beef production systems require a considerable volume of water. Beckett and Oltjen (1993) reported that 3,682 liters of water are needed to produce one kilogram of beef, considering the volume of drinking water ingested by the animals, the water from the food, the water used in the production of these foods, as well as the water used in the carcass processing.

Of the total water used in beef cattle worldwide, 93.5% corresponds to rainwater (green water), 3.6% to water from rivers and lakes (blue water) and 2.9% corresponds to water needed for dilution of waste to achieve appropriate quality levels for use (gray water) (Mekonnen and Hoekstra, 2012). In Brazil, 98.7% of the water used in livestock comes from rainfall, while only 0.71 and 0.59% correspond to the demand for blue and gray water, respectively (Mekonnen and Hoekstra, 2012). The prevalence of the use of green water in livestock makes meat production systems more sustainable, as it integrates such systems into the natural hydrological cycle, since the portion of water from precipitation can be retained in the soil, evaporate, or even be incorporated into plants and organisms.

Water supplied to drinkers to be ingested is an important component of total water demands, as water intake varies from 8.0 to 9.8% of bovine body weight (Ahlberg et al., 2018). However, research evaluating the amount of drinking water used by beef cattle is still limited (Araújo et al., 2010; Brew et al., 2011). Thus, the inclusion of this chapter in this BR-CORTE update allows the determination of water demands and, consequently, it is possible to guarantee the availability of water for the animals. Thus, this chapter aims to discuss the factors that influence and predict water intake by beef cattle under tropical conditions.

WATER IN THE ORGANISM

Water is as important for the productive performance of animals as protein, energy, minerals, and vitamins. This importance is related to the functions it performs and the proportion in the animal body. Among the functions, water is essential for the hydrolysis of proteins, carbohydrates, and lipids, it is a solvent of amino acids, glucose, minerals, and several vitamins. Water is essential for the process of regulating body temperature, digestion, lactation, general metabolism, and excretion of metabolic wastes. Thus, the importance of water should not be minimized once it corresponds to approximately 70% of the weight of animals (NASEM, 2016).

WATER QUALITY

In addition to the concern about the amount of water available to the animals, it is essential to check its quality, because, depending on the water source (rivers, lakes, wells, rain catchment, among others), it may contain contaminants, toxic elements, among others. Water quality can impact the amount of water ingested by the animal, as cattle is sensitive to its taste and odor (Willms et al., 1996). Thus, like any other nutrient, water intake below nutritional requirements results in reduced productive performance.

As well as the taste and odor of water (organoleptic characteristics), the physicochemical characteristics (pH, total dissolved solids and hardness), the presence of toxic components (heavy metals, for example), the presence of pathogenic bacteria (such as fecal coliforms), excess minerals (such as sodium, sulfates, and iron, among others) and components that may cause intoxication when in high concentrations (nitrates, for example), must be measured to determine the quality of the water to be supplied to the animals. Therefore, according to Wright (2007), the first step regarding water quality is to measure the concentrations of organic and mineral contaminants. Also, according to this author, samples should be obtained from each water source at least once a year.

Water supply and quality maintenance

In addition to the characteristics of the water for abstraction, care must be taken in the storage and supply of water to the animals. Thus, the periodic cleaning of reservoirs and drinking fountains is of paramount importance for the optimal performance of the animals. This cleaning must be planned in such a way as not to compromise the supply of the drinking fountains so that the animals do not spend long periods without access to water.

For grazing animals, priority should be given to drinking water from drinking fountains, and not from natural watercourses, such as rivers and lakes. Providing water at drinking fountains ensures not only the maintenance of water quality, without the suspension of clay particles or even contamination of the water with animal feces, for example, but also the protection of local water resources. In addition, when cattle have access to water both in drinking fountains and in a natural course, animals prefer to drink water from drinking fountains more than 90% of the time (Sheffield et al., 1997). Furthermore, Bica et al. (2021) reported that cattle with access to water from drinking fountains had an average daily gain of 29% higher than animals that ingested water directly from lakes.

The location of the drinkers should also be considered as an item of great importance, since cattle can change water intake according to the distance from the drinker, reducing their performance. To ensure adequate water intake for beef cattle in grazing-based systems, it is recommended that the walk to the drinker be a maximum of 250 meters (RSPCA, 2020). Thus, drinkers should be positioned close to the resting areas and not so far from the troughs. To reduce costs, drinkers can be positioned between two stalls or paddocks. In feedlots, drinkers should be far away enough from the troughs to minimize the accumulation of food residues and ensure water quality by minimizing the frequency of cleaning. Branco (2015) recommends that the distance between the trough and the drinker in feedlots be 10 meters. Branco (2015) also recommends that the surroundings of the drinking fountains be provided with paving and preferably located at the bottom of the stalls, facilitating the maintenance of ideal conditions in the stall.

Drinker spacing can also compromise water intake. In the literature, the minimum recommendations range from 3 linear cm/animal (Branco, 2015) to 4 linear cm/AU (Santos et al., 2005) of drinking fountains. Tavares and Benedetti (2011) suggest sizing the drinking trough according to the size of the batch, and for batches with up to 50 animals the proportion is 1 linear meter of a drinking fountain for every 10 animals, while in batches with more than 600 animals the proportion drops to 1 meter for every 30 animals. Such variation is related to the fact that both the location of the drinker and the social hierarchy can influence the water intake behavior of cows in grazing-based systems (Coimbra et al., 2012). In addition to the size of the drinker, the flow of water to replenish it must also be checked to guarantee continuous access to water for the animals.

FACTORS THAT INFLUENCE WATER INTAKE

Several factors affect water intake by beef cattle, such as racial characteristics, dry matter intake (DMI) and diet composition, body weight and physiological state, and climatic variables. In addition to the mentioned factors, the influence of metabolism and individual behavior of animals are not well established. Consequently, NASEM (2016) reported that it is impossible to list water needs very accurately due to the number of factors that influence its needs.

Racial characteristics

There are reports in the literature (Brew et al., 2011; Ittner et al., 1951; Winchester and Morris, 1956; Valente et al., 2015) of higher water intake by taurine cattle than by zebu cattle raised in similar conditions. Factors mainly related to body thermal homeostasis may help to explain the higher water intake observed for taurine breeds. Hansen (2004) reported a higher level of acclimation to heat stress for zebu, which is probably related to the different climates where these species develop. This indicates that during genetic adaptations, zebu breeds may have acquired thermoregulatory characteristics, such as lower rates of basal metabolism and skin characteristics, reducing dependence on mechanisms involving water to alleviate heat stress (Hansen, 2004).

