Nutrient Requirements of Zebu and Crossbred Cattle

BR-CORTE

Fourth Edition

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Animal Nutrition (Centre Mondial de lInnovation Roullier, Roullier Group, Saint-Malo, France). Between 2017 and 2022 he was Editorial Board Member of the Journal of Animal Science. He has experience in the area of Nutrition and Production of Ruminants, working mainly on the following topics: nutrition of beef cows, gestational nutrition and fetal programming, strategic supplementation of grazing beef cattle, nutritional requirements of beef cattle and data analysis in animal agriculture.

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Summary

Brazil is one of the last agricultural frontiers in the world and has the largest commercial herd. Our challenge is to increase productivity, since national production indexes are still relatively low, despite of considerable improvement occurred on recent years. The use of new technologies is essential to improve animal productivity of Brazilian beef cattle. One way to increase animal productivity is to improve the nutritional requirements systems, using data produced under tropical conditions, making more efficient activity.

Experiments conducted in Brazil evaluating the nutritional requirements of cattle, in contrast to other countries, are relatively new, and started only in the 70s. Especially, professors José Fernando Coelho da Silva and Celso Boin at *Universidade Federal de Viçosa* (UFV) and *Escola Superior de Agricultura Luiz de Queiroz* (ESALQ), respectively, who were the pioneers in this research area in Brazil. Later, other professors/researchers from other institutions started their research in this theme. The first publication on this subject was made at the International Symposium on Nutritional Requirements of Ruminants in October of 1995 in Viçosa, Minas Gerais.

In June of 2006, during the V SIMCORTE, the first edition of Nutritional Requirements of Zebu and Feed Composition system was published, named BR-CORTE. Only data of Zebu cattle was used with a small number of individual data (187 observations).

The second edition of the BR-CORTE was published in June of 2010, during the VII SIMCORTE. This edition included Zebu and their crosses with beef cattle. In this version, the database (752 individual observations) was increased and could be considered reliable.

Subsequently, a software was developed to formulate diets and to calculate the nutritional requirements, named BR-CORTE 1.0, which was made available online on the website www.brcorte.com.br in June of 2012. This software has been updated in 2014, including performance prediction, named BR-CORTE 2.0, also available on the same website.

The third edition of Nutrient Requirements of Zebu and Crossbred cattle (BR-CORTE) included four new chapters, using a new and updated database to estimate the nutritional requirements of cattle, being the only system specifically described for Zebu cattle. The committee of this third edition was composed of members from different universities in Brazil: UFV-MG, UFBA-BA, UFLA-MG, UFMG-MG and UESC-BA.

The fourth edition of the Nutritional Requirements of Zebu and Crossbred beef cattle – (BR-CORTE, 2023), included 5 new chapters: 1- Experimental and commercial carcass weight estimation; 2- Water intake estimation; 3- A review on vitamins for beef cattle; 4- Additives for beef cattle; 5- The final chapter presented the nutritional requirement tables of all nutrients. New information was added to the database, allowing new equations to be adjusted in different chapters. The committee for this fourth edition was composed of members from different universities: UFV-MG, UFBA-BA, UFLA-MG, UFMG-MG, UESC-BA, UDESC-SC e IFSULDEMINAS- MG.

Chapter 1 provides equations to estimate body weights of cattle in different physiological conditions. Equations to estimate shrunk body weight from body weight and empty body weight from shrunk body weight, using allometric models are presented. New equations were fitted to estimate shrunk body weight from body weight.

Chapter 2 presents equations for estimating dry matter intake (DMI) of beef cattle, including dairy crossbred, composed of Zebu, especially Gyr, crossed with dairy breeds, especially Holstein cattle. A new equation was adjusted to estimate feedlot zebu feed intake. Moreover, equations to estimate DMI of animals fed different concentrate levels in the diet were developed and an equation from animals raised on pasture receiving supplements.

Chapter 3 presents different techniques to measure rumen degradable protein, including equations to estimate microbial contamination in the residues of ruminal incubation in roughage and concentrate. Moreover, the equations developed to estimate the microbial protein synthesis, from crude protein and TDN intakes were maintained. A new equation was fitted to estimate urinary creatinine excretion.

Chapter 4 presents the equations to estimate feed energy value, in terms of TDN, digestible energy and metabolizable energy from its chemical composition. In this chapter, equations to estimate digestion and passage rates of potentially digestible neutral detergent fiber were proposed. Due to lack of new information, this chapter has not been changed.

Chapter 5 presents the prediction of carcass and empty body composition of zebu and crossbred beef and dairy cattle, using the cut between the 9th and 11th ribs. Equations to estimate the composition of non-carcass components are also presented. In addition, several equations were included to estimate body composition from measurements obtained using dual-energy X-ray densitometry (DXA) in seven half-carcass sections.

Chapter 6 is new and discusses the main factors that affect beef yield and carcass composition. We emphasize that estimating carcass weight from BW properly allows nutritionists to make more precise adjustments in nutrition and management during the production cycle, as well as helping to define the best moment for slaughter. Thus, equations are presented to predict experimental and commercial carcass weight, subcutaneous fat thickness, as well as body weight loss during transport of Zebu cattle.

Chapter 7 evaluates the use of the respirometry technique for estimating the net energy from diet and the efficiency of metabolizable energy (ME) use for maintenance, weight gain, pregnancy and lactation. Moreover, an equation is presented to estimate metabolizable energy from the dietary digestible energy concentration. Also some equations are presented for estimating methane production.

Chapter 8 provides the energy requirements for maintenance and weight gain of Zebu and crossbred cattle of different sexual conditions. This chapter discusses the requirements for cattle on feedlot or pasture. Also, the maturity weight of Zebu and crossbred from different sexes was estimated, making possible to use a single equation to estimate net energy requirements for gain adjusted to different sexes and crosses. Furthermore, new equations are presented to estimate energy requirements using carcass weight and carcass gain instead of empty body weight.

Chapter 9 presents the equations to estimate the metabolizable protein requirements for maintenance, and a new and unique equation to estimate the net protein requirements for weight gain of cattle of different crosses and sex classes. It also presents as a novelty the requirements of liquid and metabolizable amino acids for weight gain. At the end of the chapter, results of

two experiments are presented comparing the performance of cattle fed diets containing different crude protein levels.

Chapter 10 presents net requirements, true retention coefficients, and dietary requirements for all minerals. It was included a discussion of inorganic mineral sources, comprising oxides, chlorides, and sulfates; and organic, which includes minerals complexed or associated with organic molecules (complexes and chelates), such as polysaccharides, amino acids or proteins. Also, it was included the bioavailability of organic minerals. Finally, this publication presents some information not available in the international literature on micromineral requirements.

Chapter 11 describes energy and protein requirements for maintenance and pregnancy of Zebu cows. The metabolizable energy efficiency for pregnancy is presented. Considering the scarcity of information on pregnancy requirements, this chapter has not been updated, and the recommendations of the previous edition are maintained.

Chapter 12 shows energy, protein and mineral requirements for lactating Nellore cows and their calves. This edition includes new equations to estimate the dry matter intake of lactating cows and the milk production of multiparous and primiparous Nellore cows.

Chapter 13 discusses regarding to environmental management. Considering that this subject has been much debated lately, the third edition tested equations described in the literature to estimate the excretion of nitrogen compounds (N) and phosphorus (P). As these equations did not adequately estimate these excretions, equations were adjusted to estimate N and P excretions in the environment for tropical conditions. Considering the scarcity of new data on N excretion, this chapter has not been updated, and the recommendations of the previous edition are maintained.

Chapter 14 is new and addresses the prediction of water intake for beef cattle, showing the factors that influence water intake. We emphasize that several equations in the literature were tested and did not validate the water intake of zebu cattle in tropical conditions. Thus, an equation was fitted to predict water intake by beef cattle in tropical conditions.

Chapter 15 is new and discusses the main aspects related to water-soluble and fat-soluble vitamin supplementation for beef cattle. In addition, two studies evaluating the effects of vitamin supplementation on the productive performance, physiology and metabolism of feedlot Nellore cattle raised in tropical conditions are presented.

Chapter 16 is new and presents a review of the main additives available for beef cattle in Brazil. Subsequently, a meta-analysis on the effects of monensin and functional oils on the productive performance and ruminal parameters of cattle raised under Brazilian conditions is presented. Also, it was included the results of a research that jointly evaluated six additives.

Chapter 17 is new and shows a compilation of the nutrient requirements for energy, protein and minerals for zebu and crossbred beef and dairy cattle of different sexual conditions, and for lactating Nellore cows and their lactating calves, in the form of different tables.

We hope this book will help farmers and researchers involved in beef cattle production.

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Adjusting cattle body weight to physiological and feeding conditions

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The result of weighting cattle does not represent the true weight of its body. Approximately 10–20% of the body weight of cattle measured by a scale is the content of the gastrointestinal tract. This proportion may vary depending on whether the animal is fed or fasting. The ratio between the weight on the scale and the true body weight of an animal can also vary as a function of age. In females, these ratios also vary according to the physiological stage (non-pregnant, lactating, and pregnant). To measure growth and performance, or estimate nutrient requirements of beef cattle, the true weight of their constituents must be known exactly. This chapter describes mathematical models developed from experiments carried out to estimate, with the maximum possible accuracy, the body weight of a bovine as a function of its feeding state and physiological conditions.

INTRODUCTION

The BR-CORTE system and all the other beef cattle feeding systems currently in use (NRC, ARC, AFRC, CSIRO, INRA, etc.) are the result of extensive and painstaking research. In these situations, animals are weighed rigorously and precisely, and variations in weight are normally taken by weighing after a period of fasting or by weighing the body constituents after slaughter.

The aim of weighing after fasting is to have a mean closer to the true body weight of the animal (empty body weight). Weighing after fasting improves experimental precision because there is a reduction in the proportion of the observed weight that results from filling (gastrointestinal tract contents). Variations in gastrointestinal tract contents (GIT) are considered to be the greatest source of error when measuring body weight gain in ruminants (Lofgreen et al., 1962).

Estimates of nutrient requirements from the BR-CORTE system are obtained mostly by meta-analyses through comparative slaughter experiments. These cases provide the true weight of the animal, because immediately after slaughter, the GIT is washed and weighed empty, then joined to other portions of the animal's body to form an exact measurement of the mass of an animal, the empty body weight (EBW). Because it represents exactly the animal mass, the EBW is used as a base to calculate most of the nutrient requirements in the BR-CORTE and in other feeding systems. However, fasting animals are rarely weighed in beef cattle production systems in Brazil. Therefore, methods are necessary to accurately estimate the shrunk and empty body weights of the animals as a function of their body weights collected in field conditions.

Variation in the ratios among fed, fasting and empty body weight can be affected by sex, genetic group, and animal weight. Little attention has been paid to these ratios and to the factors that act on them in previous editions of feeding systems around the world.

This chapter was written aiming to establish weighing ratios in beef cattle and the definitions of weighing, so that the necessary measurement can be accessed correctly from a measurement obtained in the field to estimate the nutrient requirements of the animal.

DEFINITIONS OF WEIGHING IN RESEARCH AND IN FIELD CONDITIONS

Although people usually refer to the weight of an animal, in fact, its mass is being considered. Mass and weight are different physical values: mass is an inert value while weight is a vector value. Mass is the quantity of matter present in a body and measured on scales, whose standard unit in the International System of Units is kilogram (kg). Weight is the product of the mass of a body and the local gravity acceleration, which depends on the attraction that one body exercises over the others, as given by gravity acceleration, whose

standard unit in the International System is Newton (N). However, on Earth's surface, the force of gravity is constant, and therefore the mass-weight ratios do not usually vary. Thus, although the weight of an animal is referred to, mass is being considered. Although this is a conceptual error, it does not alter the practical use of the concept of mass. Therefore, when there is a reference to an animal with a weight of 300 kg, what is truly considered is a mass of 300 kg, or a true weight of 300 force kilograms or approximately 3000 Newtons.

The simplest measurement used to refer to the mass of an animal is the result of weighing the animal in normal feeding conditions, carried out at any time of the day. This measurement is normally referred to as live weight or body weight (BW), although there are no practical differences between both. The term BW is adopted in this system. This measurement represents the weight of the animal in fed status (fed weight), which is also called "full weight". Although in the field there is no determined time to take this measurement, under research conditions, to establish standardization, and searching for the least possible variability, the animal is always weighed in the morning, between 05:00 and 07:00 A.M..

Although BW is the most used weighing measurement in practice, in research, weighing in fasting is preferred to reduce the filling effect and improve the precision of the measurements. Weighing the animals after a defined period of fasting from solids reduces the percentage of measurements taken that represents GIT filling. There are suggestions to weigh animals after fasting varying from 12 to 16 hours. In all the studies that form the base of the BR-CORTE System, weighing in fasting is carried out after 16 hours fasting from solids, and the measurement is given the name of shrunk body weight (SBW). In experiments comparing weight gain of animals submitted to different treatments, the SBW has been considered the most adequate measurement to be taken at the beginning and at the end of the experiment. It is used to calculate the shrunk average daily gain (SADG) as the difference between the final and initial weights in fasting, divided by the number of days of assessment. However, this measurement has always been referred to as average daily gain (ADG), even when taken from the differences between weighs during fasting. Unlike the SADG, the ADG represents, in theory, the average daily gain calculated based on the difference of two weightings without fasting (BW). Although they are theoretically different, differences have not been expressed between the two measurements (SADG and ADG). In practice, the differences are negligible (0.56%, based on the database of the BR-CORTE System), so that the use of ADG is not problematic when taken from different weightings in fasting or from different weightings in fed animals. However, it should be noted that the ADG measurement should be obtained from the difference between two weightings in the same fed status. That is, if the initial weighing was taken in fasting, the final weighing should also be taken in fasting.

Although the SBW represents the mass of an animal more accurately than the BW, there is still a considerable fraction of GIT content in the SBW measurement. The accurate measurement of body mass can only be obtained by weighing the animal completely free of GIT. As it is impossible to take such a measurement with live animals, the EBW value is only obtained after slaughtering the animal, when the GIT is washed, and its weight added to the other body constituents. Most of the values for cattle nutritional requirements are calculated from the EBW, because EBW represents the true body mass of the animal. The true accumulation of body weight obtained after a determined assessment period, divided by the number of days of assessment, is named the empty body gain (EBG).

Estimates of energy requirements adopted by the cattle feeding systems are expressed in metabolic size unit. Metabolic size is a concept that was created to compare the metabolic rates of animals with different body sizes (Kleiber, 1932, 1947; Brody, 1945; Kleiber, 1965; White and Seymour, 2005). It is based on the observation that the surface area of two bodies with similar shape and density is proportional to ¾ of their weight. Consequently, the metabolic rates of these different bodies are proportional to their weights, raised to the power of 0.75 ($BW^{0.75}$), a value obtained from comparing the heat production in fasting of adult animals from

different species (Brody, 1945). In the BR-CORTE System, the metabolic size concept is used to express energy requirements for maintenance, where the necessary expenditure for maintenance is expressed in units of metabolic empty body weight ($EBW^{0.75}$).

Another weight relationship used by the BR-CORTE System is the equivalent weight or equivalent empty body weight (EQEBW). The EQEBW is a measurement based on the estimated weight at animal maturity. The weight at maturity represents the weight at which the growth of muscle mass practically stops, and from then on significant growth occurs only through the accumulation of energy reserves, which can also be determined from the body fat content. The EQEBW is, therefore, a ratio used to describe animals from different sexes or genetic groups on the same scale of proportion of weight at maturity. It is used to simplify the expression of energy requirements for growth, as animals of different sexes or genetic groups reach maturity with different EBW.

The Table 1.1 shows a summary of the abbreviations, practical and theoretical definitions of the different ways of expressing animal mass used in the BR-CORTE System. The suggested ways to estimate the ratios between the units presented in Table 1.1 are described in the following items.

Table 1.1 - Weighing definitions used in the BR-CORTE system

Abbreviation	Definitions found	True definition	How to obtain
BW	Body weight, live weight, fed weight	Animal mass with feed and water permanently available (kg)	Weigh the animal without fasting from solids or liquids, between 05:00 and 07:00 A.M.
SBW	Shrunk body weight, shrunk weight	Animal mass measured after 16 hours fasting from solids (kg)	Weigh the animal in the morning, after 16 hours fasting from solids
EBW	Empty body weight	Animal mass without the gastrointestinal tract content or true mass of the body constituents of the animal (kg)	Immediately after slaughter, wash the gastrointestinal tract and weigh empty. Add the weight of the empty gastrointestinal tract to the other body constituents (hide, blood, carcass, viscera, head, limbs, etc. …)
$EBW^{0.75}$	Metabolic empty body weight	Animal mass without gastrointestinal tract contents raised to the power of 0.75 or empty metabolic mass (kg)	Raise the EBW to the power of 0.75
EQEBW	Equivalent empty body weight	Animal mass without the gastrointestinal tract contents proportional to the weight at maturity of a reference animal	Divide the EBW by the weight at maturity of the respective sex/genetic group and multiply by the reference weight

DATABASE FOR WEIGHT ADJUSTMENTS

In the last edition of BR-CORTE (BR-CORTE, 2016), a database containing information from 40 experiments carried out in Brazil from 1991 to 2016 was used to establish the weight ratios (BW to EBW and ADG to EBG) for growing and finishing animals (Table 1.2). A histogram of the frequency distribution of the SBW variable is shown in Figure 1.1.

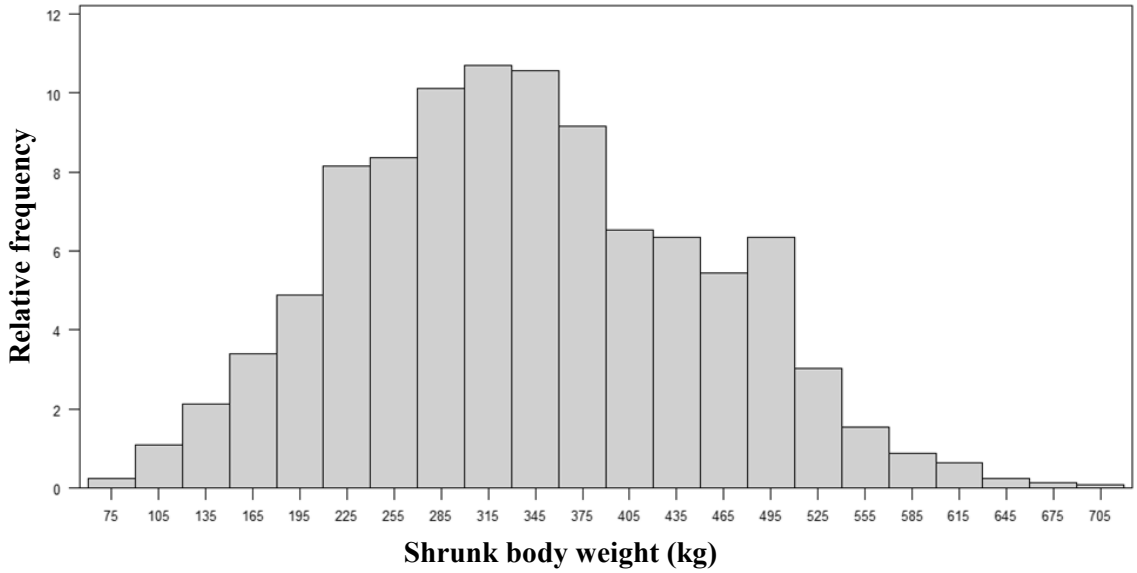


Figure 1.1 - Histogram of the frequency distribution of the SBW variable.

Table 1.2 - Description of the database used to establish weight ratios in the BR-CORTE (2016)

Item[1]	Variable								
	BW (kg)	SBW (kg)	EBW (kg)	ADG (kg/d)	SADG (kg/d)	EBG (kg/d)	SBW/BW	EBW/SBW	EBG/ SADG
N	409	2,855	1,514	129	1,020	1,020	409	1,514	953
Minimum	81.0	74	63	-0.24	-0.54	-0.55	0.90	0.76	0.71
Mean	381	340	290	0.77	0.91	0.88	0.98	0.88	0.96
Median	388	333	285	0.89	0.94	0.90	0.98	0.88	0.96
Maximum	710	701	600	1.61	2.66	2.74	1.01	0.97	0.98
SD	144	111	93.0	0.44	0.52	0.52	0.02	0.04	0.21
CV (%)	38.0	33.0	32.0	58.0	57.0	59.0	2.00	5.00	22.0

[1]SD = standard deviation; CV = coefficient of variation.

WEIGHT RATIOS

After assessing adherence to the normal distribution, the first step to check the weight ratios to be used in the BR-CORTE (2016) was to assess the fit of models that best describe these statistical and biological relationships. In the second edition of BR-CORTE (BR-CORTE, 2010) linear relationships between EBW and SBW, and between EBG and SADG were established and presented in the energy requirements chapter (Marcondes et al., 2010). The BW:SBW ratio was not estimated in the BR-CORTE in 2010, and the fixed ratio as suggested (SBW = BW × 0.96) by the NRC (2000) was adopted.

The use of linear weight relationships implies that the proportions of fasting weight lost in the BW and GIT content in the SBW are constant and do not vary with increasing animal weight. There is evidence, however, that these relationships are not linear (Gionbelli et al., 2015). Therefore, in the last edition of this publication (BR-CORTE, 2016), the fit was assessed using two mathematical model structures (linear and non-linear) for the relationships between weights, as showed in Table 1.3. The structures of the model presented in Table 1.3 were compared by the Akaike Information Criterion (AIC) (Akaike, 1974). For all the relationships assessed, the use of the non-linear model, although with a greater number of parameters, presented the lowest AIC value, indicating the best fit. Analysis of the relationship between predicted and observed values was carried out by fitting simple linear regression (predicted values = X, observed values = Y) to assess the quality/lack of fit of the nonlinear models to the three ratios. In this case, the hypothesis that $\beta_0 = 0$ and $\beta_1 = 1$ was accepted ($P \geq 0.89$). The probability of a better fit of the non-linear model in relation to

the linear model was estimated by calculating the evidence ratio for the absolute difference between the estimated AIC values for the fit of the two model structures (Motulsky and Christopoulos, 2003). The result of the evidence ratio (or relative probability) of the AIC favorable to the nonlinear model is also shown in Table 1.3 and can be interpreted as the probability that the non-linear model presents a better fit than the linear model.