Dry matter intake and diet composition

Dry matter intake influences water intake, just as water intake influences dry matter intake. The reduction in dry matter intake is followed by a reduction in water intake (Bond et al., 1976; Cardot et al., 2008; Kramer et al., 2009). This behavior can be explained by the rate of dilution of the rumen fluid (Adams et al., 1981; Adams and Kartchner, 1984) or by the caloric increase caused by the heat of fermentation and digestion (Finch, 1986).

The rumen is an organ of fermentation and digestion, and these functions depend on the regular entry of food and the movement of digesta and microorganisms to the rest of the gastrointestinal tract. Digesta consists of insoluble particles and soluble fractions. However, the liquid fraction passes into the omasum two to four times faster than insoluble particles (Russell and Hespell, 1981). An increase in the rate of liquid dilution is usually followed by an increase in bacterial growth and nutrient flow through the gastrointestinal tract.

However, microbial metabolic activity dissipates free energy as heat during fermentation in the digestive tract, particularly in the rumen (Czerkaski, 1980; Russell and Hespell, 1981). Bergen and Yokoyama (1977) reported that heat loss during the fermentation process ranges from 3.0 to 12.0% of gross dietary energy in ruminants, versus approximately 1.0% for non-ruminants. The relationship between body temperature control and water intake is attributed to the temporary reduction in the rumen temperature immediately after water intake (Blackshaw and Blackshaw, 1994; Bewley et al., 2008).

Cattle fed *ad libitum* drink more water than animals managed with restrictions, isolating the effects of climatic parameters (Ahlberg et al., 2018). Thus, when steers had access to water restricted by 80 and 60%, DMI decreased by 5 and 23%, respectively (Utley et al., 1970). However, this relationship is not consistent and is influenced by several factors, such as ambient temperature, which, being higher, can reduce DMI and increase water intake (Kreikemeier and Mader, 2004; NASEM, 2016).

Furthermore, the composition of the diet can influence water intake. Water intake is positively related to the concentration of sodium (Murphy et al., 1983), potassium (Fraley et al., 2015), and dietary mineral matter (Appuhamy et al., 2014). Higher concentrations of these minerals may be correlated with increased osmotic pressure in the rumen by dietary salt (Rogers et al., 1979). Likewise, the concentration of total salts dissolved in water has been reported to increase water intake by livestock (Alves et al., 2017).

Body weight and physiological state

Body weight is related to water intake due to the relationship between body weight and dry matter intake. Thus, a larger animal consumes more food, and a greater dry matter intake induces a greater intake of water, as discussed before.

Furthermore, basal metabolism is almost proportional to the body weight of the animal (Kleiber, 1932), and basal metabolism generates approximately 33% of the heat generated by an animal (Finch, 1986). Consequently, a larger animal generates more heat from basal metabolism than a smaller one. Furthermore, for the same physiological maturity, a larger animal has more body fat than a smaller one. Body fat acts as an insulator and makes it more difficult for a fatter animal to dissipate heat (Finch, 1986; Gaughan et al., 2010).

In addition, peripheral vasodilation helps to dissipate heat from the central region of the body. However, vasodilation becomes more difficult in animals with higher body weight (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 through sweat depends on the skin surface area for water evaporation (Hansen, 2004). As the surface area to body weight ratio decreases as the animal grows, larger animals have more difficulty dissipating body heat through this mechanism.

Climate variables

As previously mentioned, water plays a crucial role in the body thermal homeostasis. Thus, water intake is strongly associated with climatic variables such as ambient temperature, relative air humidity, and all parameters associated with it. Initially, in addition to the temporary reduction in rumen temperature immediately after the aforementioned water intake, such importance is attributed to the direct effect of evaporative cooling in reducing a thermal load (Bernabucci et al., 2010; Arias and Mader, 2011). Thus, after water intake, there are reductions in overall heat stress, respiration rate, and skin and rectal temperatures (Purwanto et al., 1996).

Berman (2003) reported that heat exchange between the environment and the animal is the main component for the regulation of body temperature. Arias and Mader (2011) also reported maximum temperature as a primary factor influencing water intake. These variables interact strongly with other environmental variables, such as average and minimum daily temperatures (Bernabucci et al., 2010). Regarding temperature, non-evaporative heat loss mechanisms decrease with increasing ambient temperature and the animal is dependent on evaporative mechanisms (Silanikove, 2000).

Relative humidity has been reported to be the main contributor to heat stress in hot climates (Blackshaw and Blackshaw, 1994). At high relative humidity, 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). As a result, by isolating the effect of relative humidity from other factors, under conditions of high humidity, evaporative water loss is reduced and therefore water intake is also reduced.

PREDICTION OF WATER INTAKE IN TROPICAL CONDITIONS

Several water intake prediction equations/recommendations (WI, L/d) have been reported in the literature and are summarized in Table 14.1. The NRC (2000) recommends the equation proposed by Hicks et al. (1988), as a function of maximum temperature, DMI, rainfall, and the inclusion of salt in the diet. In addition to the equation proposed by Hicks et al. (1988), two other equations are reported by NASEM (2016) proposed by Arias and Mader. These equations have DMI, solar radiation, the minimum daily temperature, and the temperature and humidity index (THI) as predictor variables. The THI is calculated through the equation $THI = [0.8 \times T + (RH/100) \times (T - 14.4) + 46.4]$ (Thom, 1959) which uses the relative humidity of the air (RH, %) and the average daily temperature (T, ºC). For moderate climates, Meyer et al. (2006) proposed the prediction as a function of average daily temperature, DMI, the inclusion of roughage in the diet, and respective dry matter content and body weight. The CSIRO (2007) recommends predicting water intake according to dry matter intake and average daily temperature, based on the work by Winchester and Morris (1956).