In addition, applying non-linear models to the weight ratios shown in Table 1.3 is also more adequate from a biological point of view, as it considers that the weight ratios and gain rate vary as the animal varies in weight. For the EBW:SBW ratio, for example, it is suggested that the proportion of the SBW that is represented by GIT fill decreases with the increase in size of the animal. Then the effects of feeding system (pasture × feedlot), sex and genetic group on the weight ratios were tested, as described in the following items.

Table 1.3 - Weight ratios, structures of models assessed to describe the weight ratios and value of the Akaike Information Criterion evidence ratio favorable to use of the non-linear model

Ratio	Linear model	Non-linear model	AIC evidence ratio favorable to the non-linear model
$SBW = f(BW)$	$SBW = a \times BW$	$SBW = a \times BW^{b}$	89%
$EBW = f(SBW)$	$EBW = a \times SBW$	$EBW = a \times SBW^{b}$	80%
$EBG = f(ADG)$	$EBG = a \times ADG$	$EBG = a \times ADG^{b}$	100%

Estimating shrunk body weight (SBW) from body weight (BW)

Although weighing after a 12 to 16 hour fasting from solids presents a lower value than weighing a fed animal, the need to establish a relationship between SBW and BW for Zebu cattle and their crosses has only been observed recently. Although the difference between BW and SBW is not greater than 5%, it is extremely important to consider it, because it represents the first connection between measurements obtained in experiments (SBW) and measurements taken in the day-to-day of productive systems (BW).

For the lastest edition of BR-CORTE (BR-CORTE, 2016), BW and SBW data were collected over 6 years (from 2010 to 2016) from the same animals in most of the experiments carried out to compose its database. Then, the animals were weighed in fed status on one day (BW); solid food was removed 16 hours before the next weighing that was performed at the same time on the next day (SBW). In this way, 409 BW and SBW measurements were obtained for the same animals, with a one-day interval. The value of one day of ADG obtained in the assessment period in which these measurements were taken was discounted from the SBW value to correctly establish the ratio, because these measurements had been taken with one day of difference.

Since measurements of the SBW:BW ratio had begun recently, only data from Zebu and crossbred dairy cattle were available for writing this chapter in 2016. The number of experiments carried out with animals of different sexes was also sufficient to assess the effect of sex on the meta-analysis. Therefore, only the test of the possible difference between Zebu and crossbred dairy animals kept in feedlot, regardless of sex, was considered.

Non-linear models to estimate the SBW as a function of the BW were fitted to the data from Zebu and dairy crossbred by the NLMIXED procedure of SAS considering effect of repeated measures when the BW and SBW measurements were taken more than once on the same animal. An *F* ratio was calculated to test whether the estimate of specific parameters for each genetic group significantly improved the fit of the data in relation to the use of single parameters for both genetic groups. The P value for F-distribution applied to the calculated ratio showed there was statistical gain for the fit of

different parameters for Zebu and dairy crossbred compared to the use of single parameters (P=0.007). Then the effects of the genetic group were tested on each of the parameters of the nonlinear model using the ESTIMATE function of the NLIN procedure of SAS. Differences were observed between Zebu and dairy crossbred for the parameters *a* (P<0.003) and *b* (P<0.004). Thus, two models were generated with independent parameters for Zebu and dairy crossbred in the last edition of this publication (BR-CORTE, 2016), as follows:

Zebu cattle:

$$SBW = 0.8800 \times BW^{1.0175} \quad \text{Eq. 1.1}$$

Crossbred dairy cattle:

$$SBW = 0.9664 \times BW^{1.0017} \quad \text{Eq. 1.2}$$

where SBW = shrunk body weight and BW = body weight.

An example of the use of the equations proposed in 2016 to estimate the SBW of animals from different genetic groups from different BW values is shown in Table 1.4. It was observed for Zebu animals that the proportional weight loss as a function of 16 hours fasting solids was greater when the size of the animal was smaller and close to that attributed by the NRC (2000) only in light animals (approximate 150 kg). Although they are data from growing and finishing animals, the variation in the ratio as a function of weight increase is similar to that observed for adult Zebu cows (Gionbelli et al., 2015). In dairy crossbred, the mean ratio between SBW and BW is practically linear and greater than that attributed by the NRC (2000).

Table 1.4 - Application of Eq. 1.1 and Eq. 1.2 to estimate shrunk body weight from body weight according to BR-CORTE (2016)

BW (kg)	SBW (kg)		SBW/BW		Difference in weigh (kg)		Decrease in BW (%)	
	Zebu	Crossbred dairy cattle	Zebu	Crossbred dairy cattle	Zebu	Crossbred dairy cattle	Zebu	Crossbred dairy cattle
150	144.1	146.2	0.961	0.975	5.9	3.8	3.9	2.5
300	291.7	292.7	0.972	0.976	8.3	7.3	2.8	2.4
450	440.7	439.4	0.979	0.976	9.3	10.6	2.1	2.4
600	590.5	586.2	0.984	0.977	9.5	13.8	1.6	2.3

For beef crossbred, although it was not possible to establish the ratio based on real data at that time, the use of Eq. 1.2 (dairy crossbred) was suggested because the BW-GIT fill ratios of these animals are more similar to those observed for crossbred dairy cattle as opposed to Zebu (Lana et al., 1992). It is also considered more appropriate to use Eq. 1.2 than the fixed ratio adopted by the NRC (2000) (0.96) because it was developed from animals raised under tropical conditions.

Although the equations proposed in the BR-CORTE (2016) were generated from animals in feedlot, it was considered more prudent at that time to estimate SBW from BW using Eq. 1.1 (the experiments with animals on pasture, that are part of the last edition of this publication, were carried out mostly with Zebu animals) than to calculate or use the fixed ratio of 0.96. The EBW estimate of the animals on pasture was obtained from the SBW data of experiments carried out on pasture, where the animals were confined in a paddock with solids fasting until the SBW was measured, always in the morning.

Several studies evaluating the SBW:BW ratio of feedlot cattle from different genotype (Zebu, beef crossbred, and dairy crossbred) and sex (bulls, steers, and heifers) have been performed in Brazilian conditions since the last publication of BR-CORTE (BR-CORTE, 2016), which allowed authors to expand this database and better evaluate this relationship according to cattle genotype and sex in the current edition. The same statistical procedures were caried out using the extended database.

No differences for the parameters *a* and *b* ($P < 0.05$) were observed between Zebu and crossbred beef cattle, regardless of sex. However, both *a* and *b* parameters were different for crossbred dairy cattle. Thus, two new models were recommended, being one for Zebu and crossbred beef cattle and the other for crossbred dairy cattle in the current edition of this publication, as follows:

Zebu and Crossbred beef cattle:

$$SBW = 0.8915 \times BW^{1.0151} \quad \text{Eq. 1.3}$$

Crossbred dairy cattle:

$$SBW = 0.9247 \times BW^{1.0085} \quad \text{Eq. 1.4}$$

where SBW = shrunk body weight and BW = body weight. Unfortunately, we still have a low number of observations of cattle raised on pasture. Therefore, the authors considered that it was more appropriate to estimate SBW from BW cattle raised on pasture using Eq. 1.3 (the experiments with animals on pasture that are part of the last editions of this publication were carried out mostly with Zebu animals).

Estimations of SBW of animals from different genetic groups from different BW values based on the new recommended equations are shown in Table 1.5.

Table 1.5 - Application of Eq. 1.3 and Eq. 1.4 to estimate shrunk body weight (SBW) from body weight (BW)

BW (kg)	SBW (kg)		SBW/BW		Weight difference (kg)		Weight difference (%)	
	Zebu/ Crossbred Beef cattle	Crossbred Dairy cattle	Zebu/ Crossbred Beef cattle	Crossbred Dairy cattle	Zebu/ Crossbred Beef cattle	Crossbred Dairy cattle	Zebu/ Crossbred Beef cattle	Crossbred Dairy cattle
150	144.2	144.7	0.961	0.964	5.8	5.3	3.9	3.5
300	291.5	291.2	0.971	0.972	8.5	8.8	2.8	2.9
450	439.9	438.3	0.978	0.974	10.1	11.7	2.2	2.6
600	589.1	585.8	0.982	0.976	10.9	14.2	1.8	2.4

Estimating empty body weight (EBW) from shrunk body weight (SBW)

The last edition of this publication (BR-CORTE, 2016) presented abundant data (n=1514, Table 1.2) to establish the relationship between EBW and SBW. Therefore, the effects of feeding system, sex and genetic group were tested on the parameters of the linear model fitted to the ratio. The *F* test showed that there was statistical improvement (P<0.04) in the fit of the separate models, according to the different classes of the fixed effects tested (feeding system, sex and genetic group).

Data from animals raised on pasture were contrasted with data from animals of the same genetic groups (Zebu and crossbred dairy cattle) and sexes (steers and bulls) raised in a feedlot by meta-analysis considering only the fixed effect of the feeding system and random effects of sex, genetic group and experiment (number of experiments with variation in sex and genetic group did not allow comparison to fit the parameters for these effects). Feeding system influenced both parameters of the non-linear model (P<0.01). A non-linear model was then fitted to establish the relationship between EBW and SBW of animals on pasture, as follows:

$$EBW = 0.8507 \times SBW^{1.0002} \quad \text{Eq. 1.5}$$

where EBW = empty body weight and SBW = shrunk body weight.

The Eq. 1.5 showed that the EBW:SBW ratio was practically linear in animals raised on pasture. Although the number of experiments has increased, the ratio was close to that proposed in the second edition of the BR-CORTE (BR-CORTE, 2010; EBW = 0.863 × SBW).

For animals in feedlot, significant effects were observed for sex and genetic group interactions on the parameters of the non-linear model (P<0.003). However, differences were not observed between dairy and beef crossbred for parameters *a* (P>0.70) and *b* (P>0.63). Because of this, independent models were fitted considering the differences among bulls, steers, and heifers, and between Zebu animals and their crosses (dairy or beef) in the last edition of this publication (Table 1.6).

Table 1.6 - Equations proposed in the BR-CORTE (2016) for predicting empty body weight (EBW) from shrunk body weight (SBW) of feedlot cattle

Genetic group	Sex	Equation	Number
Zebu	Bulls	$EBW = 0.8126 \times SBW^{1.0134}$	Eq. 1.6
	Steers	$EBW = 0.6241 \times SBW^{1.0608}$	Eq. 1.7
	Heifers	$EBW = 0.6110 \times SBW^{1.0667}$	Eq. 1.8
Crossbred beef and dairy cattle	Bulls	$EBW = 0.7248 \times SBW^{1.0314}$	Eq. 1.9
	Steers	$EBW = 0.6586 \times SBW^{1.0499}$	Eq. 1.10
	Heifers	$EBW = 0.6314 \times SBW^{1.0602}$	Eq. 1.11

In the second edition of the BR-CORTE (BR-CORTE, 2010), a single linear ratio was proposed to establish the ratio between EBW and SBW for feedlot animals (EBW = 0.895 × SBW). Considering the estimates of Eq. 1.6 to Eq. 1.11, and animals from 150 to 600 kg SBW, it was observed that the EBW:SBW ratio in Zebu and their crosses on feedlot ranged from 84.6 to 93.6%, with a mean of 89.7% (0.897), a similar value to that adopted for animals in feedlot in the second edition of the BR-CORTE (BR-CORTE, 2010). Although this suggests that the EBW:SBW ratio may vary from 85–95%, the NRC (2000) suggests the use of a fixed ratio of 0.891. However, the use of multiple equations with effects of sex and genetic group to estimate EBW, as proposed in the last edition of this publication (BR-CORTE, 2016), improves the accuracy and precision of the estimates of EBW. Table 1.7 shows an example of applying Eq.1.5 (pasture) and Eq. 1.6 (feedlot) to estimate EBW for Zebu bulls. An example of the variability in the EBW and SBW ratios obtained from Eq. 1.6 to Eq. 1.11 is shown in Table 1.8.

Table 1.7 - Example of applying Eq. 1.5 and Eq.1.6 to estimate empty body weight from shrunk body weight of Zebu bulls on pasture and feedlot

BW (kg)	SBW (kg)	Pasture		Feedlot	
		EBW (kg)	EBW/SBW	EBW (kg)	EBW/SBW
150	144.2	122.8	0.852	125.2	0.869
300	291.5	248.3	0.842	255.6	0.877
450	439.9	374.7	0.852	387.9	0.882
600	589.1	501.8	0.852	521.5	0.885

Table 1.8 - Ratio between empty body weight and shrunk body weight (EBW/SBW) in Zebu and their crosses, on feedlot, at different weights, estimated from Eq. 1.6 to Eq.1.11

SBW (kg)	Bulls		Steers		Heifers	
	Zebu	Crossbred	Zebu	Crossbred	Zebu	Crossbred
150	0.869	0.847	0.884	0.844	0.851	0.852
300	0.877	0.866	0.881	0.874	0.892	0.888
450	0.882	0.877	0.904	0.892	0.917	0.911
600	0.885	0.885	0.920	0.905	0.935	0.927

The relationship between EBW and SBW were also evaluated with the expanded database as described in the last section. However, no statistical improvement was observed when the new data was included in the BR-CORTE (2016) database. Therefore, the current committee decided to maintain the recommendations of the last edition of this publication (BR-CORTE, 2016) for predicting EBW from SBW of cattle raised in pasture and feedlot.

Estimating empty body gain (EBG) from the average daily gain (ADG)

The relationship between EBG and ADG was also evaluated in the last edition of this publication (BR-CORTE, 2016). First, an assessment of the relationship between the SADG (measured from two weightings after fasting) and the ADG (measured from two weightings in fed status), regressed as a function of the SADG, showed that the intercept and the coefficient of inclination did not differ from 0 and 1 (P>0.14 and P>0.39, respectively). Therefore, the differences between SADG and ADG were not significant and the use of a single measurement, referred to only as ADG, could be adopted. That is, although they are theoretically different, in practice, SADG and ADG do not differ.

Statistical gains were not observed for the fitting of independent models instead of a single model as a function of feeding systems (P>0.16), sex (P>0.24) or genetic group (P>0.11). A single non-linear model was recommended to describe the relationship between EBG and ADG, as follows:

$$EBG = 0.9630 \times ADG^{1.0151} \qquad \text{Eq. 1.12}$$

where EBG = empty body gain and ADG = average daily gain or average daily gain in fasting.

An example of applying Eq. 1.12 is shown in Table 1.9. The EBG/ADG ratio ranged from 0.943–0.971 when considering gains of 0.25–1.75 kg/d. The second edition of BR-CORTE (BR-CORTE, 2010) suggested the use of a fixed EBG/ADG ratio of 0.955 for animals on pasture and 0.936 and 0.966 for Zebu and their crosses, respectively, in feedlot. The NRC (2000) uses a fixed relation of 0.951. The data in Table 1.9 show that the estimates proposed from Eq. 1.12 agree with the data in the literature. Nevertheless, there was a gain in precision and accuracy with the use of a variable EBG:ADG ratio, obtained from the non-linear model, as proposed in the last edition of this publication (BR-CORTE, 2016).

Table 1.9 - Ratio between the empty body gain and average daily gain (EBG:ADG) based on applying Eq. 1.12

ADG (kg/d)	EBG (kg/d)	EBG/ADG	Decrease in ADG (%)
0.25	0.24	0.943	5.7
0.50	0.48	0.953	4.7
0.75	0.72	0.959	4.1
1.00	0.96	0.963	3.7
1.25	1.21	0.966	3.4
1.50	1.45	0.969	3.1
1.75	1.70	0.971	2.9

As discussed in the previous section, no statistical improvement was obtained for the prediction of EBG from ADG when new data was included in the BR-CORTE (2016) database. Therefore, the recommendations of the last edition of this publication (BR-CORTE, 2016) are still valid for predicting EBG from ADG of cattle.

Thus, in the current edition of BR-CORTE, new equations are recommended to estimate shrunk body weight of zebu and crossbred beef cattle:

$$SBW = 0.8915 \times BW^{1.0151} \qquad \text{Eq. 1.3}$$

and another one for crossbred dairy cattle:

$$SBW = 0.9247 \times BW^{1.0085} \qquad \text{Eq. 1.4}$$

WEIGHT ADJUSTMENTS FOR ADULT COWS AS A FUNCTION OF FEEDING AND PHYSIOLOGICAL STATUS

The weight ratios presented so far are applicable to growing and finishing animals, in a condition of physiological homeostasis. That is, they are applicable to healthy animals, in a growth phase (intake > maintenance), that have not reached physiological maturity yet. In the case of females that have already reached physiological maturity, weight adjustment as a function of fed status and physiological state (pregnant or not) was described by Gionbelli et al. (2015) using Nellore multiparous cows. The equations proposed by Gionbelli et al. (2015) were recommended for weight adjustments of adult cows in the last edition of BR-CORTE (2016). These equations are still recommended in the current edition as no new data were generated since then.

To adjust pregnant cow weight, Gionbelli et al. (2015) suggested the concept of pregnant compound (PREG) as represented by:

$$PREG = (UTpreg - UTnp) + (UDpreg - UDnp) \quad \text{Eq. 1.13}$$

where PREG = pregnant compound, UTpreg = weight of the pregnant or gravid uterus, UTnp = weight of the non-pregnant uterus, UDpreg = udder weight of the pregnant cow and UDnp = udder weight for the cow in non-pregnant status. Then, the PREG value includes the increase in weight in the uterus that occurs as a function of pregnancy (pregnant uterus minus non-pregnant uterus) plus the increase in udder weight due to pregnancy (udder in the pregnant condition minus the udder of the cow in non-pregnant condition).

The use of PREG makes it possible to estimate the portion of a pregnant cow's as a function of pregnancy and the portion of weight as a function of maternal tissues.

The "gestational weight' of a cow is therefore separated from its "empty weight", regardless of the gestational stage. In general, pregnancy (referenced by PREG) is considered mathematically as an extra component of the cow. Thus, for example, the weight gain of a cow can be calculated over a period relative to the increase in maternal tissues and the weight gain due to pregnancy. Therefore, the concepts of gestational weight (BWpreg, SBWpreg, and EBWpreg) and non-gestational or non-pregnant weight (BWnp, SBWnp and EBWnp) were created; their relationships are simply described by:

$$BWpreg = BWnp + PREG$$

$$SBWpreg = SBWnp + PREG$$

$$EBWpreg = EBWnp + PREG$$

The weights adjusted to the pregnant and non-pregnant condition are also the base for calculating the nutritional requirements for adult cows for maintenance and pregnancy, described in Chapter 11.

The equations used to estimate the fed, shrunk or empty body weight for non-pregnant and pregnant cows are described in Table 1.10. The detailed description of the abbreviations used in the equations presented in Table 1.10 is shown in Table 1.11. Since estimates of pregnant cow weight ratios require the use of several equations (Table 1.10), Gionbelli et al. (2015) prepared an Excel spreadsheet to facilitate calculations. This spreadsheet can be downloaded directly from the site of the journal where the study was published (open access study), through the link: <http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0112111>.