Table 14.1 - Summary of equations found in the literature to predict water intake (WI) by beef cattle

Authors	Equation[1]
Hicks et al. (1988)	$WI_{HICKS} = -6.0716 + 0.70866 \times T_{MAX} + 2.432 \times DMI - 3.87 \times PP - 4.437 \times IS$
Meyer et al. (2006)	$WI_{MEYER} = -3.85 + 0.507 \times T + 1.494 \times DMI - 0.141 \times IR + 0.248 \times DMR + 0.014 \times BW$
CSIRO (2007)	$WI = 3.0 \times DMI$, for T < 15ºC $WI = 3.5 \times DMI$, for T = 20ºC $WI = 4.5 \times DMI$, for T = 25ºC $WI= 6.0 \times DMI$, for T = 30ºC $WI = 8.0 \times DMI$, for T > 35ºC
Arias e Mader (2011)	$WI_{AM1} = 5.92 + 1.03 \times DMI + 0.04 \times SR + 0.45 \times T_{MIN}$ $WI_{AM2} = -7.31 + 1.00 \times DMI + 0.04 \times SR + 0.30 \times THI$
Sexson et al. (2012)	$WI_{SEXSON} = -14.07 + 0.163 \times RH - 0.0017 \times RH^2 + 0.0096 \times T_{MAX}^2 - 0.00032 \times RH_{MAX}^2 + 1.01 \times T_{MIN} - 0.026 \times T_{MIN}^2 + 0.038 \times RH_{MIN} + 0.396 \times AP - 0.055 \times WS - 1.395 \times BW - 0.249 \times AP_{MAX} - 0.411 \times AP_{MIN} + 0.0012 \times T_{MAX\_ANT}^2 + 8.79 \times MBW$
Ahlberg et al. (2018)	$WI_{AHLBERG\_ADLIBITUM} = 0.71 + 2.63 \times DMI - 0.009 \times MBW + 0.76 \times T - 0.06 \times RH + 0.23 \times SR - 0.11 \times WS$ $WI_{AHLBERG\_SUMMER} = -9.74 + 2.32 \times DMI + 0.11 \times MBW + 1.31 \times T - 0.17 \times RH - 0.03 \times SR - 0.27 \times WS$
BR-CORTE (2023)	$\mathbf{WI_{BR\text{-}CORTE} = 9.449 + 0.190 \times MBW + 0.271 \times T_{MAX} - 0.259 \times RH + 0.489 \times DMI}$

1: Adapted from Hicks et al. (1988), with values converted from ºF to ºC. T_{MAX} = maximum temperature (ºC); DMI = dry matter intake (kg); PP = rainfall (cm); IS = inclusion of salt in the diet (%); T = average daily temperature (ºC); IR = inclusion of roughage in the diet (%); DMR = dry matter content of the roughage (%); BW = body weight (kg); SR = solar radiation (W/m²); T_{MIN} = minimum temperature (ºC); THI = temperature and humidity index, where; RH = relative air humidity (%); RH_{MAX} = maximum relative humidity (%); RH_{MIN} = minimum relative humidity (%); AP = atmospheric pressure (mmHg); WS = wind speed (m/s); AP_{MAX} = maximum atmospheric pressure (mmHg); AP_{MIN} = minimum atmospheric pressure (mmHg); T_{MAX_ANT} = maximum temperature of the previous day (ºC); MBW = metabolic body weight ($kg^{0.75}$).

Sexson et al. (2012) proposed an equation based on mean, maximum, and minimum relative humidity, TMAX, and TMIN, on the TMAX of the previous day, on average, maximum and minimum atmospheric pressures, on wind speed, on body weight, and metabolic body weight. Still, Ahlberg et al. (2018) proposed five equations for predicting water intake based on the season (winter and summer) and food level. Both equations have as parameters DMI, MBW, T, RH, WS, and SR.

The equations described above were evaluated by Zanetti et al. (2019), using a database composed of data collected in 4 experiments, with Nellore cattle, confined in tropical conditions (1: Prados et al., 2017; 2: Zanetti et al., 2017; 3: data not published; and 4: Menezes et al., 2019; Table 14.2). Water intake in these experiments was measured using drinking fountains equipped with a scale to measure intake and individual identification of each access to the drinking fountain (Model WD-1000 Master, Intergado Ltda, Contagem, MG, Brazil). None of the equations was able to accurately predict the water intake of cattle under these conditions. The low accuracy of the equations was justified by the predominance of taurine animals in the database used to build the models and by the fact that most of the tests were conducted in a temperate climate, with temperature, humidity, and rainfall characteristics different from those found in Brazil.

Thus, Zanetti et al. (2019) proposed an equation to estimate water intake of beef cattle in tropical conditions, where the climatic variables and the predominant breeds in beef cattle are different from those described so far in the literature. In addition to the four experiments mentioned above, a fifth experiment was added to the database to validate the equation proposed (Pacheco, 2018). The information from the five experiments is presented in Table 14.2.

Among all the variables measured in the experiments to validate the equations, those related to body weight, dry matter intake, temperature and humidity showed the highest correlation with water intake. Metabolic body weight, maximum temperature, relative air humidity, and daily dry matter intake were included as predictors of water intake. The summary of these parameters for each experiment is presented in Table 14.3.

Validation

To recommend the equation proposed by Zanetti et al. (2019) to predict water intake by beef cattle under tropical conditions, an independent database validation was carried out, using data collected in five other experiments, totaling 14,774 daily measurements (Table 14.4). Data on water and dry matter intake, body weight, maximum daily temperature, and relative air humidity were collected from the five experiments. These data are described in Table 14.5.

Water intake estimated by the equation proposed by Zanetti et al. (2019) was compared to the water intake values measured in the experiments, using the following regression model: $Y = \beta 0 + \beta 1 \times X$, where Y is the observed value; $\beta 0$ and $\beta 1$ are the intercept and slope of the regression, respectively; and X is the predicted value. The regression was evaluated through the test of two hypotheses: where H0: $\beta 0 = 0$ and H0: $\beta 1 = 1$ and Ha: not H0. If both null hypotheses are not rejected, it is concluded that the tested equation accurately estimates water intake. In addition, the mean square of the prediction error (MSEP; Bibby and Toutenburg, 1977) was also calculated to assess the accuracy of the equation. These analyzes were performed using the MES (Model Evaluation System Software, version 3.1.13; Tedeschi, 2006).

The proposed equation accurately estimated water intake ($P \geq 0.05$; Table 14.6 and Figure 14.1). The regression of the water intake values predicted by the equation evaluated in terms of the observed values showed an intercept equal to -0.3109 and a slope equal to 1.005. These values were statistically equal to 0 and 1 ($P = 0.066$ and $P = 0.617$, respectively).