Table 1.10 - Equations used to adjust weight of pregnant and non-pregnant Zebu cows

Variable to be estimated	Predicting variables	Ratio	Equation
		Non-pregnant cows	
SBWnp	BW	$SBWnp = 0.8084 \times BWnp^{1.0303}$	Eq. 1.14
EBWnp	SBW	$EBWnp = 0.8424 \times SBWnp^{1.0122}$	Eq. 1.15
		Pregnant cows	
SBWpreg	BWpreg	$SBWpreg = 0.8084 \times BWpreg^{1.0303}$	Eq. 1.14
BWnp	BWpreg and PREG	BWnp = BWpreg – PREG	Eq. 1.16
SBWnp	SBWpreg and PREG	SBWnp = SBWpreg – PREG	Eq. 1.17
PREG	If TG ≤ 240: UTfg If TG > 240: UTfg and UDfg	If TG ≤ 240: PREG=UTfg If TG > 240: PREG = UTfg + UDfg	Eq. 1.18
UTfg	UTpreg and UTnp	UTfg = UTpreg -UTnp	Eq. 1.19
UTpreg	TG or TG and BCS	$UTpreg = 0.008010 \times CBW \times BCS^{0.3225} \times \exp^{((0.02544 - 0.0000286 \times TG) \times TG)}$ or $UTpreg = 0.007521 \times CBW \times \exp^{((0.03119 - 0.00004117 \times TG) \times TG)}$	Eq. 1.20 Eq. 1.21
UTnp	SBWpreg and UTpreg	If TG ≤ 240: UTnp = 0.0012 × (SBWpreg – UTpreg + 0.6) If TG > 240: UTnp = 0.0012 × (SBWpreg – UTpreg + 0.6 – 2)	Eq. 1.22
UDnp	UTfg, SBWpreg and BCS	If TG ≤ 240: $UDnp = (SBWpreg - UTfg) \times 0.00589 \times BCS^{0.2043}$ If TG > 240: $UDnp = (SBWpreg - UTfg - 2) \times 0.00589 \times BCS^{0.2043}$	Eq. 1.23
UDfg	UDnp and TG	If TG ≤ 240: UDfg = 0 If TG > 240: $UDfg = UDnp \times \exp^{((TG - 238) \times 0.0109)} - UDnp$	Eq. 1.24
EBWpreg	EBWnp and PREG	EBWpreg = EBWnp + PREG	Eq. 1.25

Table 1.11 - List of abbreviations (in alphabetical order) used in the equations presented in Table 1.10 and their definitions

Abbreviation	Definition
BCS	Body condition score (scale 1 to 9). When not available, use BCS=5
BWpreg	Pregnant body weight (kg)
BWnp	Non-pregnant body weight (kg)
CBW	Estimated weight of calf at birth (kg). It is suggested to use the mean weight of calves of the herd for which the estimates are being made.
EBWpreg	Pregnant empty body weight (kg)
EBWnp	Non-pregnant empty body weight (kg)
PREG	Pregnant compound (kg)
SBWpreg	Pregnant shrunk body weight (kg)
SBWnp	Non-pregnant shrunk body weight (kg)
TG	Days pregnant (d)
UDfg	Udder weight that increased as a function of pregnancy (kg)
UDnp	Udder weight for non-pregnant status (kg)
UTfg	Uterus weight that increased as a function of pregnancy (kg)
UTpreg	Weight of pregnant or gravid uterus (kg)
UTnp	Uterus weight for non-pregnant status (kg)

To show the applications of the equations and relationships shown in Table 1.10 (Gionbelli et al., 2015), we took as base a Nellore cow with 450 kg BW (weight obtained in the field, without fasting), BCS = 4.5 and five months pregnant (TG = 150 days). Assuming that the same cow has been weighed again four months later, when the following data were obtained: BW = 520 kg, BCS = 5 and TG = 270. It is further considered that the average weight at birth of the calves from such herd would be 35 kg (CBW = 35 kg). The equations and ratios presented in Table 1.10 can be used to estimate the shrunk and empty body weight and the weight of maternal constituents together with the pregnant compound, in the two weightings carried out, as follows:

First weighing	Second weighing (four months later)
BW = 450 kg / BCS = 4.5 / TG = 150 days / CBW = 35 kg	BW = 520 kg / BCS = 5 / TG = 270 days / CBW = 35 kg
$SBWpreg = 0.8084 \times BWpreg^{1.0303}$ (Eq. 1.14) $SBWpreg = 0.8084 \times 450^{1.0303} = 437.76$ kg	$SBWpreg = 0.8084 \times BWpreg^{1.0303}$ (Eq. 1.14) $SBWpreg = 0.8084 \times 520^{1.0303} = 508.07$ kg
$UTpreg = 0.00801 \times CBW \times BCS^{0.3225} \times \exp^{((0.02544 - 0.0000286 \times TG) \times TG)}$ (Eq. 1.20) $UTpreg = 0.00801 \times 35 \times 4.5^{0.3225} \times \exp^{((0.02544 - 0.0000286 \times 150) \times 150)} = 10.87$ kg	$UTpreg = 0.00801 \times CBW \times BCS^{0.3225} \times \exp^{((0.02544 - 0.0000286 \times TG) \times TG)}$ (Eq. 1.20) $UTpreg = 0.00801 \times 35 \times 5^{0.3225} \times \exp^{((0.02544 - 0.0000286 \times 270) \times 270)} = 56.33$ kg
$UTnp = 0.0012 \times (SBWpreg - UTpreg + 0.6)$ (Eq. 1.22) $UTnp = 0.0012 \times (437.76 - 10.87 + 0.6) = 0.51$ kg	$UTnp = 0.0012 \times (SBWpreg - UTpreg + 0.6 - 2)$ (Eq. 1.22) $UTnp = 0.0012 \times (508.07 - 56.33 + 0.6 - 2) = 0.54$ kg
$UTfg = UTpreg - UTnp$ (Eq. 1.19) $UTfg = 10.87 - 0.51 = 10.36$ kg	$UTfg = UTpreg - UTnp$ (Eq. 1.19) $UTfg = 56.33 - 0.54 = 55.79$ kg
$UDnp = (SBWpreg - UTfg) \times 0.00589 \times BCS^{0.2043}$ (Eq. 1.23) $UDnp = (437.76 - 10.36) \times 0.00589 \times 4.5^{0.2043} = 3.42$ kg	$UDnp = (SBWpreg - UTfg\text{-}2) \times 0.00589 \times BCS^{0.2043}$ (Eq. 1.23) $UDnp = (508.07 - 55.79\text{-}2) \times 0.00589 \times 5^{0.2043} = 3.68$ kg
UDfg = 0 kg (Eq. 1.24)	$UDfg = UDnp \times \exp^{((TG-238) \times 0.0109)} - UDnp$ (Eq. 1.24) $UDfg = 3.68 \times \exp^{((TG-238) \times 0.0109)} - 3.68 = 1.54$ kg
PREG = UTfg (Eq. 1.18) PREG = 10.36 kg	PREG = UTfg + UDfg (Eq. 1.18) PREG = 55.79 + 1.54 = 57.33 kg
SBWnp = SBWpreg – PREG (Eq. 1.17) SBWnp = 437.76 – 10.36 = 427.40 kg	SBWnp = SBWpreg – PREG (Eq. 1.17) SBWnp = 508.07 – 57.33 = 450.75 kg
$EBWnp = 0.8424 \times SBWnp^{1.0122}$ (Eq. 1.15) $EBWnp = 0.8424 \times 427.40^{1.0122} = 387.66$ kg	$EBWnp = 0.8424 \times SBWnp^{1.0122}$ (Eq. 1.15) $EBWnp = 0.8424 \times 450.75^{1.0122} = 409.10$ kg
EBWpreg = EBWnp + PREG (Eq. 1.25) EBWpreg = 387.66 + 10.36 = 398.01 kg	EBWpreg = EBWnp + PREG (Eq. 1.25) EBWpreg = 409.10 + 57.33 = 466.42 kg
Interpretation: over 120 days the cow gained 70 kg in weight (520 - 450). In this period, however, the cow increased 46.97 kg in weight relative to pregnancy (57.33 – 10.36). This corresponds to an average daily gain of 0.39 kg for pregnancy. The shrunk weight gain for maternal tissues in the period was only 21.44 kg (409.10 – 387.66), that corresponds to an average daily gain of 0.18 kg for maternal tissues disposition. That is, from the total shrunk body weight gain of the cow in the period (68.41 kg), 68.7% was relative to pregnancy and 31.3% was relative to maternal tissue deposition.	

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Regulation and prediction of dry matter intake

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INTRODUCTION

Dry matter intake (DMI) is the most important variable that affects animal performance (Waldo and Jorgensen, 1981), because it guarantees to the organism adequate nutrients and energy substrates for biochemical reactions that contribute to oscillations in cell metabolism, especially in beef cattle. One must consider the economic importance and complex digestive systems of these animals, which are characterized by unusual metabolic functions (Forbes, 2007).

In beef cattle production, variations in feed intake happen during the growth cycle to maintain a dynamic balance in face of constant challenges from metabolic and environmental needs.

Limitations on feed intake can prevent nutrient requirements to be met. As most of the nutrients of the beef cattle diet are used to meet maintenance requirements, a small change in feed intake can limit the efficiency of the productive processes, resulting in decreased growth rate. The genetic potential for gain will not be reached and the profitability of the livestock-raising activity will be reduced. Furthermore, problems can arise in association with feed stress, resulting in negative health impacts and digestive disturbances.

FEED INTAKE REGULATION BY CATTLE

Neuro-hormonal factors

The brain is the organ that coordinates feeding behavior. According to Konturek et al. (2005), there is an indication that the solitary tract nucleus (STN) in the brain stem works as a gateway for neural signals coming from the gastrointestinal tract to the central intake regulator in the hypothalamus. These authors also suggest that the amygdaloid body, the prefrontal cortex, and the area postrema (chemical receptor trigger zone or "vomit center") have been responsible for feeding disorders and inadequate energy storage or conservation. The arcuate nucleus (ARC) and the paraventricular nucleus (PVN) are also important centers for feed intake control. The ARC and PVN are sites where several hormones released from the gastrointestinal tract and adipose tissue converge to regulate feed intake and energy expenditure (Crespo et al., 2014).

Hetherington and Ranson (1940) and Anand and Brobeck (1951) were the pioneers to propose a model consisting of the hunger center in the lateral hypothalamic (LHA) and satiety in the ventromedial hypothalamic region. The lateral area of the hypothalamus has neurons that induce the animal to start a new feeding cycle, while stimuli in the ventromedial area induce satiety (Mayer and Thomas, 1967). There are indications that the lateral hypothalamus region, known as the hunger center, would always be ready to induce hunger. Or so, this region would be chronically active, and its activity would be temporarily inhibited by the satiety center in the ventromedial hypothalamus (Konturek et al., 2005). Thus, feed intake could be stimulated by the absence of satiety signals (Allen et al., 2005).

Therefore, the hypothalamic nucleus does not act separately in the context of controlling energy homeostasis, but acts synergistically with other structures; the signals between them are transmitted by specific neuropeptides. The ARC plays an important role in integrating signals that regulate intake (Stanley et al., 2005).

A series of complex systems maintain energy homeostasis to maintain the body weight and provide sufficient energy for all metabolic processes (Dietrich and Horvath, 2009). According to Ketelaars and Tolkamp (1996), feed intake generates benefits and

costs. The benefits are related to energy for maintenance and gain, while the costs are related to the oxygen consumed, which generates free radicals responsible for aging. These authors assume that the regulation of feed intake is due to the oxygen economy. On the other hand, Forbes and Provenza (2000) concluded that animals regulate their daily intake to avoid metabolic or physical discomfort.

After feed intake, signals from receptors located in the pharynx and orogastric veins travel to the brainstem, which is part of the central nervous system (CNS). Further, gastric distension mechanisms, chemical stimulation of receptors in the gastrointestinal mucosa and several hormones are released from the gastrointestinal mucus (Konturek et al., 2005). In addition, there are receptors on the wall of the dorsal anterior rumen-reticulum region that can send information, via afferent fibers, projected to the feed intake control centers in the STN (Leek, 1986).

CNS receives (through the STN) several neural impulses and hormones from peripheral organs, especially from the gastrointestinal tract, adipose tissue, and the pancreas. These structures are involved in short and long-term feeding control, managing information on energy expenditure in response to constant alterations in energy balance (Konturek et al., 2005).

Intestinal peptides signal the hypothalamus via the ARC to mediate appetite stimuli (+), which are activated by neurons that secrete neuropeptide Y (YNP) and agouti-related peptide (AgRP), or appetite inhibiting factors (-) through neurons that contain a pro-opiomelanocortin (POMC) precursor of the alpha-melanocyte stimulating hormone (α-MSH) and through peptide from the production of the cocaine and amphetamine regulated transcript (CART) to the hunger center in the LHA and the satiety center in the PVN in the medial hypothalamus (Currie et al., 2005).

In a study about the intake control center in ruminants, Miner (1992) suggested that YNP is a neurotransmitter involved in the intake regulation by the CNS. YNP / AgRP and POMC / CART in the arcuate nucleus of the hypothalamus play key roles in regulating the energy balance. Activation of the YNP / AgRP neurons has an orexigenic effect, promoting feed intake, while the POMC/CART neurons have the opposite effect, that is, anorexigenic. POMC is activated by post transcriptional modifications to the α-MSH. These two neuron circuits receive signals from circulating hormones.

The summary of neural hormonal control on feed control described by Bell et al. (2005) suggests that:

- Leptin is secreted by adipose tissue, and its circulatory levels are proportional to the adipose reserve of the body. Its effects are exercised through the leptin receptor (LEPR), inhibiting the YNP / AgRP neurons and stimulating the POMC / CART neurons.
- The pancreas secretes insulin that has an anorexigenic influence on the ARC, but an increase in insulin plasma levels is stimulated by the YNP.
- Ghrelin is mostly produced (60%) by the stomach and stimulates the YNP / AgRP neurons through receptors that secrete the growth hormone (GH).
- Peptide YY 3-36 (PYY3-36) is secreted in the distal gastrointestinal tract and has an affinity with and bonds to the Y2 (Y2Rs) receptors, producing inhibitory effects on the YNP / AgRP neurons and therefore is a powerful peripheral anorexigenic signal.
- The YNP / AgRP neurons also have an inhibiting effect on the POMC / CART neurons through the release of γ-aminobutyric (GABA) acid, which can be stimulated by the bonding of ghrelin to GH.
- The orexigenic and anorexigenic signals, that are produced by the YNP / AgRP and POMC / CART neurons, respectively, are then sent to second order flow effector neurons, which also receive afferent modifications for signals from dopamine, serotonin, and endocannabinoids; and
- These effector neurons express receptors that include the receptor Y1 (Y1R) and the melanocortin-4 receptor.

Among the anorexigenic peptides, the first recognized feed intake inhibitor was cholecystokinin (CCK), a product of endocrine cells I in the duodenal jejunum. CCK is a physiological mediating hormone for short term feed intake inhibition. It collaborates with signals from gastrointestinal tract mechanoreceptors that are generated by the

digestive tract distension and are transmitted to the brain by the afferent vagus nerve (Konturek et al., 2005).

However, in ruminants, there is a long-time interval between feed intake and arrival in the duodenum, where CCK is produced. Thus, CCK is less important in ruminants than in non-ruminant animals. Nevertheless, an increase was observed in the CCK plasma concentrations in cows three hours after feeding (Choi and Palmquist, 1996), indicating that CCK also has some function in feed intake control in ruminants.

These modulators interact to establish a total balance between feed intake and energy expenditure and thus provoke stimuli in the animal to begin or not a new feeding cycle.

Psychogenic factors

Psychogenic regulation of feed intake, such as perception and learning, involves animal behavior in response to inhibiting or stimulating factors in the feed or feed management that are not related to the energy value of the feed, nor to the filling effect. The psychogenic factors that alter feed intake consist of feed flavor, smell, and texture; vision, emotional states, social interactions and animal learning, and the greatest impact on psychogenic feed intake modulation is palatability (Mertens, 1994).

Animal related factors

a) Body weight

Body weight (BW) is a determining factor in cattle DMI. Galyean and Hubbert (1992) observed that initial body weight represented 59.8% of the variation in the DMI in diets with NEm concentrations ranging from 1 to 2.4 Mcal/kg DM. In a wide discussion on DMI prediction models, Pittroff and Kothmann (2001) assessed 12 different equations and, regardless of their degree of complexity and mathematical sophistication, ten of them took into consideration body weight, giving great importance to the inclusion of this variable in DMI prediction equations.

b) Genetic group

According to the NRC (1987), genetic selection for performance has produced animals with greater DMI potential and suggests specific adjustment factors for DMI prediction. Allen (1992) stated that Continental (European) breeds can consume 10% more than British breeds and, based on this information, the AFRC (1993) proposed adjustment factors in DMI prediction for several pure breeds.

The NRC (2000) adopted the adjustments for breed proposed by Fox et al. (1988), where the DMI prediction should be increased by 8% for the Holstein cattle and by 4% for Holstein and British crossbred animals. The NRC (2000) does not suggest changes in the DMI for Zebu cattle.

c) Body composition

The body composition of feedlot cattle is not constant and changes over feedlot time and with an increase in BW. Body composition, specifically the body fat percentage, seems to be the main component that affects DMI (NRC, 1987). According to Grant and Helferich (1991), this is due to the deceleration of muscle growth and adipose tissue development, with the increase in BW. Fox et al. (1988) suggested altering DMI when cattle presented an empty body fat percentage higher than 21.3%. Jorge et al. (1997) observed a higher body fat percentage (24.41%) for Nellore animals compared to crossbred beef (21.62%) and dairy cattle (19.50%). Fox et al. (1988) suggested reducing DMI by 3, 10, 18 and 27% when the empty body fat percentage was 23.8, 26.5, 29.0 and 31.5%, respectively.

d) Sex

Marcondes et al. (2008), Véras et al. (2008) and Lage et al. (2012) did not report influence of sexes (heifers, steers, and bulls) for DMI, but Paulino et al. (2008) observed that DMI was 9.3% greater in heifers compared to bulls, while steers DMI did not differ from either. According to the authors, the higher intake of females occurred because they were young.

For heifers, the NASEM (2016) suggested that the DMI prediction should be decreased by 10% for heifers with medium body condition, because heifers reach physiological maturity before males (NRC, 2000), which could allow greater body fat accumulation at an earlier time-point in

comparison to males. As fat indirectly influences DMI through leptin secretion by the adipocytes, a hormone that has been correlated to intake reductions (Nkrumah et al., 2005), it is expected that the DMI capacity of the heifers decreases with an increase in BW. Thus, the sex effect cannot be considered in isolation because the body condition or body fat percentage is directly influenced by the sex. According to Huuskonen et al. (2013), the sex influence on DMI may be confused with other random experimental effects.

Environmental factors

The weather in Brazil is diverse due to factors such as geographic, territorial extension, relief, and air mass dynamics. The latter is extremely important because it acts directly on both temperature and rainfall, causing regional climatic differences. However, the Brazilian cattle herd is found in greater density in the tropical region with temperatures normally above 25ºC because they are concentrated mainly in the states of Mato Grosso, Minas Gerais, Mato Grosso do Sul and Goiás, which together represent more than 40% (Alvares et al., 2013; Teixeira and Hespanhol, 2015).

Regarding the environmental factors, Fox et al. (1988) suggested to reduce DMI prediction by 10% in temperatures ranging from 25 to 35ºC, and when over 35ºC, reducing it by 35%.

Ingvartsen et al. (1992) assessed the effect of day length on DMI capacity and observed that the expected DMI maybe 1.5 to 2% higher on long days and 1.5 to 2% lower on short days.

Management and diet factors

There is a relationship between the energy concentration of the diet and DMI for beef cattle. Based on the concept that in lower digestible diets, that is, with low energy (high-fiber), the DMI is controlled by factors known as ruminal filling and physical impediment of digestive passage, while in higher digestible, high energy (low-fiber) diets, DMI is controlled by the energy requirement of the animal and metabolic factors (NRC, 1987).

The strong correlation between neutral detergent fiber (NDF) and the physical regulation of intake is mainly due to the high volume occupied by the cell wall fraction of forage (Mertens, 1994) and to its characteristics of low density and slower degradation compared to the cell content (Van Soest, 1994; NRC, 2001). Distension in the rumen-reticulum compartment caused by filling stimulates receptors in the muscle layer mainly located at the reticulum and cranial sac level (Allen, 1996, 2000), where mechanoreceptors are excited by mechanical and chemical stimuli and tensoreceptors respond to the distension itself (Allen, 2000), stimulating the end of the feeding period.

However, this approach has been criticized because it presumes that physical and metabolic mechanisms are independent of each other. This consideration is physiologically unlikely, since the regulating signals work in an integrated manner to create a positive or negative signal on voluntary dry matter intake (Detmann et al., 2014).

NDF intake, or its diet concentration, is associated with the physical mechanism (Detmann, 2010), so a single estimate of NDF concentration is not sufficient to understand or predict cattle voluntary intake (Detmann et al., 2014). Thus, separating the total NDF into undigested NDF and potentially degradable NDF (pdNDF) may improve the associations with voluntary intake (Huhtanen et al., 2007; Harper and McNeill, 2015). For tropical conditions, Detmann et al. (2003) suggested that NDF intake above 13.53 g/kg BW would regulate intake by physical mechanisms, but Oliveira et al. (2011) reported that the forage source should be considered and indicated a mean value of 13.2 g/kg BW for corn silage and 9.4 g/kg BW for sugarcane. They also recommended qualitative discrimination of the NDF and lignin fractions for their efficacious use in DMI prediction models.

Regarding tropical conditions, Detmann et al. (2014) related DMI to digestible organic matter content (DOM) and undigested NDF and observed a quadratic effect: DMI (g/kg) = -5.50 + 0.092 × DOM – 0.00007 × DOM^2 with a maximum point of 658 g DOM/kg DM and a decreasing linear effect: DMI (g/kg) = 27.8 – 0.016 × undigested NDF, respectively. These authors observed that the point of equilibrium between physical and chemical regulation of intake for beef cattle occurred with a DMI of 20.86 g/kg BW,

and this value was observed for diets with DOM concentration of 660 g/kg DM and undigested NDF of 228 g/kg DM. This shows that DMI is regulated simultaneously by physical and physiological limitations.

Protein deficiency (<7–8% CP) is another diet characteristic that can decrease DMI, because it limits rumen microorganisms from fully using the fibrous carbohydrates in tropical forage (Lazzarini et al., 2009; Sampaio et al., 2009). In a diet poor in nitrogen but rich in forage fiber, the supplementation with nitrogen increases DMI (Galyean and Goetsch, 1993).

Therefore, the factors that control feed intake are complex, truly multifactorial and there is no consensus on how ruminants regulate this important activity (Forbes, 2007).

All these factors should be considered when mathematically predicting the true biological behavior of dry matter intake by beef cattle under tropical conditions. However, no type of equation will be applicable if the feeding conditions (feed availability, stocking rate, space in the pen, access time to feed, feeding frequency, etc.) are limiting intake (Mertens, 1992).

Adaptation for feedlot cattle

Adaptation for the feedlot may influence DMI. Animals from pasture consume high roughage diets and start the feedlot with high proportions of concentrates after long transportation without water and food (Loerch and Fluharty, 1999). Normally, they leave the pastures without or with low concentrate supplementation and start feedlot with high concentrate, often 90% in less than 14 days (Brown et al., 2006; Pereira et al., 2020). Due to these changes, acidosis has been identified as the second biggest health problem in feedlot systems in the last six years (Pinto and Millen, 2018; Silvestre and Millen, 2021). Proper management of this phase may influence intake and performance throughout the feedlot period. According to Estevam et al. (2020), one of the determining factors for the adaptation protocol is the energy content of finishing diets. According to these authors, systems that use less energy in the diets can reduce the adaptation periods without health problems and performance reduction.

Often, cattle are adapted to the feedlot with a gradual increase in the concentrate diet over periods of 14 to 21 days (Bierman and Pritchard, 1996). In Brazil, Silvestre and Millen (2021) indicated that an average of 3 diets are used, with intervals of 7 days, during the period of adaptation to the feedlot. These authors reported that multiple diets, with an increase in the concentrate on defined days, represent 61.1% of the receiving diets formulated during the feedlot, on average for 19 days. In addition, they reported that the smallest part (39.9%) of feedlots use other options during adaptation, such as a single diet with less energy than in the finishing phase for 25 days; two diets for 7-8 days each; finishing diet with feed restriction for 40 days of adaptation; and use multiple diets associated with restriction of intake (Silvestre and Millen, 2021). In that study, most nutritionists suggested starting the adaptation using 36.5% of roughage in the total DM of the diet.