The estimated average water intake was 16.3 L/d versus an observed water intake of 16.1 L/d. As for the amplitude of the predicted and observed values, the minimum water intake of 2.3 L/d and the maximum of 32.3 L/d were estimated, while the minimum and maximum values observed were equal to 2.0 and 49.9 L /d, respectively. The correlation coefficient of concordance was equal to 0.574, and the bias correction was equal to 0.903. Regarding the mean squared error of the prediction, 99.8% were involved with the random error, showing the accuracy of the prediction.

The positive coefficients associated with metabolic body weight, maximum environmental temperature, and dry matter intake indicate that the larger the animal size, maximum temperature, and dry matter intake, the greater the water intake. However, higher relative air humidity reduces water intake by animals, given its negative coefficient.

Table 14.2 - Information of the experiments used by Zanetti et al. (2019) to predict water intake by beef cattle

Experiment	n	Category	Initial body weight (kg)	Number of observations
Prados et al. (2017)	32	Bulls	274 ± 34	984
Zanetti et al. (2017)	42	Bulls	270 ± 36	762
Menezes et al. (2019)	42	Bulls	260 ± 8	3967
Unpublished data [1]	16	Heifers	377 ± 49	323
Pacheco (2018)	42	Bulls	299 ± 32	3605

[1] Data was collected between February and April 2015. Diets based on sugarcane or elephant grass with or without 400 g/kg DM concentrate.

Table 14.3 - Descriptive statistics of water and dry matter intake, body weight, maximum temperature, and relative humidity of the experiments used by Zanetti et al. (2019)

Parameter	Experiment[1]	Average	Standard deviation	Maximum	Minimum
Water intake, L/d	Prados et al. (2017)	17.0	7.86	55.6	2.0
	Zanetti et al. (2017)	17.2	5.94	39.7	0.6
	Menezes et al. (2019)	12.4	7.28	47.9	2.0
	Unpublished data	16.7	6.14	45.0	3.0
	Pacheco (2018)	17.9	6.31	43.7	0.8
Dry matter intake, kg/d	Prados et al. (2017)	7.5	1.67	16.3	1.5
	Zanetti et al. (2017)	7.0	1.68	17.6	1.8
	Menezes et al. (2019)	6.5	2.45	14.5	2.0
	Unpublished data	7.6	1.02	10.0	5.0
	Pacheco (2018)	7.5	1.35	10.9	3.8
Metabolic body weight, $kg^{0.75}$	Prados et al. (2017)	80.9	9.25	106.3	56.1
	Zanetti et al. (2017)	83.5	11.90	111.3	55.2
	Menezes et al. (2019)	76.1	5.46	90.0	66.9
	Unpublished data	89.9	8.69	113.5	46.6
	Pacheco (2018)	82.3	8.50	106.9	56.5
Maximum temperature, °C	Prados et al. (2017)	27.0	3.74	35.9	17.5
	Zanetti et al. (2017)	26.0	3.37	34.6	17.6
	Menezes et al. (2019)	26.6	2.68	31.3	19.4
	Unpublished data	21.2	2.51	26.9	16.2
	Pacheco (2018)	27.3	3.33	34.2	19.6
Relative humidity, %	Prados et al. (2017)	70.4	10.12	95.0	48.3
	Zanetti et al. (2017)	76.5	8.36	95.3	36.8
	Menezes et al. (2019)	82.8	4.79	94.4	73.1
	Unpublished data	74.0	8.07	92.2	53.4
	Pacheco (2018)	68.8	7.74	88.0	43.4

Table 14.4 - Information from the experiments used to validate the equation proposed by Zanetti et al. (2019) to predict water intake

Experiment[1]	n	Category	Initial body weight (kg)	Number of observations
Andrade (2021)	38	Bulls	261 ± 27	5097
Meneses (2021)	6	Heifers	310 ± 30	343
Alhadas et al. (2021)	35	Bulls	267 ± 30	3700
Godoi et al. (2022)	12	Heifers	217 ± 26	549
Pacheco (unpublished data)	42	Bulls	273 ± 29	5085

Table 14.5 - Descriptive statistics of water and dry matter intake, body weight, maximum temperature, and relative humidity of the experiments used in this chapter to validate the equation proposed by Zanetti et al. (2019)

Parameter	Experiment[1]	Average	Standard deviation	Maximum	Minimum
Water intake, L/d	Andrade (2021)	16.2	6.8	49.9	2.0
	Meneses (2021)	14.7	5.8	33.0	2.0
	Alhadas et al. (2021)	13.8	6.5	49.5	2.1
	Godoi et al. (2022)	10.1	3.5	22.1	2.4
	Pacheco (unpublished data)	17.3	6.9	48.3	2.2
Dry matter intake, kg/d	Andrade (2021)	6.4	1.5	15.7	0.6
	Meneses (2021)	6.5	1.5	11.5	2.8
	Alhadas et al. (2021)	6.4	1.7	15.1	0.6
	Godoi et al. (2022)	5.4	1.0	8.4	2.4
	Pacheco (unpublished data)	7.2	1.7	14.8	0.3
Metabolic body weight, $kg^{0.75}$	Andrade (2021)	85.4	108	119.4	55.2
	Meneses (2021)	81.5	7.2	94.9	69.2
	Alhadas et al. (2021)	83.9	11.5	118.9	54.1
	Godoi et al. (2022)	67.1	7.1	85.4	46.1
	Pacheco (unpublished data)	84.0	10.7	114.2	56.5
Maximum temperature, ºC	Andrade (2021)	27.5	3.9	36.6	16.2
	Meneses (2021)	29.8	4.8	34.3	22.1
	Alhadas et al. (2021)	26.1	3.1	33.0	18.4
	Godoi et al. (2022)	24.9	2.2	29.5	18.4
	Pacheco (unpublished data)	27.2	3.4	19.6	35.1
Relative humidity, %	Andrade (2021)	76.5	8.5	95.1	53.6
	Meneses (2021)	74.8	4.8	34.3	59.2
	Alhadas et al. (2021)	80.8	7.0	95.3	65.9
	Godoi et al. (2022)	79.8	6.5	95.2	66.0
	Pacheco (unpublished data)	71.5	8.8	94.8	42.5

Table 14.6 - Regression parameters and accuracy between the water intake estimates of the evaluated equation and observed values of water intake for Nellore cattle under tropical conditions

Item	Observed	Estimated
Average, L/d	16.1	16.3
Standard deviation	6.6	4.2
Minimum, L/d	2.0	2.3
Maximum, L/d	49.9	32.3
Regression parameters		
Intercept	-	-0.3109
P-value	-	0.066
Slope	-	1.0050
P-value	-	0.617
CCC[1]	-	0.574
Cb[2]	-	0.903
Mean square of the prediction error		
Average bias	-	0.0525 (0.201%)
Systematic bias	-	0.0004 (0.002%)
Random error	-	26.054 (99.797%)

[1] CCC = Concordance Correlation coefficient; ranges from -1 to 1, which represent, respectively, perfect disagreement and agreement between Y and X.
[2] Cb = Bias correction; ranges from 0 to 1; 1 indicates no deviation from Y = X.

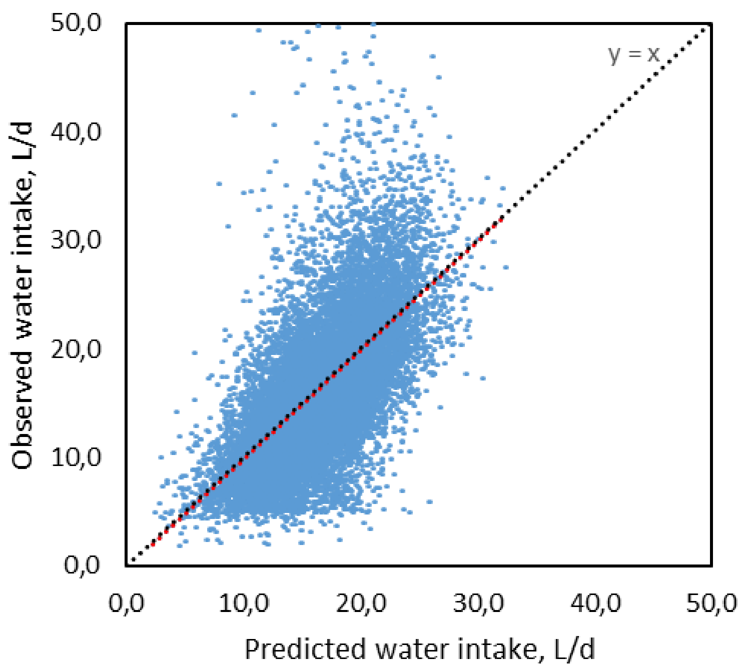

Figure 14.1 - Predicted (x-axis) and observed (y-axis) water intake. Values predicted using the equation $\mathbf{WI = 9.449 + 0.190 \times MBW + 0.271 \times T_{MAX} - 0.259 \times RH + 0.489 \times DMI}$ (Zanetti et al., 2019), where WI is the daily water intake (kg/d), MBW is the metabolic body weight ($kg^{0.75}$), T_{MAX} is the maximum temperature (ºC) and RH is the relative humidity (%).

The relationship of the variables selected as predictors in the equation with water intake is well described in the literature. These four parameters are associated with animal homeostasis and body temperature control. In addition, all the previously published equations included temperature, or parameters derived from temperature as a partial component of the equation. Furthermore, the relationship between ambient temperature and water intake is based on the role of water in body temperature homeostasis (Cunningham et al., 1964; Purwanto et al., 1996; Bewley et al., 2008). High temperatures make it difficult to lose body heat, as well as high water vapor saturations in the environment make evaporative heat loss processes more difficult (Berman, 2003).

OTHER CONSIDERATIONS REGARDING WATER INTAKE

Feed moisture: The moisture content of the food provided to the animals can directly influence water intake in the drinkers, since most of the forages, such as silage and pastures, and by-products used in the feeding of beef cattle have high water content. However, for the development of the recommended equation for predicting water intake by beef cattle in this chapter proposed by Zanetti et al. (2019), data were collected from experiments in which the dry matter contents of the diets ranged between 25.17 (Unpublished data, diet composed of elephant grass and urea) and 65.5% (Prados et al., 2017), and that the roughage proportion or the roughage water content were not included among the predictive variables of the model.

A direct relationship between water intake and DMI: Despite the strong relationship between climatic factors and water intake, in practical situations, fluctuations in temperature and humidity between days can make it difficult to plan the water supply to animals. All previously published water intake prediction equations use dry matter intake or body weight as a predictor variable. As previously mentioned, feed intake is closely linked to body weight and water intake. Higher dry matter intakes are related to the greater need for dilution of rumen fluid and the caloric increase caused by rumen fermentation (Adams and Kartchner, 1984; Finch, 1986). Thus, additionally, the isolated relationship between water intake and DMI was established. Separately, from the database of this chapter, the average relationship between water intake and DMI is 2.5, that is, for each kilogram of dry matter ingested, beef cattle under tropical conditions are expected to have an intake of 2.5 liters of water.

Individual relationship between water intake and body weight: Higher body weights are associated with higher body heat production and a smaller area for heat dissipation (Hansen, 2004), so heavier animals ingest more water. Similar to the DMI from the database of this chapter, the relationship between water intake and body weight was established, isolated from the other factors. It is observed that there is a daily intake of 43.5 mL of water for each kilogram of body weight, that is, the cattle ingests 4.35% of its body weight in water daily.

APPLICATION EXAMPLES

- Estimated water intake for a Nellore bull, with an average body weight of 520 kg in a feedlot, in Campo Grande/MS, in January (historical averages of maximum temperature equal to 29.0 ºC and relative humidity of the air equal to 79.0%).

  - Calculation of dry matter intake (according to chapter 02, considering average daily gain equal to 1.4 kg/d): 10.62 kg/d
  - Metabolic body weight: $520^{0.75} = 108.9$
  - $WI = 9.449 + 0.190 \times MBW + 0.271 \times T_{MAX} - 0.259 \times RH + 0.489 \times DMI$
  - $WI = 9.449 + 0.190 \times 108.89 + 0.271 \times 29.0 - 0.259 \times 79.0 + 0.489 \times 10.62$
  - $WI = 9.449 + 20.69 + 7.86 - 20.46 + 5.19$
  - **$WI = 22.73$ L/d**

- Estimated water intake for a Nellore bull, with an average body weight of 520 kg in a feedlot, in Campo Grande/MS, in June (historical averages of maximum temperature equal to 25.7 ºC and relative humidity of the air equal to 65.0%).