Other factors to be considered in the feedlot adaptation phase are the initial amount of concentrate in the diet and the daily amount of DM. Parra et al. (2019) evaluated adaptation protocols for 7, 14, and 21 days. The animals received 55, 65, and 75% concentrate and finished on diets with 85% concentrate, initially receiving 1.76% of the BW for DMI of the diet, with increments of 200 to 206 g DM/d. These authors concluded that the increase in adaptation time did not influence intake and animal performance. Barducci et al. (2019) evaluated animals adapted for 9 or 14 days. In the adaptation of 9 days, the diets were changed every 3 days, and in the adaptation of 14 days, the changes in the diets occurred on days 4 and 9. Animals started with 55% of concentrate, increasing by 10% in each adaptation phase until 85% in the finishing phase. The adaptation phase did not influence DMI and animal performance.

Bunk management

Bunk management needs to be simple and sensitive to detect changes in diet intake (Schutz et al., 2011), to avoid underperformance, feed losses, and digestive problems. In Brazil, nutritionists use four

trough management methods: clear bunk, with 1 to 3% orts, 3 to 5% orts, and 5 to 10% orts (Millen et al., 2009). Clear bunk management is based on the satiety concept without feed losses. In this management, troughs and animal behavior are monitored daily to enable an adequate supply of feed without orts. Bunk management with 1 to 3% or 3 to 5% or even 5 to 10% orts is usually made into scores to simplify the decision about increasing or reducing feed supply. Recently, Brazilian nutritionists have been using less orts. According to Millen et al. (2009), only 25.8% of the nutritionists used clear bunk management, while 48.4% used 1 to 3% orts.

The restriction in feed supply reflects the increase in the cost of diets, which demonstrates the importance of developing precise and accurate equations in the prediction intake that allows maximum performance without feed losses.

PREDICTION OF DRY MATTER INTAKE FOR FEEDLOT CATTLE

To plan an efficient feeding program capable of finding the best feed management to meet nutrient requirements, it is necessary to predict with the highest precision and accuracy the voluntary intake of growing and finishing cattle under *ad libitum* feeding.

A DMI prediction model is a simplified representation of the complex system of voluntary feed intake (Keady et al., 2004). If it were possible to include all the physiological, environmental, diet and management factors that interfere in the DMI, the model obtained could be difficult to interpret biologically.

STATE OF THE ART ON DRY MATTER INTAKE PREDICTION

For a long time, the DMI prediction models proposed by the NRC (1984, 2000) were the most used in Brazil. However, the models proposed by the NRC (1984, 2000) and the NASEM (2016) were developed mainly with *Bos taurus taurus* animals. According to ANUALPEC (2015), 80% of the Brazilian herd consists of Zebu cattle, with an estimated 150 million Zebu. The contribution of Zebu cattle to meat and milk production in Brazil in a self-sustainable production system is due to their characteristics of fertility, rusticity, adaptability to the tropical condition and to the Brazilian meat production systems. Nellore breed is predominant in beef production systems in Brazil.

Fox et al. (1988) observed that the genetic group is recognized as one factor that interferes with DMI. Based on this study, the NRC (1987) and the AFRC (1993) adopted the adjustment factor related to the genetic group in DMI prediction equations, because breeds were identified with greater intake potential than others. Furthermore, steroid stimulants were used in the cattle in the database used for the DMI prediction model proposed by the NRC (1984, 2000). In Brazil, steroid use was prohibited for any purpose in 1961, and currently, Ministerial Regulation nº 51 (Brasil, 1991) is in force and prohibits the production, importation, commercialization, and use of products for purposes of growth and weight gain in slaughter animals. Non-steroid compounds with anabolizing effects are prohibited even for therapeutic purposes.

According to Neal et al. (1984), DMI prediction models should be tested under conditions similar to those that characterize the intended location of use. Therefore, there is no single model that can be applied in every situation, and DMI prediction models need to be developed and validated for tropical conditions. For this, equations to predict beef cattle DMI under Brazilian conditions and with Zebu cattle (Nellore cattle) were carried out and validated by Valadares Filho et al. (2006 a,b), that along with energy, protein and mineral requirements resulted in the publication entitled Nutrient Requirements for Zebu cattle and Tables of Feed Composition – BR-CORTE, described by Valadares Filho et al. (2006b).

Fifteen dissertations and/or theses were used in the BR-CORTE (2006) to develop the database for Zebu animals (mainly Nellore cattle). In the crossbred beef cattle database, 10 dissertations and/or theses were used totalling 273 experimental units. Thus, the following equations were recommended to predict DMI:

- For Zebu cattle:
DMI (kg/d) = -2.4001 + 0.0201 × BW + 4.8195 × ADG – 1.5176 × ADG^2

- For crossbred beef cattle:
DMI (kg/d) = -1.4105 + 0.0171 × BW + 5.4125 × ADG – 1.8691 × ADG^2.

where BW = average body weight (kg) and ADG = average daily gain (kg/d). The DMI models proposed indicated that the predictive values were equivalent to those observed under practical feeding conditions for feedlot beef cattle under tropical conditions.

Ribeiro et al. (2008) assessed the DMI based on Zebu genetic group and compared the values observed with those predicted by the NRC (2000), CNCPS 5.0 and BR-CORTE (2006) systems. The authors observed that the Brazilian system (BR-CORTE, 2006) was more accurate for DMI predictions by breed and Zebu cattle overall.

Valadares Filho et al. (2006a) also observed a lack of fit for the models proposed by the NRC (1984, 2000) in predicting DMI for beef cattle under tropical conditions. So, the equations proposed by the NRC (1984, 2000) would not be able to explain the higher percentage in the observed variation in the DMI compared to the equations adopted by the BR-CORTE (Valadares et al., 2006b).

Brazilian researchers collected data from multiple published studies and tried to establish a quantitative model that better explains the observations. Generally, studies differ due to their objectives and ignore these differences in joint data analysis results in an erroneous estimate of the parameters (intercept and slope) of the regression models. Therefore, the use of meta-analysis was proposed in the BR-CORTE, described by (Azevêdo et al. 2010), to integrate the study effect and random effects of the interactions such as components of a mixed model (St-Pierre, 2001) and generate more precise and accurate DMI prediction models. Thus, in the second edition of the Nutrient Requirements of Zebu cattle, BR-CORTE (2010), the database was increased for DMI, and the models used by the NRC were assessed together with new equations to predict DMI, using meta-analysis, which were developed and validated.

The data included 561 observations from 27 theses and/or dissertations (study) that were published at the Federal University of Viçosa and the University of São Paulo. The BR-CORTE (Azevêdo et al. 2010), showed that the equations proposed by the NRC were not adequate to predict DMI for cattle under tropical conditions and the following DMI prediction equations were suggested:

- For Zebu cattle:
DMI (kg/d) = -2.7878 + 0.08789 × $BW^{0.75}$ + 5.0487 × ADG – 1.6835 × ADG^2.

- For crossbred cattle:
DMI (kg/d) = -2.6098 + 0.08844 × $BW^{0.75}$ + 4.4672 × ADG – 1.3579 × ADG^2.

where $BW^{0.75}$ = average metabolic body weight (kg) and ADG = average daily gain (kg/d).

Ferreira et al. (2021) evaluated DMI prediction models by BR-CORTE (Azevêdo et al., 2010 and 2016) and NRC (2000) nutritional systems, with 47 feedlot Nellore cattle, bulls, the average initial body weight of 413 kg and 19 months of age. They concluded that the BR-CORTE model (Azevêdo et al., 2016) was more precise to predict DMI of Nellore cattle.

The main research group that acted on the changes regarding DMI prediction for beef cattle in the 8th edition of the NASEM (2016) – Nutrient Requirements of Beef Cattle Model – was led by Professor and Researcher Michael L. Galyean, from the *Texas Tech University, Department of Animal and Food Sciences*.

His research group recently published four articles on this subject. The first was "Evaluation of the National Research Council (1996) dry matter intake prediction equations and relationships between intake and performance by feedlot cattle" by McMeniman et al. (2009). This article aims to assess the NRC (1996) DMI prediction models. From a database containing 3,363 records of collective pens, representing 632,306 animals on three commercial feedlots collected during a period of four years (2003 to 2006), they concluded that the equations proposed by the NRC (1996) were not useful to predict the DMI of commercial feedlot

cattle and suggested the need to develop new and more accurate and precise equations.

The second article was "Development and evaluation of feeding-period average dry matter intake prediction equations from a commercial feedlot database" by McMeniman et al. (2010). These authors proposed DMI prediction models that took into consideration sex and previous DMI information at the start of the feedlot.

In the third article, Galyean et al. (2011) published "Predictability of feedlot cattle growth performance". These authors validated the equations proposed by McMeniman et al. (2010) and suggested equations to predict DMI for feedlot beef cattle fed high-concentrate diets.

In the fourth article, "Evaluation of current methods and equation development" by Anele et al. (2014), new equations were developed but, according to these authors, these equations gave only modest improvements for the best of the hypotheses; in some cases, they did not offer any true advantage in comparison to the equations proposed by the NRC (1996) for predicting DMI in growing or finishing beef cattle.

Anele et al. (2014) were disappointed to know that their research managed to improve only a little the prediction capacity for DMI and recognized the difficulty to develop precise DMI predictions for growing and finishing beef cattle. The influence of the complex factors that control DMI makes the difficult to adequately explain DMI biological performance using regression mathematical models and some independent variables.

According to Anele et al. (2014), the NASEM (2016) recommended to continue the use of the equation proposed by the NRC (2000) to predict net energy intake for maintenance (NEIm, Mcal/d) and later estimate the DMI, obtained by dividing the NEIm by the net energy concentration for maintenance of the diet (NEm):

- For *yearlings*:
NEIm (Mcal/d) = $BW^{0.75} \times (0.2435 \times NEm - 0.0466 \times NEm^2 - 0.0869)$,

where $BW^{0.75}$ is the average metabolic body weight for the feeding period. For diets with NEm concentration ≤ 0.95 Mcal/kg DM, the NASEM (2016) recommended dividing the result of this equation by 0.95.

However, because the results of this equation under or overestimated the DMI depending on the diet and animal conditions as reported by Anele et al. (2014), the NASEM (2016) recommends that the DMI equation as a function of body weight described by Anele et al. (2014) also could be used to predict DMI in growing or finishing beef cattle:

DMI (% BW) = $1.2425 + 1.9218 \times NEm - 0.7259 \times NEm^2$ ($R^2 = 0.6188$),

where BW = average body weight (kg). The NASEM suggests there is no reason to recommend a single equation to estimate DMI.

Based on the validation study by Galyean et al. (2011), the NASEM (2016) recommends the use of equations described by McMeniman et al. (2010), with adjustments for sex, to estimate the DMI of feedlot cattle fed high-grain diets (≥ 2.06 Mcal/kg NEm and ≥ 1.4 Mcal/kg NEg):

- Steers:
DMI (kg/d) = 3.83 + 0.0143 ×iSBW.

- Heifers:
DMI (kg/d) = 3.184 + 0.01536 × iSBW.

where iSBW, mean initial shrunk body weight.

In the seventh edition of the NRC (2000), the methods described to predict DMI were planned to give a general orientation. There is no one equation that can be applied to all production scenarios. It would be correct to develop specific DMI prediction models for determined production situations. Thus, these models would be capable to explain a greater percentage of the variation observed in the DMI, compared to a generalized model.

Although Brazil has a beef herd of a practically stagnant size, improvement in productive conditions has increased productivity indexes. For these indexes to continue increasing to reduce production costs and make the product more accessible to the consumer, the knowledge generated by research must be constantly updated and validated. This means that the greatest number of variation sources should be known

and considered. Likewise, an increase in the number of individual cattle intake data, from research under tropical conditions, means that the statistical procedures to estimate DMI become more sensitive to the variations resulting from various production factors.

DESCRIPTION OF DATABASE USED TO PREDICT NEW MODELS FOR FEEDLOT CATTLE IN EXPERIMENTAL CONDITIONS

Brazil is a country with continental dimensions. There is wide climatic diversity that permits raising cattle of predominantly Zebu breeds and the use of different genetic groups specialized in meat production to obtain benefits from the hybrid vigor to increase herd productivity.

Furthermore, in Brazil, a significant part of the meat produced is from males derived from dairy herds, which are used for growing and finishing animals such as beef cattle. Faced with this genetic diversity among the cattle raised in Brazil and knowing that physiologically there are differences in growth potential and nutrient requirements, the database was separated into three genetic groups to predict new models to estimate DMI for cattle under tropical conditions: Zebu cattle (predominantly Nellore animals), crossbred beef cattle (animals derived from crosses of Zebu with breeds specialized in meat production, predominantly Angus x Nellore) and crossbred dairy cattle (animals derived from crosses of Zebu with breeds specialized in milk production, mainly Holstein).

To generate DMI prediction models capable of being biologically representative and explaining the greater percentage of variation observed in the DMI of cattle under tropical conditions, mainly in commercial conditions, Menezes et al. (2022) used BR-CORTE (Azevêdo et al., 2016) database with Zebu breeds bulls and included 479 (56.452 Zebu breeds) pens in one commercial feedlot. The proposed equation was evaluated and compared with a 2.1 equation proposed in the BR-CORTE (Azevedo et al., 2016), and equations proposed by McMeniman et al. (2010), Anele et al. (2014), and Silva et al. (2021) in two other independent commercial feedlots with 222 and 231 pens, totaling 23,531 and 6,384 animals. The equations validated were the 2.1 in the BR-CORTE and the equation proposed by Menezes et al. (2022). However, the equation proposed by Menezes et al. (2022) was more precise in predicting DMI. Therefore, in this edition, we used the equation proposed by Menezes et al. (2022) using a total of 1128 experimental units of zebu breeds, derived from research and commercial feedlot with high management systems on growing or finishing cattle, with recorded individual or in group intake that also respected an adaptation period to minimize the impact of compensatory growth on DMI.

Descriptive analysis (Triola, 1999) (Table 2.1) of the data gave the dataset profile from the central tendency and dispersion means. In general, the total amplitudes of the different variables present in the database used to develop the DMI prediction equations (Table 2.1) represented the Brazilian characteristics of feedlot beef cattle production systems, so there are variations from low to high initial BW, final BW, ADG, DMI and variations in the NDF and CP intakes. Thus, representative projections were faced with the universe of diets used for cattle for beef production under tropical conditions and their interactions with genetic groups and interference in the DMI regulation patterns.

The Pearson correlation coefficient was used to measure the intensity of the linear relationship between DMI and the other quantitative variables. The correlation analysis showed that the greatest coefficients found were those that explained the linear relationship between the DMI and the cattle weights and performance, with positive and significant coefficients ($P<0.05$). The variables related to the diets (NDF and CP, g/kg), not only had low correlation coefficients, regardless of the genetic group assessed, but the NDF did not present significant coefficients ($P>0.05$) and CP was only significant for the Zebu and crossbred dairy genetic groups. In face of the results of the Pearson correlation, $BW^{0.75}$ and ADG were adopted as variables to be used in the DMI prediction models.

According to St-Pierre (2001), the study effect needs to be verified on the database. Study effect was observed

(P<0.0001) and this was considered in further analysis.

Equations were developed to predict DMI as a function of the genetic groups.

Zebu cattle:
$$DMI\ (kg/d) = -2.1948 + 0.08338 \times BW^{0.75} + 3.9328 \times ADG - 0.9030 \times ADG^2 \quad (R^2 = 0.859) \qquad \text{(Equation 2.1)}$$

Crossbred beef cattle:
$$DMI\ (kg/d) = -0.6273 + 0.06453 \times BW^{0.75} + 3.871 \times ADG - 0.614 \times ADG^2 \quad (R^2 = 0.626) \qquad \text{(Equation 2.2)}$$

Crossbred dairy cattle:
$$DMI\ (kg/d) = -2.8836 + 0.08435 \times BW^{0.75} + 4.5145 \times ADG - 0.9631 \times ADG^2 \quad (R^2 = 0.788) \qquad \text{(Equation 2.3)}$$

The negative coefficient for the ADG^2 (kg/d) variable for all fitted equations indicated that the DMI estimates presented a plateau. The explanation for this fact may be directly related to the energy concentration of the diets used. Starting from the principle that to reach maximum ADG, the diet energy concentration must have been high, inhibiting DMI, which suggests the theory of energy intake regulation proposed by Mertens (1994).

Considering the importance of this effect, the NASEM (2016) proposed equations that included NEm and NEm^2 variables. However, due to the practical difficulties of determining NEm before knowing which feeds will make up the diet, Thornton et al. (1985) developed a model to predict DMI that included initial body weight and days on feedlot (DOF). According to these authors, the initial DMI increases gradually as a function of DOF until it reaches a plateau and then decreases in the last DOF due to an increase in the body fat content of the animals. Fat starts to concentrate slowly in the carcass at the beginning of the feeding period but accumulates rapidly at the end of it (Simpfendorfer, 1974).

VALIDATING DRY MATTER INTAKE PREDICTION EQUATIONS

The research results from mean values (independent experiments) published from 2005 until October 2014 in the *Revista Brasileira de Zootecnia, Boletim da Indústria Animal, and the Arquivo Brasileiro de Medicina Veterinária and Zootecnia* were compiled and used to build a database to validate the DMI prediction equations for Zebu cattle and crossbred beef and dairy cattle finished in feedlot under tropical conditions (Table 2.2).

Table 2.2 shows the dispersion of the variables used in the database to validate the DMI prediction equations. The minimum and maximum values for BW, ADG and DMI indicate that many diets were used. It can be observed that the selection criterion used was representative because it did not interfere in the mean values of the variables used to develop the DMI prediction equations. It is important to point out that in this database for validation, there are data from different Brazilian states that give larger representation of the national herd.

The ratios obtained between the observed and predicted values by the equations as a function of the genetic groups: Zebu, crossbred beef and dairy cattle (Table 2.3), show that the probability values both for the intercept and slope do not differ (P>0.05) from zero and 1, respectively. That is, the DMI values (Table 2.3) predicted by the equations developed are equivalent to the DMI observed in practical beef cattle feeding conditions, in feedlot under tropical conditions. Table 2.4 shows the dry matter intake estimated for Zebu, crossbred beef and dairy cattle finished in a feedlot, obtained for different body weight and gain.

Table 2.1 - Descriptive statistics of the variables used to predict dry matter intake and nutrient intake for Zebu cattle under experimental and commercial conditions, and for crossbred beef and dairy cattle under experimental conditions

Variable	N	Mean	SD	Minimum	Maximum
Zebu cattle					
Feedlot, days	1128	102	36.9	42.0	271
Initial body weight, kg	1128	330	70.0	110	499
Final body weight, kg	1128	450	91.3	125	652
ADG, kg/d	1128	1.23	0.49	-0.36	2.00
Intake					
Dry matter, kg/d	1128	8.41	2.10	1.29	13.2
NDF, kg/d	951	2.88	0.71	0.79	7.61
iNDF, kg/d	388	1.24	0.55	0.13	2.43
Crude protein, kg/d	951	1.03	0.19	0.29	1.74
TDN, kg/d	949	6.03	1.14	1.00	10.2
Crossbred beef cattle					
Feedlot, days	270	112	35.6	55.0	232
Initial body weight, kg	270	352	55.3	215	580
Final body weight, kg	270	455	78.6	220	607
ADG, kg/d	270	1.22	0.48	-0.19	2.37
Intake					
Dry matter, kg/d	270	8.57	1.94	2.46	12.5
NDF, kg/d	188	3.25	1.24	0.83	6.97
iNDF, kg/d	30	0.81	0.16	0.50	1.09
Crude protein, kg/d	163	1.15	0.28	0.30	1.67
TDN, kg/d	141	5.52	1.50	1.74	9.22
Crossbred dairy cattle					
Feedlot, days	409	107	53.7	30.0	242
Initial body weight, kg	409	323	77.3	139	494
Final body weight, kg	409	429	87.5	206	661
ADG, kg/d	409	1.06	0.52	-0.13	2.64
Intake					
Dry matter, kg/d	409	8.03	2.41	2.18	15.1
NDF, kg/d	265	2.86	1.17	0.65	6.14
iNDF, kg/d	30	0.98	0.26	0.42	1.44
Crude protein, kg/d	264	0.99	0.35	0.18	2.01
TDN, kg/d	138	5.64	1.63	2.53	9.45

N: number of experimental units; SD: standard deviation; ADG: average daily gain; NDF: neutral detergent fiber; iNDF: indigestible NDF; TDN: total digestible nutrients.

Table 2.2 - Descriptive statistics of the variables used to validate the equations developed to predict dry matter intake for Zebu cattle, and crossbred beef and dairy cattle in feedlot under experimental conditions

Variable	N	Mean	SD	Minimum	Maximum
Zebu cattle					
Feedlot, d	78	95.4	27.5	56.0	194
Initial body weight, kg	78	364	43.5	251	438
Final body weight, kg	78	479	37.2	404	583
ADG, kg/d	78	1.20	0.24	0.63	1.75
Dry matter intake, kg/d	78	8.79	1.06	6.04	10.8
Crossbred beef cattle					
Feedlot, d	111	103	29.6	21.0	199
Initial body weight, kg	111	326	62.8	18	463
Final body weight, kg	111	464	48.2	340	579
ADG, kg/d	111	1.38	0.25	0.76	2.15
Dry matter intake, kg/d	111	8.83	1.44	6.11	12.7
Crossbred dairy cattle					
Feedlot, d	48	81.8	12.3	56.0	102
Initial body weight, kg	48	259	94.4	67.9	380
Final body weight, kg	48	336	116	151	499
ADG, kg/d	48	0.95	0.38	0.14	1.72
Dry matter intake, kg/d	48	6.69	2.24	2.80	11.1

N: number of experimental units; SD: standard deviation; ADG: average daily gain.

Table 2.3 - Statistics for the ratio between the observed and predicted values by the equations for Zebu, and crossbred beef and dairy cattle in feedlot

Variable	**Zebu**	**Crossbred beef cattle**	**Crossbred dairy cattle**
Intercept	-0.602	-1.5386	0.6697
P-value[1] (H_0: a = 0)	0.655	0.2022	0.0710
Slope	1.052	1.1316	0.9449
P-value[2] (H_0: b = 1)	0.729	0.3150	0.3112
r^2	0.426	0.4087	0.8704
Mean bias	-0.137	-0.3329	0.3189
CCC	0.544	0.5262	0.9234
MSEP	0.698	1.3306	0.7557
Decomposition of the MSEP			
Mean bias	0.0188 (2.70%)	0.1108 (8.33%)	0.1017 (13.46%)
Systemic error	0.0011 (0.15%)	0.0113 (0.85%)	0.0146 (1.93%)
Random error	0.6777 (97.2%)	1.2085 (90.82%)	0.6395 (84.62%)

CCC = concordance correlation coefficient; MSEP = mean square error of prediction; [1]Probability value for the hypothesis test where the value of parameter a = 0 (Neter et al., 1996). [2] Probability value for hypothesis test where the value of parameter b = 1 (Neter et al., 1996).

Table 2.4 - Dry matter intake estimated for Zebu, crossbred beef and dairy cattle finished in feedlot obtained for different body weights and weight gains

Body weight (kg)	Weight gain (kg/d)	Dry matter intake (kg)		
		Zebu cattle (Equation 2.1)	**Crossbred beef cattle** (Equation 2.2)	**Crossbred dairy cattle** (Equation 2.3)
200	0.75	4.68	5.36	4.45
	1.00	5.27	6.06	5.15
	1.25	5.74	6.68	5.74
	1.50	6.11	7.23	6.21
	1.75	6.36	7.70	6.55
250	0.75	5.49	5.99	5.26
	1.00	6.08	6.69	5.97
	1.25	6.55	7.31	6.56
	1.50	6.91	7.85	7.02
	1.75	7.16	8.32	7.37
300	0.75	6.26	6.58	6.04
	1.00	6.85	7.28	6.75
	1.25	7.32	7.90	7.33
	1.50	7.68	8.45	7.80
	1.75	7.93	8.92	8.15
350	0.75	6.99	7.15	6.79
	1.00	7.58	7.85	7.49
	1.25	8.06	8.47	8.08
	1.50	8.42	9.02	8.55
	1.75	8.67	9.49	8.89
400	0.75	7.70	7.70	7.51
	1.00	8.29	8.40	8.21
	1.25	8.77	9.02	8.80
	1.50	9.13	9.57	9.27
	1.75	9.38	10.0	9.61
450	0.75	8.39	8.24	8.20
	1.00	8.98	8.93	8.91
	1.25	9.46	9.56	9.50
	1.50	9.82	10.10	9.96
	1.75	10.1	10.6	10.3
500	0.75	9.06	8.75	8.88
	1.00	9.65	9.45	9.59
	1.25	10.1	10.08	10.17
	1.50	10.5	10.6	10.6
	1.75	10.7	11.1	11.0

VALIDATION OF DRY MATTER INTAKE PREDICTION EQUATIONS FOR ZEBU AND CROSSBRED BEEF CATTLE IN COMMERCIAL FEEDLOTS

DMI, BW, and ADG data from Zebu and crossbred beef animals were collected in three commercial feedlots with individual intake per group and used for validation. Data were collected in Minas Gerais (16°01'54"S 43°47'28"W), Goias (15°25'19.61"S 51°32'17.04"W) and Mato Grosso (16°45'30 "S 54°23'03"W). Data from 231 and 222 stalls were compiled, totaling 29,915 Nellore animals and 27, 76, and 20 stalls with crossbred beef cattle, totaling 11,713 animals (Table 2.5). The feeding management in the commercial feedlot used the average adaptation period to the finishing diets for 21 days. The observed values were compared with the values predicted by Equation 2.1 using the regression model: $Y = a + b*x$. Where: Y = represents the observed response

values; X = represents the predicted values; a = represents the intercept of the Equation, and b = represents the slope of the Equation. The regression was evaluated with the following statistical hypotheses (Neter et al., 1996): H_0 = a = 0 and b = 1; Ha = No H_0. The database used to generate Equations 2.1 covers data from commercial feedlots and allows its use in predicting their intake. The values for intercept and slope did not differ (P>0.05) from 0 and 1, respectively (Table 2.6). Therefore, predicted and observed values in commercial and large experimental feedlots in tropical conditions are the same.

Table 2.5 - Descriptive statistics of the variables used to validate the equations 2.1 and 2.2 to predict dry matter intake

Variable	N	N animals	Mean	DP	Minimum	Maximum
Feedlot. 1 **(Zebu cattle)**[1]						
Feedlot, d	231	6.384	103	14.8	70	127
Initial body weight, kg	231	6.384	426	37.0	344	570
Final body weight, kg	231	6.384	593	45.6	527	763
ADG, kg/d	231	6.384	1.62	0.21	1.08	2.24
Dry matter intake, kg/d	231	6.384	9.14	0.76	7.14	12.2
Feedlot. 2 **(Zebu cattle)**[1]						
Feedlot, d	222	23.531	129	30.8	66.0	206
Initial body weight, kg	222	23.531	309	42.9	229	523
Final body weight, kg	222	23.531	497	35.9	386	714
ADG, kg/d	222	23.531	1.49	0.190	1.02	2.32
Dry matter intake, kg/d	222	23.531	11.0	0.79	8.79	13.2
Feedlot. 3 **(Crossbred beef cattle)**						
Feedlot, d	27	2469	116	5.51	110	126
Initial body weight, kg	27	2469	397	28.79	363	453
Final body weight, kg	27	2469	625	29.77	572	681
ADG, kg/d	27	2469	1.956	0.185	1.600	2.186
Dry matter intake, kg/d	27	2469	11.7	0.517	10.2	12.3
Feedlot. 4 **(Crossbred beef cattle)**						
Feedlot, d	76	8707	153	38.16	66	235
Initial body weight, kg	76	8707	294	70.52	221	486
Final body weight, kg	76	8707	517	80.08	440	829
ADG, kg/d	76	8707	1.500	0.325	1.087	2.423
Dry matter intake, kg/d	76	8707	9.31	1.429	7.39	12.2
Feedlot. 5 **(Crossbred beef cattle)**						
Feedlot, d	20	537	105	24.0	62.3	150
Initial body weight, kg	20	537	412	31.1	361.1	462
Final body weight, kg	20	537	539	23.4	502.7	592
ADG, kg/d	20	537	1.223	0.133	0.970	1.506
Dry matter intake, kg/d	20	537	9.45	0.680	8.30	11.19

N: number of experimental units; SD: standard deviation.
[1]Adapted data published by Menezes et al., (2022).

Table 2.6 - Statistics for the ratio between the observed values of feedlots 1, 2, 3, 4 and 5 and those predicted by equations 2.1 (feedlots 1 and 2) for zebu beef cattle and 2.2 (feedlots 3, 4 and 5) for crossbred beef cattle

Variable	[3]Feedlot. 1	[3] Feedlot. 2	Feedlot. 3	Feedlot. 4	Feedlot. 5
Intercept	-0.051	1.05	-0.721	0.400	1.317
P-value[1] (H_0: a = 0)	0.934	0.076	0.501	0.682	0.660
Slope	1.04	0.886	1.051	0.936	0.905
P-value[2] (H_0: b = 1)	0.598	0.075	0.648	0.505	0.715
r^2	0.511	0.465	0.785	0.561	0.411
Mean bias	0.327	-0.001	-0.236	-0.250	0.225
CCC	0.600	0.659	0.860	0.680	0.535
MSEP	0.414	0.317	0.482	0.286	0.198
Decomposition of the MSEP					
Mean bias	0.107 (25.8%)	0.000 (0.00%)	0.056 (11.6%)	0.063 (21.9 %)	0.051 (25.6 %)
Systemic error	0.0004 (0.090%)	0.005 (1.43%)	0.004 (0.75%)	0.001 (0.471%)	0.001 (0.564 %)
Random error	0.3068 (74.11%)	0.312 (98.6%)	0.422 (87.7%)	0.222 (77.7 %)	0.146 (73.8 %)

CCC: concordance correlation coefficient; MSEP = mean square error of prediction; [1]Probability value for the hypothesis test where the value of parameter a = 0 (Neter et al., 1996). [2] Probability value for hypothesis test where the value of parameter b = 1 (Neter et al., 1996);[3] Adapted data published by Menezes et al. (2022).

Prediction and validation of dry matter intake in diets with fixed roughage: concentrate ratio

High-concentrate diets have recently become economically viable due to the increase in roughage production costs, temporary reductions in concentrate prices and increased supply of industry by-products (Cervieri et al., 2009). In Brazil, finishing diets have increased concentrate levels in recent years. Studies carried out between 2009 and 2014 showed an increase of 11% in the proportion of concentrate in feedlot diets (71.2% and 79%, respectively) (Millen et al., 2009; Oliveira and Millen, 2014). In a study carried out by Pinto and Millen (2018), it was pointed out that 87.9% of feedlots in the country used more than 71% concentrate in the diet, and of these, 54.6% used more than 80%. In a recent study, Silvestre and Millen (2021) found that the average inclusion of concentrate in the feedlot diet is 83.2%. With the increasing use of diets with high concentrate levels for feedlot cattle in Brazil, adequate nutritional management has become necessary, so it is fundamental to predict DMI.

Data that is considered valid for selection were those that included information regarding sex, initial and final body weight (BW), dry matter intake (DMI), average daily gain (ADG) and concentrate or roughage level in the total diet.

The descriptive statistic of the data used to validate the DMI prediction of cattle fed a fixed concentrate level diet is shown in Table 2.7. The following equations were got for the genetic groups:

Zebu cattle:

$$DMI\ (kg/d) = -1.303 + 0.0029 \times CL - 0.00005 \times CL^2 + 0.0843 \times BW^{0.75} + 2.243 \times ADG - 0.271 \times ADG^2 \quad (R^2 = 0.797) \qquad \text{(Equation 2.4)}$$

Crossbred beef cattle:

$$DMI\ (kg/d) = -4.8196 + 0.0081 \times CL - 0.00011 \times CL^2 + 0.1239 \times BW^{0.75} + 2.8189 \times ADG - 0.775 \times ADG^2 \quad (R^2 = 0.717) \qquad \text{(Equation 2.5)}$$

where CL = concentrate level in the diet (% total diet DM); $BW^{0.75}$ = mean metabolic body weight; ADG = average daily gain, in kg/d.

An independent database was used to validate the results with 106 experimental units for Zebu and 137 for crossbred beef cattle (Table 2.8). The data were obtained from publications between 2005 and 2015 in the *Revista Brasileira de Zootecnia, Arquivo Brasileiro de Medicina Veterinária e Zootecnia, Semina; Ciências Agrárias*, Acta Scientiarum: Animal Sciences, *Revista de*

Ciência Agronômica, Journal of Animal Science and Boletim.

When selecting this database, there was no concern to establish selection for high-concentrate diets, so, to verify the sensitivity of the prediction model for different proportions of concentrate in the diet were evaluated. This can be seen in the descriptive statistics for the validation database (Table 2.8).

The results observed in Table 2.9 indicated that the DMI prediction equation with fixed concentrate content can be used safely. Thus, considering that the diet formulator knows which concentrate level will be used in the diet, or has a fixed roughage: concentrate ratio, the BR-CORTE suggested that this equation can be used.

Based on Equations 2.4 and 2.5, the Table 2.10 shows the estimated dry matter intake for Zebu and crossbred beef cattle finished in feedlot obtained for different body weights and weight gains, considering three concentrate contents (30, 60 and 90%) in the diet.

Table 2.7 - Descriptive statistics of the variables used to develop dry matter intake prediction equation for cattle fed fixed concentrate level diet

Item	N	Mean	SD	Minimum	Maximum
Zebu cattle					
Dry matter intake, kg/d	983	7.55	2.07	2.05	13.8
Body weight, kg	983	362	88.3	133	647
Metabolic body weight, kg	983	82.9	15.8	39.2	128.2
Average daily gain, kg/d	983	0.97	0.41	-0.14	2.26
Concentrate level, %	983	45.6	24.0	0.00	85.0
Crossbred beef cattle					
Dry matter intake, kg/d	432	8.22	1.73	2.75	12.9
Body weight, kg	432	383	61.8	231	538
Metabolic body weight, kg	432	86.4	10.6	59.3	112
Average daily gain, kg/d	432	1.32	0.34	0.48	2.44
Concentrate level, %	432	61.9	21.6	25.0	100

N: number of experimental units; SD: standard deviation.

Table 2.8 - Descriptive statistics of the variables used to validate dry matter intake prediction by cattle fed different concentrate levels

Variable	N	Mean	SD	Minimum	Maximum
Zebu cattle					
Dry matter intake, kg/d	106	8.68	1.61	2.96	12.3
Body weight, kg	106	416	53.5	223	494
Metabolic body weight, kg	106	91.9	9.18	57.7	105
Average daily gain, kg/d	106	1.19	0.30	0.15	1.75
Concentrate level, % total diet DM	106	62.1	20.3	0.00	95.4
Crossbred beef cattle					
Dry matter intake, kg/d	137	8.98	1.47	6.11	13.60
Body weight, kg	137	394	48.2	265	520
Metabolic body weight, kg	137	88.3	8.18	65.6	109
Average daily gain, kg/d	137	1.40	0.27	0.76	2.17
Concentrate level, % total diet DM	137	55.0	17.9	11.0	100

N: number of experimental units; SD: standard deviation.

Table 2.9 - Statistics for the ratio between the observed and predicted values by the DMI prediction equations for cattle fed with different concentrate levels

Variable		Zebu	Crossbred beef cattle
Intercept		-1.3568	-1.5386
	P-value[1] (H_0: a = 0)	0.0623	0.2022
Slope		1.1577	1.1316
	P-value[2] (H_0: b = 1)	0.0582	0.3150
r^2		0.6552	0.4087
Mean bias		0.0105	-0.3329
CCC		0.7602	0.5262
MSEP		0.9254	1.3306
	Mean bias	0.0001 (0.01%)	0.1717 (12.30%)
	Systemic error	0.0315 (3.41%)	0.0040 (0.29%)
	Random error	0.8938 (96.58%)	1.2203 (87.41%)

CCC = concordance correlation coefficient; MSEP = mean square error of prediction; [1]Probability value for the hypothesis test where the value of parameter a = 0 (Neter et al., 1996). [2] Probability value for hypothesis test where the value of parameter b = 1 (Neter et al., 1996).

Prediction and validation of dry matter intake by pasture-raised cattle receiving supplementation

Brazil is a country with continental dimensions, and it is the fifth in the world in terms of territorial extension, with an area of 8.5 million km^2 where 172.3 million hectares are pasture (IBGE, 2007). It also has a great diversity of climate and vegetation, which along with the territorial extension enables the beef production systems to be characterized by using forage as the diet base. Most of the Brazilian beef production system is produced with animals under pasture conditions and of the 41.5 million cattle slaughtered in Brazil, only 15.62% were finished in the feedlot in 2020 (ABIEC, 2021).

According to Paulino et al. (2005), sustainable pasture for beef cattle production should be highlighted, because this resource is the main and the most economical source of nutrients for the animals.

Predicting intake for pasture-raised cattle is not an easy task. In their revision, Coleman et al. (1999) observed that the DMI of cattle on pasture varies as a function of the forage quality and physical characteristics and the physiological state of the animal.

According to Lardy et al. (2004), the main limitation to establish DMI prediction models for cattle on pasture is that the main studies were carried out with indirect estimates using external and internal markers to predict DMI. Furthermore, animals on pasture can assess the forage available and select a diet that meets their nutrient needs (Coleman and Sollenberger, 2007; Launchbaugh and Doherty, 2007). Thus, their selectivity ends up interfering in the possibility of quantifying the diet chemical composition of animals on pasture and predicting exactly which nutrients are ingested by these animals.

Therefore, it should be considered that the DMI prediction estimates for cattle on pasture are more complex than those for animals in feedlot and good sense should prevail when using the equations developed. Pasture should be understood as a highly complex production component because it supplies substrates to the animal and can vary qualitatively and quantitatively over the year, influenced mainly by abiotic factors, e.g., rainfall, temperature, and solar radiation (Detmann et al., 2004).

Using tropical grasses as the only protein and energy source is not feasible to meet the nutrient requirements of growing or finishing cattle (Moore, 1999) because pastures rarely contain all the essential nutrients in adequate proportions to meet the nutrient requirements of the animal. Therefore, feeding systems combining base forage and concentrate supplement are necessary to make nutritional adjustments and improve animal production on pasture.

Moore (1980) reported three possible effects to be identified between supplementation and forage intake: additive, associative and substitutional. In the first, forage intake remains constant, regardless of the level of supplementation, but the total

intake increases at the same proportion as the supplemented level; in the associative effect, the total intake also increases, but forage intake decreases; while in the substitutional, the total intake remains constant, but forage intake decreases and is substituted by supplement intake.

Table 2.10 - Dry matter intake for Zebu and crossbred beef cattle finished in feedlot obtained for different body weights and weight gains, considering three concentrate levels (30, 60 and 90%)

Body weight (kg)	Weight gain (kg/d)	Concentrate (%)	Dry matter intake (kg)	
			Zebu (Equation 2.4)	Crossbred beef cattle (Equation 2.5)
200	0.5	30	4.28	3.13
		60	4.23	3.08
		90	4.09	2.82
	1.0	30	5.19	3.96
		60	5.15	3.90
		90	5.01	3.65
	1.5	30	5.98	4.40
		60	5.93	4.34
		90	5.79	4.09
300	0.5	30	5.87	5.47
		60	5.82	5.42
		90	5.68	5.17
	1.0	30	6.79	6.30
		60	6.74	6.25
		90	6.60	5.99
	1.5	30	7.57	6.74
		60	7.52	6.69
		90	7.38	6.43
400	0.5	30	7.33	7.62
		60	7.28	7.57
		90	7.15	7.32
	1.0	30	8.25	8.45
		60	8.20	8.40
		90	8.07	8.14
	1.5	30	9.03	8.89
		60	8.99	8.84
		90	8.85	8.58
500	0.5	30	8.71	9.64
		60	8.66	9.59
		90	8.52	9.33
	1.0	30	9.62	10.47
		60	9.58	10.42
		90	9.44	10.16
	1.5	30	10.41	10.91
		60	10.36	10.86
		90	10.22	10.60

The replacement effect obtained with supplementation is directly proportional to the forage quality, where it is greater with high-quality compared to low-quality forage (Minson, 1990). With the replacement, values lower than 1.0 g/g are assumed, and a reduction is observed in pasture intake, but there is an increase in total intake (Costa et al., 2011).

Currently, most of the national beef herd is Nellore or comes from their crosses. However, the number of animals coming from dairy farms is increasing due to the high demand for meat and the lower exchange ratio of the 'arroba' of these animals in the acquisition.

Given the importance of estimating the DMI of cattle in tropical conditions raised on pasture and receiving supplementation, BR-CORTE (Azevedo et al., 2016) suggested the use of a specific prediction model considering the DMI of the supplement (DMIs, kg/d) for Nellore animals. However, with the increase in pasture-raised crossbred dairy cattle, in this version, an Equation was suggested to cover these animals and the database of Zebu animals was expanded.

Wide variation in the data was observed in the information regarding the descriptive statistics of the database (Table 2.11), so that prediction equations could be generated for more varied production systems.

The following DMI intake equation was established for Zebu on pasture, receiving supplementation, under tropical conditions:

Zebu cattle supplemented on pasture:

$$DMI\ (kg/d) = -0.4684 + 0.7732 \times DMIs + 0.0742 \times BW^{0.75} + 0.7953 \times ADG - 0.9047 \times ADG^2 \quad (R^2 = 0.638) \quad \text{(Equation 2.6)}$$

Crossbred dairy cattle supplemented on pasture:

$$DMI\ (kg/d) = 0.9951 + 0.7732 \times DMIs + 0.0742 \times BW^{0.75} + 0.7953 \times ADG - 0.9047 \times ADG^2 \quad (R^2 = 0.624) \quad \text{(Equation 2.7)}$$

where DMIs is the supplement intake, in kg/d; $BW^{0.75}$ average metabolic body weight, in kg and ADG, average daily gain, in kg/d.

To validate this Equation, an independent database from the journals was used: *Revista Brasileira de Zootecnia, Arquivo Brasileiro de Medicina Veterinária e Zootecnia, Semina: Ciências Agrárias*, Asian Australasian Journal of Animal Science, Bioscience Journal, Acta Scientiarum. Animal Sciences, Enciclopédia Biosfera, Research, Society and Development, Tropical Animal Health and Production and *Pesquisa Agropecuária Brasileira.*

The total size of the variables presented in the database for validating the intake prediction for Zebu cattle raised on pasture (Table 2.12) represents Brazilian characteristics of extensive beef cattle pasture and supplemented production systems and it is sufficiently representative to validate the equation.

Then, the responses to the predicted and observed values were exact and precise: the equation correctly estimated the DMI represented by the non-significance of the intercept and slope and by the low value of the mean square prediction error (Table 2.13), indicating that it could be applied to pasture-raised and supplemented animals.

It should be noted that equations 2.6 and 2.7 should be used to predict DMI in animals rearing or receiving moderate levels of concentrate (up to 5.32 and 3.5 kg/d for zebu and crossbred dairy animals, respectively), and that present moderate weight gains (up to 1.34 and 1.35 kg/d for zebu and crossbred dairy animals, respectively). It should be considered that most of the data used to build this Equation were obtained in periods of drought.

Table 2.11 - Descriptive statistics of the variables used to predict dry matter intake for pasture-raised Zebu and Crossbred dairy cattle

Variable	N	Mean	SD	Minimum	Maximum
Zebu cattle					
Body weight, kg	1069	278	92.0	102	568
Metabolic body weight, kg	1069	67.3	16.6	32.1	116
Average daily gain, kg/d	1069	0.53	0.32	-0.39	1.56
Dry matter intake, kg/d	1069	5.18	2.01	1.34	14.1
Supplement, kg/d	1069	0.83	0.76	0.00	5.92
Crossbred dairy cattle					
Body weight, kg	229	332	75.0	199	541
Metabolic body weight, kg	229	77.5	13.1	53	112
Average daily gain, kg/d	229	0.55	0.17	0.28	1.08
Dry matter intake, kg/d	229	7.33	1.72	4.02	11.37
Supplement, kg/d	299	0.69	0.41	0.16	1.75

N: number of experimental units; SD: standard deviation.