  - Metabolic body weight: $520^{0.75} = 108.89$
  - $WI = 9.449 + 0.190 \times MBW + 0.271 \times T_{MAX} - 0.259 \times RH + 0.489 \times DMI$
  - $WI = 9.449 + 0.190 \times 108.89 + 0.271 \times 25.7 - 0.259 \times 65.0 + 0.489 \times 10.62$
  - $WI = 9.449 + 20.69 + 6.96 - 16.84 + 5.19$
  - **<u>WI = 25.46 L/d.</u>**

REFERENCES

Adams, D. C., and R. J. Kartchner. 1984. Effect of level of forage intake on rumen ammonia, pH, liquid volume and liquid dilution rate in beef cattle. *J. Anim. Sci.* 58: 708-713. doi:10.2134/jas1984.583708x

Adams, D. C., M. L. Galyean, H. E. Kiesling, J. D. Wallace, and M. D. Finkner. 1981. Influence of viable yeast culture, sodium bicarbonate and monensin on liquid dilution rate, rumen fermentation and feedlot performance of growing steers and digestibility in lambs. *J. Anim. Sci.* 53: 780-789. doi:10.2134/jas1981.533780x

Agência Nacional de Águas (Brasil). *Manual de Usos Consuntivos da Água no Brasil / Agência Nacional de Águas*. - Brasília: ANA, 2019. 75 p

Ahlberg, C.M., K. Allwardt, A. Broocks, K. Bruno, L. McPhillips, A. Taylor, C.R. Krehbiel, M. S. Calvo-Lorenzo, C. J. Richards, S.E. Place, U. DeSilva, D. L. VanOverbeke, R. G. Mateescu, L. A. Kuehn, R. L. Weaber, J. M. Bormann, and M. M. Rolf. 2018. doi: 10.1093/jas/sky267

Alhadas, H.M., Valadares Filho, S.C., Tedeschi, L.O., Vilela, R.S., Souza, G.A., Lage, B.C., Silva, B.C., Rennó, L.N. and Paulino, M.F., 2021. Impact of different levels of low-fat dried distillers grains on performance of young Nellore bulls during the finishing phase. *Animal Science Journal*, 92(1), p.e13623.

Allen, T. E., J. W. Bennettf, Susan M. Donegan, and J. C. D. Hutchinson. 1970. Moisture, its accumulation and site of evaporation in the coats of sweating cattle. *J. Agric. Sci*. 74: 247-258. doi: 10.1017/S0021859600022863

Alves, J. N., G. G. L. Araujo, S. G. Neto, T. V. Voltolini, R. D. Santos, P. R. Rosa, L. Guan, T. McAllister, and A. L. A. Neves. 2017. Effect of increasing concentrations of total dissolved salts in drinking water on digestion, performance and water balance in heifers. *J. Agric. Sci.* 155: 847-856. doi: 10.1017/S0021859617000120

Andrade, D.R. *Desempenho e exigências nutricionais de bovinos alimentados com dietas contendo diferentes blends vitamínicos.* Dissertação (Mestrado em Zootecnia) Universidade Federal de Viçosa, Viçosa, MG. 2021.

Appuhamy, J. A. D. R. N., C. Wagner-Riddle, D. P. Casper, J. France, and E. Kebreab. 2014. Quantifying body water kinetics and fecal and urinary water output from lactating Holstein dairy cows. *J. Dairy. Sci.* 97: 6177-6195. doi:10.3168/jds.2013-7755

Araujo, G. G. L. D., T. V. Voltolini, M. L. Chizzotti, S. H. N. Turco, and, F. F. R. D. Carvalho. 2010. Water and small ruminant production. Braz. *J. Anim. Sci.* 39: 326-336. doi: 10.1590/S1516-35982010001300036

Arias, R. A., and T. L. Mader. 2011. Environmental factors affecting daily water intake on cattle finished in feedlots. *J. Anim. Sci*. 89: 245-251. doi:10.2527/jas.2010-3014

Beckett, J. L., and J. W Oltjen. 1993. Estimation of the water requirement for beef production in the United States. *J. Anim. Sci.* 71: 818-826. doi:/1993.714818x

Bergen, W. G., and M. T. Yokoyama. 1977. Productive limits to rumen fermentation. *J. Anim. Sci.* 45: 573-584. doi:10.2134/jas1977.453573x

Berman, A. 2003. Effects of body surface area estimates on predicted energy requirements and heat stress. *J. Dairy. Sci.* 86: 3605-3610. doi:10.3168/jds.S0022-0302(03)73966-6

Bernabucci, U., N. Lacetera, L. H. Baumgard, R. P. Rhoads, B. Ronchi, and A. Nardone. 2010. Metabolic and hormonal acclimation to heat stress in domesticated ruminants. *Animal* 4: 1167-1183. doi: 10.1017/S175173111000090X

Bewley, J. M., M. W. Grott, M. E. Einstein, and M. M. Schutz. 2008. Impact of intake water temperatures on reticular temperatures of lactating dairy cows. *J. Dairy. Sci.* 91: 3880-3887. doi:10.3168/jds.2008-1159.

Bibby, J., and H. Toutenburg. 1977. *Prediction and improved estimation in linear models*. Wiley, Berlin, Germany.

Bica GS, Pinheiro Machado Filho LC and Teixeira DL (2021) Beef Cattle on Pasture Have Better Performance When Supplied With Water Trough Than Pond. *Front. Vet. Sci.* 8:616904.
doi: 10.3389/fvets.2021.616904

Blackshaw, J. K., and A. W. Blackshaw. 1994. Heat stress in cattle and the effect of shade on production and behaviour: a review. *Anim. Prod. Sci.* 34: 285-295. doi:10.1071/EA9940285

Bond, J., T. S. Rumsey, and B. T. Weinland. 1976. Effect of deprivation and reintroduction of feed and water on the feed and water intake behavior of beef cattle. *J. Anim. Sci.* 43: 873-878. doi:10.2134/jas1976.434873x

Branco, A.F. Manual de instalações para confinamento de bovinos. *Maringá: IEPEC* (2015).