Table 2.12 - Descriptive statistics of the variables used to validate dry matter intake for pasture-raised Zebu and Crossbred dairy cattle

Variable	N	Mean	SD	Minimum	Maximum
Zebu cattle					
Body weight, kg	174	311	86.7	133	474
Metabolic body weight, kg	174	73.5	15.8	39.2	102
Average daily gain, kg/d	174	0.56	0.26	-0.18	1.34
Dry matter intake, kg/d	174	6.65	2.18	1.98	12.3
Supplement, kg/d	174	1.06	1.14	0.00	5.32
Crossbred dairy cattle					
Body weight, kg	42	297	68.0	194	417
Metabolic body weight, kg	42	71.3	12.3	51.9	92.3
Average daily gain, kg/d	42	0.59	0.21	0.11	1.05
Dry matter intake, kg/d	42	7.00	1.73	4.74	10.24
Supplement, kg/d	42	0.87	1.00	0.00	3.50

N: number of experimental units; SD: standard deviation.

Table 2.13 - Statistics for the ratio between the observed and predicted values by the DMI for pasture-raised Zebu and Crossbred dairy cattle

Variable		
Zebu cattle		
Intercept		0.470
	P-value[1] (H_0: a = 0)	0.170
Slope		1.05
	P-value[2] (H_0: b = 1)	0.376
r^2		0.670
Mean bias		0.761
CCC		0.741
MSEP		2.13
Decomposition of the MSEP		
	Mean bias	0.580 (27.19%)
	Systemic error	0.007 (0.33%)
	Random error	0.007 (72.47%)
Crossbred dairy cattle		
Intercept		-0.882
	P-value[1] (H_0: a = 0)	0.153
Slope		1.10
	P-value[2] (H_0: b = 1)	0.237
r^2		0.771
Mean bias		-0.168
CCC		0.851
MSEP		0.665
Decomposition of the MSEP		
	Mean bias	0.028 (4.23%)
	Systemic error	0.018 (2.72%)
	Random error	0.018 (93.06%)

CCC = concordance correlation coefficient; MSEP = mean square error of prediction; [1]Probability value for the hypothesis test where value of parameter a = 0 (Neter et al., 1996). [2] Probability value for hypothesis test where value of parameter b = 1 (Neter et al., 1996).

In intensive finishing on pasture (TIP), in which the animal intake the same amount of concentrate on pasture that is supplied when feedlot, BR-CORTE suggests using Equation 2.1 to predict DMI.

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Intakes estimated by equations 2.6 and 2.7 can be seen in Table 2.14, where it is possible to observe variations in combinations between body weight, average daily gain and supplement intake

Table 2.14 - Estimated dry matter intake for pasture-finished cattle of different body weights, weight gains and supplement intakes (DMIs)

Body weight (kg)	Weight gain (kg/d)	DMIs	DMI (Eq. 2.6)	DMI (Eq. 2.7)
200	0.00	0.00	3.48	4.94
		0.80	4.10	5.56
		1.60	4.71	6.18
	0.50	0.00	3.65	5.11
		0.80	4.27	5.73
		1.60	4.89	6.35
	1.00	0.00	3.37	4.83
		0.80	3.99	5.45
		1.60	4.61	6.07
300	0.00	0.00	4.88	6.34
		1.20	5.81	7.27
		2.40	6.74	8.20
	0.50	0.00	5.05	6.52
		1.20	5.98	7.44
		2.40	6.91	8.37
	1.00	0.00	4.77	6.23
		1.20	5.70	7.16
		2.40	6.63	8.09
400	0.00	0.00	6.17	7.63
		1.60	7.41	8.87
		3.20	8.64	10.11
	0.50	0.00	6.34	7.80
		1.60	7.58	9.04
		3.20	8.81	10.28
	1.00	0.00	6.06	7.52
		1.60	7.30	8.76
		3.20	8.53	10.00
500	0.00	0.00	7.38	8.84
		2.00	8.92	10.39
		4.00	10.47	11.93
	0.50	0.00	7.55	9.01
		2.00	9.10	10.56
		4.00	10.64	12.11
	1.00	0.00	7.27	8.73
		2.00	8.81	10.28
		4.00	10.36	11.82

FINAL CONSIDERATIONS

The equations for predicting dry matter intake for feedlot cattle in tropical conditions are:

Zebu cattle: $DMI\ (kg/d) = -2.1948 + 0.08338 \times BW^{0.75} + 3.9328 \times ADG - 0.9030 \times ADG^2$ (Equation 2.1)

Crossbred beef cattle: $DMI\ (kg/d) = -0.6273 + 0.06453 \times BW^{0.75} + 3.871 \times ADG - 0.614 \times ADG^2$ (Equation 2.2)

Crossbred dairy cattle: DMI (kg/d) = –2.8836 + 0.08435 × $BW^{0.75}$ + 4.5145 × ADG – 0.9631 × ADG^2 (Equation 2.3)

Alternatively, the equations below can be used when the concentrate level used in the diet formulation is known:

Zebu cattle: DMI (kg/d) = – 1.303 + 0.0029 × CL – 0.00005 × CL^2 + 0.0843 × $BW^{0.75}$ + 2.243 × ADG – 0.271 × ADG^2 (Equation 2.4)

Crossbred beef cattle: DMI (kg/d) = – 4.8196 + 0.0081 × CL – 0.00011 × CL^2 + 0.1239 × $BW^{0.75}$ + 2.8189 × ADG – 0.775 × ADG^2 (Equation 2.5)

The following equation is indicated to predict dry matter intake for **Zebu cattle raised on pasture**:

Zebu cattle: DMI (kg/d) = – 0.4684 + 0.7732 × DMIs +0.0742 × $BW^{0.75}$ + 0.7953 × ADG – 0.9047× ADG^2 (Equation 2.6)

Crossbred dairy cattle: DMI (kg/d) = 0.9951 + 0.7732 × DMIs +0.0742 × $BW^{0.75}$ + 0.7953 × ADG – 0.9047×ADG^2 (Equation 2.7)

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3

Ruminal protein degradation of feeds and microbial protein synthesis

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Ruminants are a group of animals characterized by the intake of diets that are altered in rumen by anaerobic microorganisms. These microorganisms have ideal conditions in the rumen for their development and growth using dietary protein as feed source. When rumen digesta flows through the gastrointestinal tract, these microorganisms become a source of protein for digestion in the small intestine of ruminants. Thus, to find an appropriate recommendation regarding protein requirements for cattle, we must characterize the changes imposed by these microorganisms and the amount of microbial protein that reaches the small intestine with a specific diet.

INTRODUCTION

The pool of potentially fermentable protein in the rumen includes dietary nitrogenous compounds, endogenous protein from saliva, loss of epithelial cells and lysed rumen microorganisms in the rumen (NRC, 2001). This protein pool that can be significantly changed in this compartment is called rumen degradable protein (RDP). Thus, ruminant´s protein nutrition is dependent on the magnitude and profile of that pool that reaches the small intestine for absorption as amino acids plus dietary protein that has not been degraded in the rumen. This protein fraction is called rumen undegradable protein (RUP). The set of all amino acids that are available for the intestinal digestion and absorption represents the metabolizable protein (MP). The nutritional requirements of MP and crude protein (CP) for beef cattle can be estimated after knowing the changes in dietary nitrogenous compounds by the rumen. Then, it is necessary to know the microbial protein that is produced in the rumen when providing different diets, the factors that affect the production and efficiency of this protein, and understand digestion and absorption of the protein in the gastrointestinal tract.

The literature found different methods to estimate the nitrogen partitioning of the diet into RDP and RUP and its intestinal digestibility. These methods include *in vivo*, *in situ* and a variety of *in vitro* methods (Schwab et al., 2003). The accuracy of *in vivo* methods provide reliable estimates of what happens during nutrient digestion. However, in most situations, the *in vivo* methods can be applied specifically for digestibility trials.

The validation of protocols that allow the use of *in vitro* and *in situ* techniques in an accurately and unbiased manner is required to obtain estimates for ruminal protein degradation, microbial production and indirectly the MP. The total estimated microbial crude protein (MCP) synthesis can also be performed using *in vivo* techniques using microbial markers in the rumen, small intestine or in the urine. Thus, alternative techniques, such as the urinary purine derivatives (PD), can be used to quantify the MCP that leaves the rumen and reaches the small intestine for absorption as amino acids. This technique can reduce handling time of animals during the experiment and dispense the use of fistulated animals. However, the urinary volume estimate must be accurate to minimize experimental errors.

Furthermore, the ability to estimate microbial production and efficiency as a function of the diet offered is an essential mathematical tool to estimate MP requirements. Then, it is necessary to find which are the variables that affect the efficiency of MCP synthesis, and to fit accurate equations to predict it. The objective of this chapter was to present the main techniques involved in the RDP and RUP estimates in feed, including effects of microbial contamination in the ruminal incubation residue. The objective was also to present techniques to quantify MCP and the

factors that affect this synthesis. This chapter also presented validated equations to estimate MCP synthesis.

PROTEIN RUMINAL DEGRADATION

In situ techniques

Among the main differences found in estimating ruminal protein degradation is the choice of technique. The *in situ* technique consists of measuring the ruminal disappearance of the feed by adding ingredients in bags of known porosity, where rumen microorganisms access the feed and degrade it. It allows the quantification of non-degraded residues. The bags are incubated in ruminal digesta of cannulated animals, which characterizes the denomination of *in situ* technique (Orskov et al., 1980). The study of degradability is important to understand feed changes in the rumen, as CP can be degraded and converted into microbial protein.

According to Nocek (1988), using *in situ* technique allows intimate contact between the feed and rumen microorganisms. There is no better way to simulate rumen digestion during certain conditions of temperature, pH, buffer substrate and microbial populations. However, as a limitation, the studied feed is not subjected to all digestive steps such as chewing, rumination, and passage rate. Then, we will be discussed the critical points and some standardizations that made the method as accurate as possible.

a) Non-degraded material losses

The loss of material inside the rumen bag is critical because particles smaller than the size of the bag pores can be lost even without prior degradation. This event can cause overestimation of the soluble fraction or its ruminal degradation rate. However, the reduction of the grinding particle size facilitates microbial access since feed bypasses the processes of chewing and rumination. To minimize this problem, some authors recommend incubations using particle sizes between 1.5- and 3-mm diameter (Huntington and Givens, 1995; Broderick and Cochran, 2000).

Using tropical forage, Casali et al. (2008) recommended particle size of 2 mm for *in situ* incubation for greater accuracy in estimates of degradable fractions. These authors found that the 3 mm size reduced the accuracy of the results probably due to the smaller specific surface for microbial action. NRC (2001) also suggested the standardization of *in situ* incubations using ground particles of 2 mm. Thus, BR-CORTE (2016) recommends milling feed samples with 2 mm sieves to perform *in situ* incubations, although for conducting chemical analyzes the porosity should be 1 mm as suggested by Valente et al. (2011) for more accurate results for neutral detergent fiber (NDF). However, even with the standardization of the particle size, there are losses of undigested material, thus, some authors recommend the correction of *in situ* degradation data by washing the bags in water and determining the immediate loss of particles (Lopez et al., 1994; France et al., 1997).

Hvelplund and Weisbjerg (2000) described a protocol for estimating the extent of particles loss and correction of degradation fractions through the difference between the loss of material from the nylon bags when these were only washed with water and the true solubility measured in filter paper. Water solubility should be measured by adding 0.5 g of sample to 40 mL of water, which should remain at room temperature for 1 h. After this time the material must be transferred to nitrogen-free paper filter to quantify the water-soluble N. The correction for particle loss can be performed using equations proposed by Weisbjerg et al. (1990):

$$DEG_{cor}(ti) = DEG(ti) - P \times \left[1 - \frac{DEG(ti) - P + SOL}{1 - (P + SOL)}\right]$$

$$a_{cor} = a - P$$

$$b_{cor} = b + P \times \left[\frac{b}{1 - (P + SOL)}\right]$$

$$c_{cor} = c$$

where: $DEG_{cor}(ti)$ = degradability corrected in incubation time ti; DEG(ti) = degradability measured in incubation time ti; P = particle loss; SOL = water solubility; a_{cor} = soluble fraction corrected; b_{cor} = potentially degradable

insoluble fraction corrected; c_{cor} = degradation rate corrected; a, b, c = no corrected fractions measured.

b) Microbial contamination of ruminal residue incubation of forage and concentrates

After the end of the *in situ* ruminal incubation, the bags must undergo a cleaning process for the microbial degradation immediate standstill and also for removing ruminal digesta and microbial residue adhered to the feed or in the bags. However, some authors (Nocek and Grant, 1987; Vanzant et al., 1998; Michalet-Doreau and Ould-Bah, 1992) reported that it is difficult to achieve a complete removal of the microbial mass adhered to particles because a specific microbial adhesion is necessary to start particles colonization. Thus, microbial contamination in incubation residues represents an important source of variation, resulting in overestimation of residues and non-degradable fractions. This consequently results in underestimation of the potentially degradable fraction. Especially for the protein fraction of low protein forages, microbial contamination has a greater impact on the estimates of degradable fractions.

However, the procedures to estimate microbial contamination require the use of microbial markers, such as diaminopimelic acid, RNA, ^{35}S and ^{15}N, which have high costs and increase the total time for chemical analysis. A solution to minimize these barriers would be the development of a correction protocol that does not require the use of microbial markers in all procedures, increasing the accuracy of the estimates without raising the experimental cost.

Machado et al. (2013) conducted a study using ^{15}N as a microbial marker to estimate microbial contamination in incubation residues of forage. These authors presented an equation to correct residues after ruminal *in situ* incubation, and to correct degradable fractions, which will be adopted in this edition of BR-CORTE. The authors reported that soluble fraction (A) and potentially degradable (B) in low protein forages can be underestimated if not corrected. The authors recommended the following equations:

(1) $A_{CP}C = 1.99286 + 0.98256 \times A_{CP}NC$

(2) $B_{CP}C = -17.2181 - 0.0344 \times B_{CP}NC + 0.65433 \times CP + 1.03787 \times NDF + 2.66010 \times NDIP - 0.85979 \times iNDF$

(3) $kd_{CP}C = 0.04667 + 0.35139 \times kd_{CP}NC + 0.0020 \times CP - 0.00055839 \times NDF - 0.00336 \times NDIP + 0.00075089 \times iNDF$

where $A_{CP}C$ = soluble fraction of CP corrected for microbial contamination, $A_{CP}NC$ = soluble fraction of CP without correction for microbial contamination, $B_{CP}C$ = potentially degradable fraction of CP corrected for microbial contamination, $B_{CP}NC$ = potentially degradable fraction of CP without microbial correction, $kd_{CP,}C$ = degradation rate of B fraction corrected for microbial contamination, $kd_{CP}NC$ = degradation rate of B fraction without microbial contamination, NDIP = neutral detergent insoluble protein, NDF = neutral detergent fiber, and iNDF = indigestible neutral detergent fiber.

Machado et al. (2013) also suggested that microbial contamination percentage in different incubation times for forages with different CP contents may be obtained by the following equation:

$$\%C = 79.21 \times (1 - e^{-0.0555 \times t}) \times e^{-0.0874 \times CP}$$

where %C = percentage of microbial contamination, t = feed incubation time in hours, CP = crude protein as a percentage of feed in DM basis.

To estimate the impact of microbial contamination on *in situ* incubation residues of concentrate feeds, Menezes et al. (2017) conducted a study using ^{15}N as microbial marker and evaluated 12 concentrate feeds, including six protein and six energetic feeds. Although there was microbial contamination in incubation residues, the authors found no difference among fractions A, B, and kd when values were corrected or not for microbial contamination after 72 hours of ruminal incubation. The authors observed that the greatest contaminations were obtained for corn straw and corncobs, and for sunflower meal and wheat bran, which are feeds with high NDF content. This study suggested that for concentrate feeds the microbial contamination makes an irrelevant contribution to incubation

residues, suggesting that for these feeds it is not necessary to correct for microbial contamination due to the lack of interference in RDP and RUP.

c) Experimental design and incubation times

The experimental protocols adopted by Machado et al. (2013) and Menezes (2016) are proper alternatives to estimate *in situ* ruminal degradation of feeds. These authors conducted repeated incubations of feeds in different animals, using a Latin square design as a tool to collect unbiased samples. According to Machado et al. (2013), the Latin square design can be used to organize data collection, allowing measurement of feed degradation and removing the animal confusion effect. The Latin square design can be used to control sources of variation and avoid animal experimental errors. Machado et al. (2013) reported that the Latin square design does not need to be used to estimate variability or to account for sources of variation in experimental error, but to conduct unbiased data collection.

When the objective of ruminal incubation is to obtain data to estimate intestinal digestibility of RUP, the incubation times proposed by Menezes et al. (2017) should be used. This author conducted a cluster analysis and estimated that, for protein concentrate feeds, the incubation time to estimate RDP should be between 6.8 to 15.4 h, considering kp = 0.05 h^{-1}.

Thus, the literature recommendations of 16 h (Calsamiglia et al., 1995) to obtain RDP feed may not be useful for all types of feed. Menezes et al. (2019) established the times needed to estimate the RDP of concentrated feeds grouped into: high-starch energy concentrates, low-starch energy concentrates, and protein concentrates, obtaining the following intervals, considering kp = 0.05 h^{-1}:

- High-starch energy concentrates – ground corn, ground sorghum and crumbled corn with straw and cob: 16 hours.
- Low-starch energy concentrates – wheat meal, rice meal and soybean hulls: 7 hours.
- Protein concentrates – cottonseed meal, soybean meal, beans, peanut meal, and sunflower meal: 10 hours.

However, it is important to emphasize that these times may not be enough to study CP degradability of tropical forages. Some Brazilian studies (Martins et al., 1999; Cabral et al., 2005; Pires et al., 2006) used 48 hours of incubation to estimate *in situ* degradation for concentrate feeds and 72 hours for forages. Despite several studies evaluating the time needed to estimate the fiber fractions for *in situ* incubation (Casali et al., 2008), few studies have evaluated the time needed to estimate RDP of forages.

d) Conditions inside the incubation bags

According to López (2005), conditions inside the incubation bags should be similar to those in the rumen. Therefore, the choice of suitable nylon for the production of bags is very important. The material must be synthetic and refractory to microbial degradation. Also according to Nocek (1997), the porosity of an adequate bag constitutes the adjustment between the limit to the influx of ruminal content without associating it with the evaluated feeds, thus allowing, the input of microbial populations for degradation; while at the same time, limiting the output of non-degraded feed particles. For many years, nylon bags, ranging from 40 to 60 μm in porosity as recommended by Nocek (1997), have been used as a standard for incubation; however, in the last years, the use of nylon has been questioned in several national and international studies. Hvelplund and Weisbjerg (2000) recommended the use of nylon bags with porosity varying between 30 and 50 μm in studies evaluating the *in situ* degradation of CP. Nevertheless, no studies were found comparing protein degradation in bags with different porosities. Thus, while studies are not conducted to evaluate the ideal porosity of nylon bags to obtain better estimates of RDP of feeds, we recommend the use of nylon bags with porosity of 40-60 μm.

The surface area of the incubated bags in relation to the amount of sample is also an important variable to be considered in the internal conditions of *in situ* degradation. According to Nocek (1988), the optimal amount of sample is that which provides enough quantity for chemical analysis at the end of the degradation process without

excessively filling the bags that delay microbial adhesion, increasing the latency phase and underestimating the digestion rates. After a literature review, the author recommended a sample of 10 to 20 mg/cm^2 of bags for most feeds, highlighting that for concentrate feeds, the higher value can be critical due to the high density and rapid degradation, causing intense gas production per unit of time. Therefore, despite having appeared in the 1980's, the study by Nocek (1988) has not been refuted yet, and is currently used as reference for *in situ* incubation studies.

e) Mathematical models to estimate ruminal degradation of crude protein

Traditional mathematical methods used to describe ruminal degradation generally calculate this variable based on substrate mass retained in the evaluated compartment. Some of these models are first-order (Waldo et al., 1972) that consider only the substrate to be digested, and others are second-order because they also consider the pool of substrates studied and the microbial mass present in the system (France et al., 1990). The Mitscherlich first-order model proposed by Ørskov and McDonald (1979) is most frequently used to evaluate CP residues obtained by *in vitro* and *in situ* methods. This simple negative exponential model is also considered as minimum return model.

The model proposed by Ørskov and McDonald (1979), in first-order kinetics, assumes that the degraded substrate for any time is proportional to the amount of potentially degradable residue in any time at a constant fractional degradation rate. This model is widely used due to its simplicity. On the other hand, this model does not have a wide diversity of changes on fractional rate due to degradation (López, 2008). Thus, López et al. (1999) studied some models that consider that the fractional degradation rate of nutrients is not a constant value, but a variable one; and that some degradation models based on the kinetics of microbial growth have a sigmoidal pattern, indicating an alternative solution for minimum return models or simple exponential models, as it is the case of the model proposed by Van Milgen et al. (1991).

Therefore, the models to adjust the CP degradation curves, both for the exponential and sigmoidal patterns, are presented below considering a constant fractional degradation rate (kd). The incubation CP residues obtained through *in vitro* or *in situ* assays as a function of time can be evaluated using mathematical models proposed by (1) Ørskov and McDonald (1979) and (2) Van Milgen et al. (1991):

(1) $Deg(t) = a + b \times (1 - e^{-kd \times t})$

(2) $Deg(t) = a + b \times [(1 + c \times t) \times (e^{-c \times t})]$

where: Deg (t) represents CP disappearance expressed as a percentage; *a* represents the water soluble fraction at time zero; *b* represents the water insoluble fraction but potentially *c* represents joint fractional lactency and degradation rate (h^{-1}); kd is the degradation rate of the fraction *b*; and *t* is the incubation time (hours).

Mitscherlich's first-order model adapted by Ørskov and McDonald (1979) assumes that degradation occurs at a constant fractional rate after a discrete latency rate; thus, the disappearance rate continuously decreases and there is no tipping point. Then, the authors included the parameter that denotes the immediately soluble fraction.

These authors presented a model with static values for the degradation rate, with a smaller number of parameters to be estimated. Therefore, we recommend the Ørskov and McDonald (1979) model, as it is simple and works relatively well to evaluate protein degradation of feedstuffs. For any model used, from the soluble fraction (a), potentially degradable fraction (b), and degradation rate (kd) measured for CP and using an estimated passage (kp), we can calculate the effective degradability that will correspond to RDP:

$$RDP = a + \left[\frac{(b \times kd)}{(kd + kp)} \right]$$

Therefore, one of the important factors that directly interfere with the RDP values is the passage rate adopted in the calculations of the effective CP degradability. The NRC (2001) previously adopted three different functions to estimate the passage rate of humid forage, dry forage and concentrates. However, Seo et al. (2006) highlighted that the data

compiled to generate these three equations were obtained in experiments that used rare earth elements as main markers, which limit the applicability of equations to current experimental data. Then, Seo et al. (2006) proposed new equations based on a database of 154 studies and 766 observations, which were able to predict the passage rate of several feedstuffs and diets based on external markers. After adjustments, the authors presented the following equations to estimate passage rate (kp) of forage, concentrates, and liquids:

$$kp\ forage = (2.365 + 0.0214 \times FiBW + 0.0734 \times CiBW + 0.069 \times Fi) / 100$$

$$kp\ concentrate = (1.169 + 0.1375 \times FiBW + 0.1721 \times CiBW) / 100$$

$$kp\ liquids = (4.524 + 0.0223 \times FiBW + 0.2046 \times CiBW + 0.344 \times Fi) / 100$$

where: kp = passage rate, h^{-1}; FiBW = forage intake in g DM/kg BW; CiBW = concentrate intake in g DM/kg BW; Fi = forage intake in kg DM.

Chemical analyses to estimate RDP and RUP: protein solubilization and fractioning

The most used method to estimate the fractions of nitrogen compounds in feeds is the subdivision protocol used in the CNCPS (Sniffen et al., 1992; Fox et al., 2000). Originally, the CNCPS divided CP of feedstuffs in 5 fractions, using 3 solvents and a precipitant. The five CP fractions are:

- A, soluble in borate-phosphate buffer (BFB), but without precipitation in trichloroacetic acid (TCA), consisting of non-protein nitrogen compounds (NPN);
- B_1, true protein rapidly degraded in the rumen, soluble in BFB, with precipitation in TCA;
- B_2, true protein and large peptides, moderately degraded in the rumen, calculated as the difference between total CP of feeds and other fractions;
- B_3, true protein slowly degraded in the rumen, calculated by the difference between neutral detergent insoluble protein (NDIP) and acid detergent insoluble protein (ADIP content) and fraction;
- C, or unavailable protein, equals ADIP.

The NDIP is obtained by estimating the CP in the insoluble residue after treatment with neutral detergent, without the use of sodium sulfite, while the ADIP is estimated after sequential extraction in the residual acid detergent. Fraction A is considered 100% degraded in rumen, while fraction C is considered as 100% undegraded in the rumen.

An interesting aspect of the approach used by CNCPS is that the analyzes (NPN, NDIP, ADIP, and soluble true protein) performed to estimate CP fractions are routine procedures in many laboratories, which facilitates the adoption of this method for use in field conditions (Schwab et al., 2003).

The CNCPS system was recently updated, when Higgs et al. (2015) presented new nomenclature for CP fractions adopted in the current CNCPS. Some changes were made to the analysis methods used by the authors, as follows:

$$P_{A1} = ammonia \times (SP/100) \times (CP/100)$$

$$P_{A2} = [SP \times (CP/100)] - P_{A1}$$

$$CP_1 = CP - (P_{A1} - P_{A2} - CP_2 - IP)$$

$$CP_2 = (NDIP - ADIP) \times (CP/100)$$

$$IP = ADIP \times (CP/100)$$

where: P_{A1} = ammonia; P_{A2} = soluble true protein; CP_1 = insoluble true protein; CP_2 = fiber linked protein; IP = indigestible protein; CP = crude protein; SP = soluble protein in borate-phosphate buffer including sodium azide; NDIP = neutral detergent insoluble protein; ADIP = acid detergent insoluble protein

MICROBIAL PROTEIN SYNTHESIS

Since ruminal microorganisms are the main modifiers of dietary protein, not only the animal's CP requirement must be considered, but also the quantification of N required for the synthesis of ruminal microbial protein. According to Puchala and Kulasek (1992), to obtain the total N required by ruminant, nutritional requirements systems need to provide an estimate of the total amount of protein that is digested and absorbed in the small intestine. This total protein comprises microbial protein synthesized in the rumen and dietary protein that escapes ruminal degradation. The nutritional requirement of

RUP is calculated as the total MP required minus the amount of digestible microbial protein that reaches the duodenum, therefore there is a need to obtain accurate estimates of this variable to quantify the nutritional requirements of MP for ruminants (Firkins, 1996).

According to Broderick and Merchen (1992), microbial markers are necessary to quantify rumen microbial protein. These can be classified as internal and external markers. Internal markers are those inherent to the microorganism, or are already chemical components of the microorganism itself, such as diaminopimelic acid. In addition to the methods mentioned, the most widely used microbial compound as an internal marker is defined as microbial nucleic acids. The high level of RNA in microbial cells makes this compound of great interest in the quantification of the pool of microbial proteins synthesized in the rumen.

External markers are those added to the rumen and able to adhere to microorganisms, as is the case of heavier isotopes such as ^{15}N. An ideal microbial marker should include characteristics such as being easy to quantify, not being present or present in small amounts in feeds, being present in a constant ratio even under experimental conditions and binge biologically stable. The use of each of these markers requires a different technique to estimate the microbial protein, however, most are invasive techniques, as fistulated animals are required to collect ruminal fluid enriched with a marker.

The discovery that urinary purine derivatives (PD) in ruminants are quantitatively important as final products of N metabolism led to further research in the area and to the establishment of relationships between ruminal nucleic acid concentrations and the excretion of urinary PD in ruminants (Topps and Elliott, 1965). This information is the basis of knowledge that led to the use of urinary PD as a non-invasive method to estimate the supply of microbial protein to the intestine in ruminants (Chen and Gomes, 1992).

Comparing ^{15}N and RNA

^{15}N has been widely used as a marker to estimate microbial protein, even though it is a stable isotope, with low environmental risk, lower cost compared to other isotopes for marking all pools of microbial N; moreover, it cannot be found naturally in feedstuffs protein and it does not mark animal protein until marked microbial amino acids are incorporated into their tissues (Broderick and Merchen, 1992). ^{15}N is well distributed in the microbial cell; then, in the case of cell lysis during bacterial isolation, the loss of protoplasm that underestimates nucleic acids is less harmful to the estimate of ^{15}N concentration.

Normally, the marker: microbial N ratio has been obtained in bacteria isolated from the liquid phase of the ruminal digesta, considering that it is similar to mixed ruminal microbial ratio, although there are differences between bacteria from liquid (LAB) and particle (PAB) phases, such as between bacteria and protozoa have been widely reported. The fractions of bacteria associated with the particle phase are greater than those associated to liquid phase, and it can represent more than 90% (Faichney, 1980) of bacteria isolated from animals receiving forage-based diets. Thus, the procedures of bacteria isolation should consider the PAB phase to estimate a more representative marker: total N ratio.

The ^{15}N:^{14}N ratio and the microbial N content, generally, can be obtained from the average in samples of LAB and PAB, since in several cases no differences are found between these two protocols of bacterial isolation (Machado et al., 2013, Rotta et al., 2014a, Prates et al., 2017, Menezes et al., 2017, e Mariz et al., 2018; Table 3.1)

Table 3.1 - Descriptive statistics of the $^{15}N:^{14}N$ ratio and the microbial N content (% OM) obtained in samples of bacteria associated to particles (PAB) and liquid (LAB) phases from different studies

Authors[1]	PAB		LAB	
	$^{15}N:^{14}N$	N (% OM)	$^{15}N:^{14}N$	N (% OM)
Machado et al. (2013)	341[2]	7.07	358[2]	7.20
Rotta et al. (2014a)	0.093[3]	7.80	0.092[3]	8.20
Menezes et al. (2017)	304[2]	5.89	322[2]	5.46
Mariz et al. (2018)	454[2]	7.17	463[2]	7.51
Prates et al. (2017)	0.076[3]	7.27[4]	0.068[3]	7.35[4]

[1]Means of the $^{15}N:^{14}N$ ratio and the microbial N content did not differ by the F test ($P>0.05$), except microbial N in Mariz et al. (2018) that were different between LAB and PAB ($P<0.05$). [2]Δ per thousand. [3]values obtained in omasal samples and considering enrichment of ^{15}N atoms as a percentage; [4]nitrogen on OM basis.

However, unicellular organisms have a high concentration of nucleic acids, especially RNA and purine bases (PB), which makes it interesting to use these organisms as internal microbial markers. About 18% of the total N of ruminal microorganisms is found in nucleic acids and PB contains approximately 11% of total N (Chen and Ørskov, 2003). According to Broderick and Merchen (1992), the use of nucleic acids as markers is well stablished. RNA can be quantified according to the model proposed by Ling and Buttery (1978), while PB according to Ushida et al. (1985).

Most feedstuffs have low concentration of RNA and, according to McAllan and Smith (1973), there is extensive exogenous degradation of RNA in the rumen. Thus, duodenal RNA flow is mainly of microbial origin. However, in proteins from animal byproducts, the RNA concentration is similar to that of microorganisms and, then, the use of RNA as markers is not suitable for animals receiving this type of feed. Although, these feedstuffs are not allowed in Brazil, it does not cause problems with the use of this technique.

According to Rotta et al. (2014b), many of the studies that evaluated different markers to estimate ruminal microbial protein utilized samples from the abomasum and duodenum and the maintenance of cannulated animals in the abomasum and duodenum is difficult and it has high operational costs, causing problems in animal handling. Reynal et al. (2005) and Ipharraguerre et al. (2007) recommended that the calculation of microbial protein flow using ^{15}N as a marker should be performed using omasum samples. However, using ^{15}N and PB as markers, these authors found differences in the values obtained for microbial flow of duodenal samples. Krizsan et al. (2010) suggested that reticulum digesta samples could replace omasal samples. Mariz et al. (2018) studied possible differences between the microbial indicators ^{15}N and PB to estimate ruminal microbial synthesis and efficiency when different levels of protein were applied to the diets of Nellore and crossbred cattle. The authors found no difference in the estimates presented.

Table 3.2 - Effects of different collection sites and microbial markers on microbial nitrogen yield and its efficiency in beef bulls fed corn silage and sugarcane-based diets

	Sampling site				P-value
Markers	Reticulum	Omasum	Abomasum	MSE[1]	L × M[2]
MN[3]	104	114	125	4.59	<0.01
PB[4]	114^{abA}	106^{bA}	130^{aA}	4.78	<0.01
^{15}N	94.1^{bB}	123^{aA}	120^{aA}	4.79	<0.01
MCP[5]/TDN[6]	101	108	118	4.39	<0.01
PB	107^{bA}	93.3^{bB}	117^{aA}	4.44	<0.01
^{15}N	95.0^{bA}	123^{aA}	118^{aA}	4.42	<0.01
MN/fermOM[7]	24.8	31.8	36.2	2.05	<0.05
PB	26.8^{bA}	29.2^{bA}	37.7^{aA}	2.09	<0.05
^{15}N	22.7^{bA}	34.4^{aA}	34.6^{aA}	2.08	<0.05

[1]Mean standard error; [2]Interaction between collection site and microbial marker; [3]Microbial nitrogen; [4]Purine bases; [5]Microbial crude protein; [6]Total digestible nutrients; [7]Fermentable organic matter. Adapted from Rotta et al. (2014b).

The similarity between microbial markers indicated that both ^{15}N and PB are adequate for estimating microbial protein synthesis and microbial efficiency when samples are collected in the omasum. Additionally, Rotta et al. (2014b) conducted a study evaluating these two markers obtained from different sampling sites (Table 3.2). Rotta et al. (2014b) reported that samples obtained from the omasum and abomasum provided similar results for microbial protein yield as well as microbial efficiency when using ^{15}N and PB as markers. Moreover, Rotta et al. (2014b) tested different schemes of sampling, using single, double, and triple markers, isolating different profiles of ruminal digesta such as single phase (single marker system) particle and liquid phase (double marker system), and large and small particles and liquid phases (triple marker system), respectively.

The authors recommended a correction in the estimates of ruminal microbial protein obtained from assays with single and double marker systems for values compatible to the triple markers system, as follows:

$$MNcor\ (g/d) = 49.71 + 0.66 \times MNsingle$$

$$MNcor\ (g/d) = 43.04 + 0.71 \times MNdouble$$

where MNcor is the ruminal microbial nitrogen corrected per day for single or double indicator use. MNsingle is the microbial nitrogen obtained from a single marker scheme, and MNdouble is the microbial nitrogen obtained from a double marker scheme.

Purine derivatives method

Nucleic acids, from bacterial origin that reach the intestine, are mostly digested and absorbed in the small intestine. Absorbed PB are catalyzed to PD (hypoxanthine, xanthine, uric acid, and allantoin) and excreted in the urine (Figure 3.2; Topps and Elliott, 1965). Thus, the microbial N flow in the small intestine can be estimated from the quantification of the excretion of urinary PD (Figure 3.2). Although there are methods to estimate microbial synthesis based on microbial markers (RNA, ^{15}N; Broderick and Merchen, 1992, Tamminga and Chen, 2000), as previously discussed, these methods present difficulties for extensive use because they are extremely invasive and require the use of cannulated animals for the estimation of DM flow through the abomasum or duodenum. These methods based on the estimation of microbial protein flow have been largely used to calibrate some calculation factors using the PD method (Tas and Susenbeth, 2007; Barbosa et al., 2011; Prates et al., 2012).

As it is true for all indirect methods, the method used to estimate microbial production based on urinary PD is susceptible to sources of variation (Chen et al., 1990b, Chen and Gomes, 1992, Tamminga and Chen, 2000, Bowen et al., 2006, Tas and Susenbeth, 2007), and some of the most important factors related to this method have undergone almost constant revisions and updates. The most recent research results related to these factors are discussed in the following items, emphasizing

the use of this method to estimate microbial protein synthesis of cattle raised in tropical conditions, especially in grazing conditions.

a) Urinary collection and experimental sampling

The method to estimate the microbial N flow in cattle is based on the quantification of the daily excretion of urinary PD (allantoin and uric acid). Therefore, daily urinary volume as well as a sample of urine are necessary. The direct quantification of urinary volume can be performed in catheterized animals or any other device that allows the total collection of urine during 24 hours. In females, Foley-type probes are usually used in which urine is passed directly from bladder to a collection recipient. In male animals, funnels are coupled in the foreskin region and are linked directly to a collection recipient. In both cases, the collection is performed for periods of 3 to 5 days with daily quantification and sampling. However, methods of total collection are often laborious which can affect the behavior and welfare of the animals and there are difficulties to apply this technique in grazing animals. In dairy cows, the large amount of urine and the handling of the collection system during milking contribute to making the use of total collection unfeasible and difficulty to conduct. Thus, an alternative technique will be discussed later.

The use of creatinine as a marker for the indirect determination of urinary volume can be an alternative to improve the well-being of animals during experiments. Creatinine is formed in the muscle by the removal of water from creatine phosphate, which is derived from muscle tissue metabolism (Harper et al., 2013). Creatine phosphate is spontaneously degraded at relatively constant rates, forming creatinine. Creatinine is a metabolic product that the body no longer needs, therefore, it is not used for the formation of new compounds, being excreted by the kidneys. The daily production of creatine and, consequently, the excretion of creatinine, depends on the muscle mass and, therefore, is proportional to the body weight of the animal (Koren, 2000). Thus, once the daily creatinine excretion is estimated in relation to the animal's weight and considering this constant concentration throughout the day, it is possible to estimate the urinary volume excreted from the creatinine concentration in a urine sample collected from an animal of known weight.

Creatinine presents constant excretion over 24 hours from constant rates of muscle tissue breakdown. Creatinine excretion is not affected by CP, non-fiber carbohydrates or non-protein nitrogen in the diet (Susmel et al., 1994; Vagnoni et al., 1997; Valadares et al., 1999; Oliveira et al., 2001; Rennó et al., 2000), thus, variations due to diet are not expected.

A meta-analysis was carried out with the results from 25 experiments (Figure 3.1) carried out at the Department of Animal Science of the Federal University of Viçosa (Appendix 3.1), aiming to study the relationship between creatinine excretion and body weight in cattle. The total database contained 882 individual information, and 80% of the data (n = 702) were randomly separated to compose the model-fitting database (Table 3.3), and 20% of the data (n = 180) was selected for the validation process (Table 3.4). Some effects were tested, such as gender and genetic groups (Nellore, *Bos taurus taurus* and crossbred animals), but these variables did not show a significant effect ($P>0.05$). The data were adjusted to an allometric function, making a total number of 702 individual pieces of information.

After the analyses, the following equation was obtained to estimate the daily urinary creatinine excretion (UCE; mg/d) in cattle as a function of body weight (BW; kg):

$$UCE = 66.2158 \times BW^{0.8384}$$

Estimates of model parameters were significant ($P<0.01$) and data fit the model satisfactorily. Therefore, it is recommended that daily excretion of creatinine be estimated using an allometric model, according to the animal's body weight in different genders and genetic groups.

A total of 20% of the data was used for the equation validation procedure, using data observed in 180 experimental units. The predicted data (Table 3.4) were estimated and contrasted with the observed data using the MES software – Model evaluation system (Texas A&M University).

Table 3.3 - Descriptive statistics of data used to fit the allometric model to estimate the relationship between body weight and daily creatinine excretion in urine, containing 80% of the total database collected.

	Creatinine (mg/d)	Body weight (kg)
Mean	8373	369
Median	8205	342
SD	2890	110
Minimum	1266	107
Maxumin	17926	728
n	702	702
Subject	25	25

It was observed that the predicted and observed creatinine data were similar (P>0.05) by the Mayer test (Table 3.5), showed a high correlation and concordance coefficient (CCC = 0.78) and a greater presence of prediction errors of random origin.

These results suggest that the proposed model is accurate for estimating urinary creatinine in cattle (Figure 3.2). The use of creatinine as an accurate tool for estimating urinary volume in different categories of animals makes the process of estimating MCP using PD excreted in urine practical. In Brazil, Pereira (2009) evaluated total creatinine excretion at intervals of 4 to 24 hours and the ratio of purine derivatives, urea, and total nitrogenous compounds to creatinine in Nellore heifers, obtained from spot collections of urine at intervals of 2 hours. The relationship between purine derivatives and creatinine did not vary (P>0.05) during the 24 hours of the day, based on spot collection of urine at 2-hour intervals, suggesting that the calculation of daily PD excretion can be effective in collections obtained at any time of the day.

However, there was an effect of the time of urine collection on the urea:creatinine and Ntotal:creatinine ratios. These relationships were close to the means at two daily points, close to the two daily times of feed supply to the animals (8 AM and 4 PM). Pereira (2009) suggested that the estimation of the excretion of nitrogenous compounds in growing animals can be performed without the need for total collection, using only two spot collections of urine, immediately after supplying the diets.

However, it is emphasized that more research is needed to confirm this suggestion. Silva Junior et al. (2018) studied the relationship between purine derivatives and nitrogenous compounds with creatinine in beef cattle on pasture, to evaluate the possibility of performing collections every 4 hours to measure MCP, nitrogen balance and N excretion.

Table 3.4 - Descriptive statistics of data used to validate the allometric model for estimating the relationship between body weight and daily creatinine excretion in urine, containing 20% of the total database collected.

	Creatinine (mg/d)	Body weight (kg)
Mean	8615	355
Median	8254	318
SD	2887	113
Minimum	18876	743
Maxumin	2887	113
n	180	180
Subject	25	25

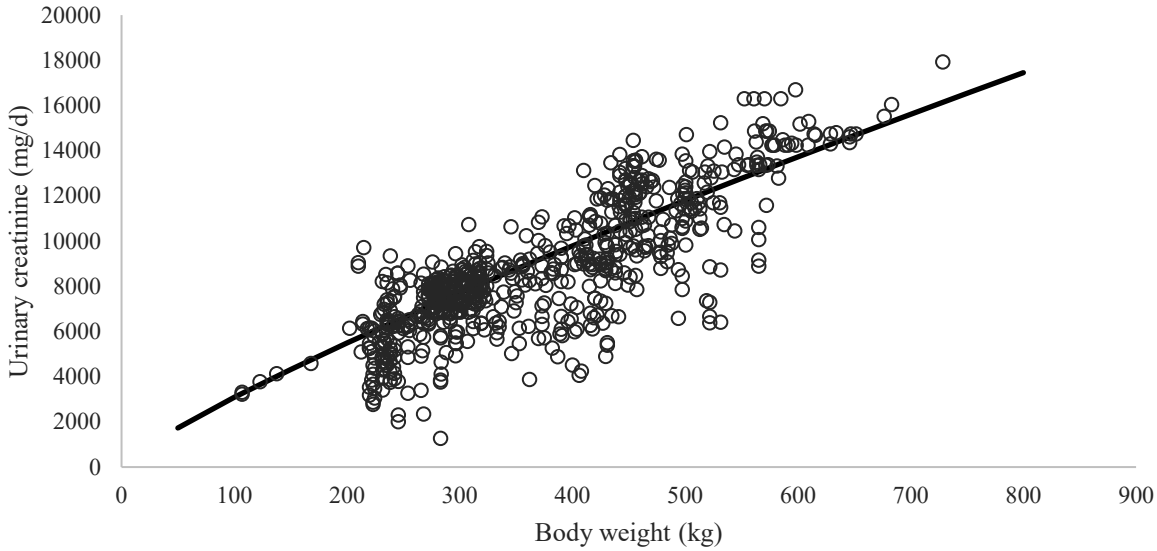


Figure 3.1 - Observed data (o) of the relationship between fasting bovine body weight (kg) and daily urine creatinine excretion (mg/d), and allometric (-) adjustment (UCE = 66.2158× $BW^{0.8384}$), obtained based on a meta-analysis with 25 studies in cattle of different sexual classes and genetic groups.