Brew, M. N., R. O. Myer, M. J. Hersom, J. N. Carter, M. A. Elzo, G. R. Hansen, and D. G. Riley. 2011. Water intake and factors affecting water intake of growing beef cattle. *Livest. Sci.* 140: 297-300. doi:10.1016/j.livsci.2011.03.030

Cardot, V., Y. Le Roux, and S. Jurjanz. 2008. Drinking behavior of lactating dairy cows and prediction of their water intake. *J. Dairy. Sci.* 91: 2257-2264. doi:10.3168/jds.2007-0204

Coimbra, P. A. D., Machado Filho, L. C. P., & Hötzel, M. J. (2012). Effects of social dominance, water trough location and shade availability on drinking behaviour of cows on pasture. *Applied Animal Behaviour Science*, *139*(3-4), 175-182.

CSIRO. 2007. *Nutrient requirements of domesticated ruminants.* Camberra, AU: CSIRO Publishing.

Cunningham, M. D., F. A. Martz, and C. P. Merilan. 1964. Effect of drinking-water temperature upon ruminant digestion, intraruminal temperature, and water consumption of non-lactating dairy cows. *J. Dairy. Sci.* 47: 382-385. doi:10.3168/jds.S0022-0302(64)88671-9

Czerkawski, J. W. 1980. A novel estimate of the magnitude of heat produced in the rumen. British *J. Nutr.* 43: 239-243. doi: 10.1079/BJN19800083

Ferguson, K. A., and D. F. Dowling. 1955. The function of cattle sweat glands. *Crop Pasture Sci.* 6: 640-644. doi:10.1071/AR9550640

Finch, V. A. 1986. Body temperature in beef cattle: its control and relevance to production in the tropics. *J. Anim. Sci.* 62: 531-542. doi:10.2134/jas1986.622531x

Fraley, S. E., M. B. Hall, and T. D. Nennich. 2015. Effect of variable water intake as mediated by dietary potassium carbonate supplementation on rumen dynamics in lactating dairy cows. *J. Dairy. Sci.* 98: 3247-3256. doi:10.3168/jds.2014-8557

Gaughan, J. B., T. L. Mader, S. M. Holt, M. L. Sullivan, and G. L. Hahn. 2010. Assessing the heat tolerance of 17 beef cattle genotypes. Int. *J. Biometeorol.* 54: 617-627. doi: 10.1007/s00484-009-0233-4

Godoi, L. A.; Silva, B. C.; Souza, G. A. P.; Lage, B. C.; Zanetti, D.; Costa e Silva, L. F.; Rennó, L. N.; Paulino, M. F.; Valadares Filho, S. C.. Influence of crude protein content and flint maize processing methods on the performance of early-weaning Nellore calves. *J. Agricultural Sci.*, 160: 1-10, 2022.

Hansen, P. J. 2004. Physiological and cellular adaptations of zebu cattle to thermal stress. *Anim. Reprod. Sci.* 82: 349-360. doi:10.1016/j.anireprosci.2004.04.011

Hicks, R. B., F. N. Owens, D. R. Gill, J. J. Martin, and C. A. Strasia. 1988. *Water intake by feedlot steers. Miscellaneous publication - Agricultural Experiment Station*, Oklahoma State University (USA).

Ittner, N. R., C. F. Kelly, and H. R. Guilbert.1951. Water consumption of Hereford and Brahman cattle and the effect of cooled drinking water in a hot climate. *J. Anim. Sci.* 10: 742-751. doi:10.2134/jas1951.103742x

Kleiber, M. 1932. *Body size and metabolism*. Hilgardia 6: 315-332.

Kramer, E., E. Stamer, J. Spilke, G. Thaller, and J. Krieter. 2009. Analysis of water intake and dry matter intake using different lactation curve models. *J. Dairy. Sci.* 92: 4072-4081. doi:10.3168/jds.2008-1957

Kreikemeier, W. M., and T. L. Mader. 2004. Effects of growth-promoting agents and season on yearling feedlot heifer performance. *J. Anim. Sci* 82: 2481-2488. doi:10.2527/2004.8282481x.

Mekonnen, M. M., and A. Y. Hoekstra. 2012. A global assessment of the water footprint of farm animal products. *Ecosystems* 15: 401-415. doi: 10.1007/s10021-011-9517-8

Meneses, J.A.M., de Sá, O.A.A.L., Coelho, C.F., Pereira, R.N., Batista, E.D., Ladeira, M.M., Casagrande, D.R. and Gionbelli, M.P., 2021. Effect of heat stress on ingestive, digestive, ruminal and physiological parameters of Nellore cattle feeding low-or high-energy diets. *Livest. Sci 252:* 104676. doi: 10.1016/j.livsci.2021.104676

Menezes, A. C. B., Valadares Filho, S.C., Pucetti, P., C. Pacheco, M. V, Godoi, L. A., Zanetti, D., Alhadas, H. M; Paulino, M. F, Caton, J. S. Oscillating and static dietary crude protein supply: II. Energy and protein requirements of young Nellore bulls. *Translational Animal Science,* v. 3, p. 1216-1226, 2019.

Meyer, U., W. Stahl, and G. Flachowsky. 2006. Investigations on the water intake of growing bulls. *Livest. Sci. 103*: 186-191. doi:10.1016/j.livsci.2006.02.009

Murphy, M. R., C. L. Davis, and G. C. McCoy. 1983. Factors affecting water consumption by Holstein cows in early lactation. *J. Dairy. Sci. 66*: 35-38. doi:10.3168/jds.S0022-0302(83)81750-0

NASEM 2016. National Academies of Sciences, Engineering, and Medicine. *Nutrient requirements of beef cattle model*. 8th rev. ed. Natl. Acad. Press, Washington, DC.Pluske, J. M., and A. C. Schlink. 2007. Managing water as a scarce resource in beef feedlots. Australasian Agribusiness Review 15: 1-13.

NRC 2000. *Nutrient requirements of beef cattle*, 7th., National research council, National Academy Sciences, Washington, D.C, USA.

Pacheco Marcos Vinicius Carneiro. Efeito das ensilagem dos grãos de milho e sorgo reidratados sobre o desempenho e características de carcaça de bovinos nelore superprecoces. 2018. Dissertação (Mestrado em Zootecnia) - Universidade Federal de Viçosa.

Palhares, J. C. P., Morelli, M., & Novelli, T. I. (2021). Water footprint of a tropical beef cattle production system: The impact of individual-animal and feed management. *Advances in Water Resources*, 149, 103853.

Pluske, J. M., and A. C. Schlink. 2007. Managing water as a scarce resource in beef feedlots. *Austr. Agribusiness Rev*. 15: 1–13.

Prados, L. F., D. F. T. Sathler, B. C. Silva, D. Zanetti, S. C. Valadares Filho, H. M. Alhadas, E. Detmann, S. A. Santos, L. D. S. Mariz, and M. L. Chizzotti. 2017. Reducing mineral usage in feedlot diets for Nellore cattle: II. Impacts of calcium, phosphorus, copper, manganese, and zinc contents on intake, performance, and liver and bone status. *J. Anim. Sci.* 95: 1-11. doi:10.2527/jas2016.1085

Purwanto, B. P., M. Harada, and S. Yamamoto. 1996. Effect of drinking-water temperature on heat balance and thermoregulatory responses in dairy heifers. *Crop Pasture Sci*. 47: 505-512. doi:10.1071/AR9960505

Renaudeau, D., A. Collin, S. Yahav, V. De Basilio, J. L. Gourdine, and R. J. Collier. 2012. Adaptation to hot climate and strategies to alleviate heat stress in livestock production. *Anim. 6:* 707-728. doi: 10.1017/S1751731111002448

Rijsberman, F. R. 2006. *Water scarcity: fact or fiction? Agricultural Water Management 80*: 5-22. doi:10.1016/j.agwat.2005.07.001

Rogers, J. A., B. C. Marks, C. L. Davis, and J. H. Clark. 1979. Alteration of rumen fermentation in steers by increasing rumen fluid dilution rate with mineral salts. *J. Dairy. Sci.* 62: 1599-1605. doi:10.3168/jds.S0022-0302(79)83467-0

RSPCA (2020). *RSPCA Welfare Standards for Beef Cattle*. Available online at: http://www.rspca.org.uk/sciencegroup/farmanimals/standards (accessed March 30, 2020).

Russell, J. B., and R. B. Hespell. 1981. Microbial rumen fermentation. *J. Dairy. Sci*. 64: 1153-1169. doi:10.3168/jds.S0022-0302(81)82694-X

Santos, P.M., Corrêa, L.D., Balsalobre, M. Guia prático para a implantação de sistemas de pastejo rotacionados para gado de corte. *Embrapa Pecuária Sudeste-Documentos (INFOTECA-E).* 2005.

Sexson, J. L., J. J. Wagner, T. E. Engle, and J. Eickhoff. 2012. Predicting water intake by yearling feedlot steers. *J. Anim. Sci*. 90: 1920-1928. doi:10.2527/jas.2009-1899

Sheffield, R.E., S. Mostaghimi, D.H. Vaughan, E.R. Collins Jr., and V.G. Allen. 1997. Off-stream water sources for grazing cattle as a stream bank stabilization and water quality BMP. *Transactions of the ASAE 40*(3):595-604.

Silanikove, N. 2000. Effects of heat stress on the welfare of extensively managed domestic ruminants. *Livest. Prod. Sci*. 67: 1-18. doi:10.1016/S0301-6226(00)00162-7.

Tavares, J. E.; Benedetti, E. Água: uso de bebedouros e sua influência na produção de bovinos em pasto. *FAZU em Revista,* Uberaba, n. 8, p. 152-157, 2011.

Tedeschi, L. O. 2006. Assessment of the adequacy of mathematical models. *Agric. Syst.* 89:225–247. doi:10.1016/j.agsy.2005.11.004

Thom, E. C. 1959. *The discomfort index. Weatherwise* 12:57–59

Tilman, D., K. G. Cassman, P. A. Matson, R. Naylor, and S. Polasky. 2002. Agricultural sustainability and intensive production practices. *Nature 418:* 671-677. doi:10.1038/nature01014

Utley, P. R., N. W. Bradley, and J. A. Boling. 1970. Effect of Restricted Water Intake on Feed Intake, Nutrient Digestibility and Nitrogen Metabolism in Steers. *J. Anim. Sci 31*:130-135. doi: 10.2527/jas1970.311130x

Valente, E. E. L., M. L. Chizzotti, C. V. R. Oliveira, M. C. Galvão, S. S. Domingues, A. C. Rodrigues, and M. M. Ladeira. 2015. Intake, physiological parameters and behavior of Angus and Nellore bulls subjected to heat stress. *Semina: Ciências Agrárias 36*: 4565-4574. doi: 10.5433/1679-0359.2015v36n6Sup2p4565

Ward, F. A., and A. Michelsen. 2002. The economic value of water in agriculture: concepts and policy applications. *Water Policy 4:* 423-446. doi:10.1016/S1366-7017(02)00039-9

Willms WD, Kenzie O, Quinton D, et al. *The water source as a factor affecting livestock production.* In: Rode LM, editor. Animal science research and development: meeting future challenges. Proceedings, Canadian Society of Animal Science. Ottawa (Canada): Minister of Supply Services, Canada; 1996. p. 41–6.

Winchester, C. F., and M. J. Morris. 1956. Water intake rates of cattle. *J. Anim. Sci. 15*: 722-740. doi: 10.2527/jas1956.153722x

Wright, C.L. Management of Water Quality for Beef Cattle. 2007. *Vet Clin Food Anim 23* (2007) 91–103

Zanetti, D., Prados, L. F., Menezes, A. C. B., Silva, B. C., Pacheco, M. V., Silva, F. A., ... & Valadares Filho, S. C. (2019). Prediction of water intake to Bos indicus beef cattle raised under tropical conditions. *J. Anim. Sci.* 97(3), 1364-1374.

Zanetti, D., L. A. Godoi, M. M. Estrada, T. E. Engle, B. C. Silva, H. M. Alhadas, M. L. Chizzotti, L. F. Prados, L. N. Rennó, and S. C. Valadares Filho. 2017. Estimating mineral requirements of Nellore beef bulls fed with or without inorganic mineral supplementation and the influence on mineral balance. *J. Anim. Sci.* 95: 1-12. doi: 10.2527/jas.2016.1190.