The authors carried out collections every 4 hours for 5 days and did not detect any difference between the day of collection and the times for the ratio between purine derivatives and creatinine, which allows inferring about the possibility of performing only one urine collection in a given period to estimate the production of MCP in grazing beef cattle, using the technique of urinary purine derivatives. However, due to the variations observed in urea nitrogen and total nitrogen to creatinine ratios over the 24-hour period, Silva Júnior et al. (2018) did not recommend using a sample at just one time to estimate the urinary excretion of nitrogenous compounds.

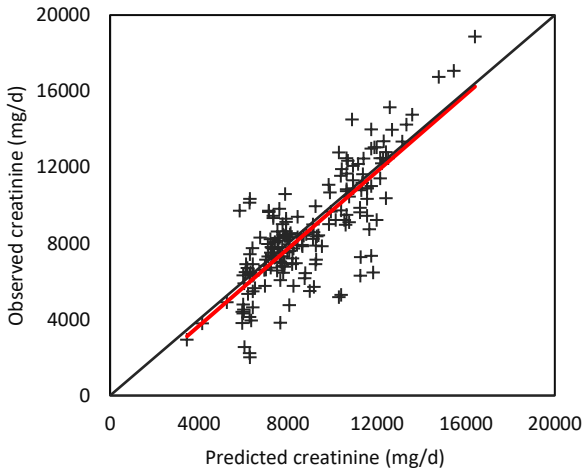


Figure 3.2 - Observed and predicted urinary creatinine values from the proposed equation UCE = 66.2158 × $BW^{0.8384}$, proposed for cattle.

Other results from the same authors (Silva Júnior et al., 2021) demonstrated that urinary creatinine excretion is constant during 24h in grazing cattle. Then, a single spot sample, under grazing conditions, is enough to estimate urinary volume. Once the relationship

between creatinine and purine derivatives is constant, also the purine derivatives can be estimated from only one urinary sample, in pasture conditions. However, two spot samples, 4 hours before and 4 hours after supplying the concentrate, are required to estimate total nitrogen excretion in cattle, since urinary urea nitrogen can vary depending on the diet.

Table 3.5 - Validation of a predicted model for determination of urinary creatinine (UCE mg/d = 66.2158× $BW^{0.8384}$) in cattle, based on body weight, using 20% of the database (n=180)

Item	Predicted creatinine
Mayer test	
Intercept	-390
Slope	1.01
P-value	0.11
RMSE	1725
CCC	0.78
MSEP	
Mean bias %	2.44
Systematic bias %	0.03
Random errors %	97.52
Predicted mean	8614
Mean bias	-269 (3.03%)
P-value	0.04

[1]RMSE: Root of mean square erros; CCC: Concordance correlation coefficient; MSEP: Mean square error of prediction.

b) Urinary recovery of absorbed purines

The relationship between urinary recovery of PD and purine duodenum flow is an important adjustment factor in the method for estimating microbial yield of urinary PD. Several studies have aimed to measure the urinary recovery of post-rumen infused purines from microbial extracts. Urinary excretion of PD was linearly correlated with abomasum infusion of nucleic acids, nucleosides, purines from beer yeast, and with duodenum infusion of nucleic acids, PB, microbial RNA, and yeast RNA (Tas and Susenbeth, 2007). An average equimolar of 0.85 was obtained by Tas and Susenbeth (2007) for urinary recovery of PD infused into the duodenum. In this type of study, the value of PD excretion is linearly related to the value of infused purines (abomasum or duodenum). The slope of the equation gives the recovery value of absorbed purines while the intercept represents the endogenous contribution.

Recent studies conducted in Brazil (Barbosa et al., 2011, Prates et al., 2012) estimated that, for Zebu cattle, the urinary recovery of PD ranged from 0.74 to 0.92 with a mean value 0.80 suggested for practical use, which will be adopted as standard in the BR-CORTE edition for both Zebu and Holstein cattle. Prates et al. (2012) did not observe differences in the recovery rate of absorbed purines between Nellore and Holstein heifers, with no need for different values for each genetic group.

c) Intestinal digestion and absorption of microbial purines

Nucleic acids of bacterial origin, that leave rumen, are extensively degraded in the small intestine and, on average, 85.9% of nucleic acids (Storm et al., 1983), 87-89% RNA, and 80-81% DNA disappeared from small intestine (McAllan, 1980; Storm et al., 1983). Barbosa et al. (2011) evaluated intestinal digestion and absorption of microbial purines in Nellore heifers and estimated the true digestibility coefficient for RNA of 0.93. Although high variability was observed in the true digestibility of ruminal microorganisms purines (Chen and Gomes, 1992, Orellana Boero et al., 2001, Tas and Susenbeth, 2007), the mean value of 0.93 obtained in the study of Barbosa et al. (2011) seems to be adequate for use in Zebu cattle

raised in Brazilian conditions, and is therefore considered as a standard value in this edition of the BR-CORTE.

In the small intestine, purine nucleotides are hydrolyzed into nucleosides (adenosine, guanosine, and inosine) and free bases (adenine and guanine), which are almost completely absorbed by the sodium-potassium dependent pump (McAllan, 1980). In cattle, high activity of the xanthine-oxidase enzyme was observed in the intestinal mucosa and blood plasma (Chen et al., 1990c), making hypoxanthine and xanthine be practically completely degraded to uric acid, unlike sheep. In the liver, uric acid is oxidized to allantoin by the enzyme uricase (Tas and Susenbeth, 2007). Allantoin and uric acid cannot be used by tissues and are excreted mainly in the urine, but also in milk and saliva (Tas and Susenbeth, 2007). In cattle, allantoin is the main PD (more than 80% of the total), while the remainder is composed of uric acid and negligible amounts of xanthine and hypoxanthine (Chen et al., 1990c). Rennó et al. (2000), evaluating the profile of PD excretion in beef heifers, estimated the allantoin and uric acid: total purine ratio of approximately 98%, which indicates that the concentration of xanthine and hypoxanthine in relation to PD would be approximately 2% and that this contribution would irrelevant in the calculation of the microbial protein yield. Thus, the BR-CORTE does not recommend performing xanthine and hypoxanthine analyzes in cattle.

d) Endogenous fraction of urinary purine derivatives

The endogenous fraction of urinary PD includes the portion of PD of nucleic acids from animal tissue degradation (Chen and Gomes, 1992). The direct measurement of endogenous excretion of PD is the use of long-period fasting animals (Chen et al., 1990a; Verbic et al., 1990). Braga et al. (2012) submitted Nellore heifers to feed restriction to evaluate endogenous losses of PD using the following scheme: feeding at 1% BW in the first eight days, 0.5% BW from the ninth to the eleventh day and complete fasting from twelfth to the sixteenth experimental day, totaling 5 days of absolute fasting in which total urine collection was performed. Braga et al. (2012) found an endogenous contribution of 0.332±0.063 mmol/$BW^{0.75}$ and 0.384 g N/$BW^{0.75}$ for growing Nellore heifers.

Alternatively, the endogenous fraction was estimated as the intercept of the linear regression between urinary excretion of PD and post-rumen infused PB. Prates et al. (2012) did not observe differences in endogenous fractions of PD between Nellore and Holstein heifers. Studies conducted in tropical conditions (Barbosa et al., 2011; Prates et al., 2012) with Zebu cattle suggested the use of a mean value of 0.30 mmol/$BW^{0.75}$ as the endogenous fraction of urinary PD, which is the value recommended by the BR-CORTE.

e) The use of urinary allantoin as the only estimator of ruminal microbial protein synthesis

The proportion of allantoin excreted in relation the total PD observed in some studies in the last ten years, we highlight a relationship from 85 to 92 % (Rennó et al., 2000; Magalhães et al., 2005; Pina et al., 2006; Leal et al., 2007; Oliveira et al., 2007; Teixeira et al., 2007; Santos et al., 2010). Then, it becomes interesting for the scientific community to know the estimated relationship between these metabolites and to adjust a mathematical model capable of predicting the uric acid content in the urine.

A meta-analysis involving 38 experiments (Appendix 3.2) performed at the DZO-UFV (Table 3.6), showed that the daily excretion (mmol/d) of uric acid (UA) in the urine can be estimated from the daily excretion of allantoin (ALA) in urine ($P < 0.05$), as follow:

$$UA\ (mmol/d) = 0.1104 \times ALA;\ r^2 = 0.76$$

Also, there was no significant effect ($P = 0.4398$) when the parameters were tested with the intercept, allowing us to estimate a linear model without an intercept.

Table 3.6 - Descriptive statistics of data used to fit linear regression models to estimate the relationship between uric acid and allantoin excreted in cattle urine, and the relationship between allantoin and total purine derivatives (PD)

	Alantoin(mmol/d)	Uric acid (mmol/d)	ALA:PD
Mean	169	20.2	89.0
Median	129	13.5	90.4
DP	123	22.9	4.97
Minimum	18,8	0.30	66.2
Maximum	864	322	99.8
n	1100	1100	1100
Subject	38	38	38

ALA:PD: Percentage of total allantoin in relation to total purine derivatives excreted in the urine.

These results suggest that allantoin can be used as the only predictor of MCP in cattle without the need of uric acid analysis, improving the budget with reagents for analysis and decreasing the time spent on chemical analyzes to estimate MCP synthesis.

Prediction of microbial protein flow of the diet

This version of BR-CORTE maintained the mathematical models proposed to estimate the MCP based on energy and protein intake previously proposed in 2016. A meta-analysis was carried out to evaluate the effect of animal and dietary characteristics on MCP synthesis. In this procedure, 32 studies published in Brazil and abroad were used, as well as theses and dissertations concluded at the Animal Science Department at the Federal University of Viçosa (Appendix 3.3), totaling 2,102 observations (Table 3.7).

The database was used to evaluate three types of energy attributes initially associated with CP intake for each model. The independent variables evaluated were total digestible nutrients intake (TDNI), metabolizable energy intake (MEI) and digested organic matter intake (dMOI). Thus, the complete database comprised all the effects evaluated, with variables classified according to experiment, genetic group (Zebu, beef crossbred, dairy crossbred, and Holstein cattle), gender (bulls, steers, heifers, and cows) and analytical method (PB, PD and ^{15}N). The random effect related to experiments was considered to estimate the parameters of the models.

Table 3.7 - Descriptive statistics of database used to fit the regression models to estimate MCP in beef cattle under tropical conditions.

Item[1]	**n**	**Mean**	**SD[2]**	**Maximum**	**Minimum**
MCP	2102	775	547	3008	66.8
CPI	2102	1.22	0.87	4.39	0.59
DMI	2102	8.52	5.31	23.8	1.76
TDNI	2102	6.22	3.74	16.8	0.83
MEI	2102	22.3	13.3	60.9	3.00
dOMI	1454	5.70	2.98	15.5	0.62
BW	1563	368	125	737	65.3

[1]Microbial crude protein, g/d; Crude protein intake, kg/d; Dry matter intake, kg/d; Total digestible nutrients intake, kg/d; Metabolizable energy intake; Total digestible organic matter intake, kg/d; Crude protein in diet, %; Body weight, kg; [2]Standard deviation.

Random effects such as genetic group, gender, and analytical method were not significant for any proposed equation (P>0.05). Then, the suggested independent variables were evaluated and their parameter estimates were carried out using the Cross Validation procedure (Duchesne and MacGregor, 2001). Linear and quadratic

polynomials were tested because MCP synthesis does not follow a linear behavior and, as in theory, it will reach a plateau. Then, the following equations were obtained (Figure 3.3):

$$MCP = - 53.07 + 304.9 \times CPI + 90.8 \times TDNI - 3.13 \times TDNI^2$$

$$MCP = - 84.87 + 328.7 \times CPI + 28.3 \times MEI - 0.25 \times MEI^2$$

$$MCP = - 93.62 + 381.7 \times CPI + 90.7 \times dOMI - 3.13 \times dOMI^2$$

The database used to estimate the previous equations was developed by data with, on average, 2.83% (± 1.03) of ether extract (EE) in the diet. However, as the NASEM (2016), an equation was developed to estimate microbial protein synthesis for high values of EE, as follows:

$$MCP = - 43.13 + 376.8 \times CPI + 90.9 \times ceeTDNI - 3.22 \times ceeTDNI^2$$

which: MCP is the microbial crude protein synthesis, CPI is the crude protein intake, ceeTDNI is the total digestible nutrients intake corrected for EE.

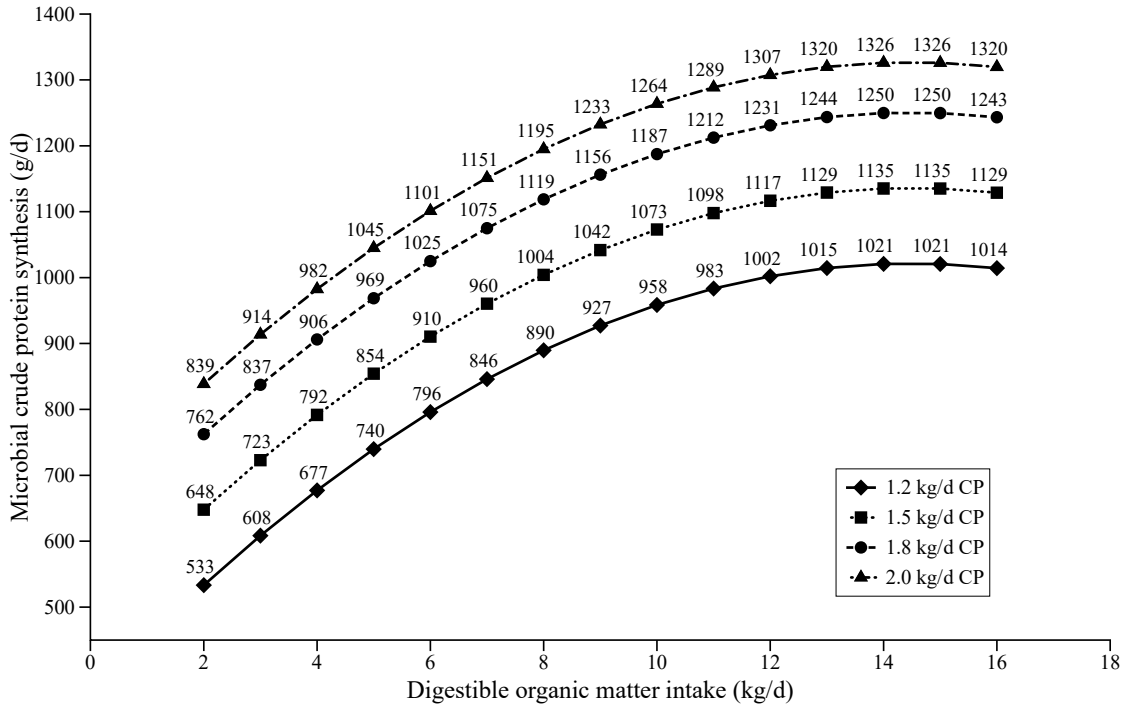


Figure 3.3 - Simulation of MCP estimated from the following equation: $MCP = - 93.62 + 381.7 \times CPI + 90.7 \times dOMI - 3.13 \times dOMI^2$, using four different values for CP intake (1.2; 1.5; 1.8 and 2.0 kg/d) in function of dOMI (kg/d)

The NASEM (2016) suggests an equation for the synthesis of MCP corrected for EE when the EE content in the diet is greater than 3.9%. In Brazil, most beef cattle diets are formulated to contain less than 3.9% EE. However, if the objective is to formulate diets with high EE content, we recommend using the equation proposed by the BR-CORTE which was generated from a database containing 1,437 animals raised under tropical conditions.

A validation process was carried out to verify the prediction accuracy of the MCP equations. The validation was performed using data treatment means (Table 3.8) of 16 published manuscripts (Appendix 3.4). Some criteria were used for the select the manuscripts, as follow: (1) the study was performed in Brazil, (2) the study was performed with Nellore or crossbred cattle, (3) the study was published after 2016 in journals that have the JCR score, (4) the study contained the dependent and independent variables described in the tested equations and, (5) presented standardized residual values calculated for the difference between predicted and observed from -4 to 4.

Table 3.8 - Descriptive statistics of data collected in the literature for validate models to estimate MCP for beef cattle in tropical conditions

Iten[1]	Min	Max	Mean	SD[2]	N
MCP	225.6	1025.0	533.4	182.1	66
TDNI	2.3	7.7	4.3	1.2	66
dOMI	2.1	7.4	4.1	1.1	66
CPI	0.4	1.4	0.8	0.2	66
MEI	9.9	34.0	18.9	5.2	66

[1]Microbial crude protein (MCP) in g/d; intake of total digestible nutrients (ITDN) in kg/d; intake of digestible organic matter (dOMI) in kg/d; crude protein intake (CPI) in kg/d; metabolizable energy intake (MEI) in Mcal/d; Average value; [2]Standard deviation.

There was no effect (P > 0.05) in the Mayer's test for all the variables studied in the validation procedure (Table 3.9), which indicates that the data predicted by the models proposed by the BR-CORTE are the same as those observed in the dataset from the literature (Figure 3.4).

The values of CCC and RMSE are also close to the proposed equations. The equation proposed for the MEI presented the highest QMEP, with the lowest percentage of random errors, which indicates that the accuracy of this model is slightly lower than the others.

The same patterns can be observed when analyzing the mean deviation of -25.7 g (P=0.09), which was greater than the deviation calculated for the other models. Therefore, it is recommended that the model for estimating ruminal MCP should be performed from the MEI only when the values of TDNI and dOMI were not available. Both TDNI and dOMI provided more accurate and precise estimates when compared to those obtained with MEI. The proposed equation based on the dOMI was used to calculate the estimated MCP considering different scenarios (Figure 3.3). The different scenarios have variations in both CP and energy intake, and such equations are used in the BR-CORTE to use the transformation of liquid and metabolizable protein requirements in RDP and RUP requirements, as well as in the estimation of CP requirements in different groups of beef cattle.

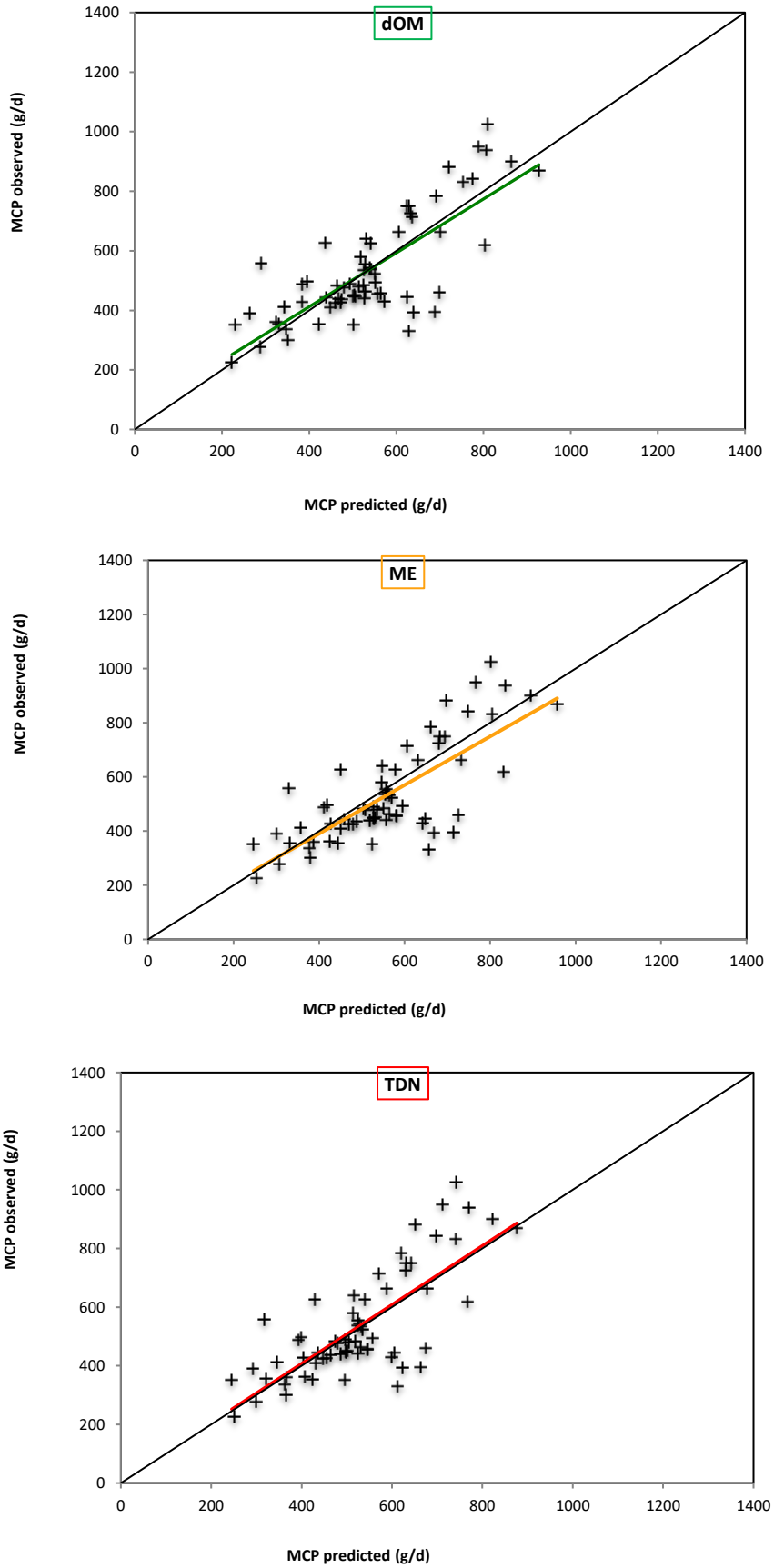


Figure 3.4 - Observed and predicted values of MCP by the equations proposed from the dOMI, MEI and TDNI for beef cattle.

Table 3.9 - Validation of prediction models to estimate MCP (g/d) in beef cattle, based on CP and energy intake in three different presentations (TDN, dOM and ME), using treatment means from 16 published studies (n= 66) collected in scientific literature

Item[1]	TDN	dOM	ME
Mayer test			
Intercept	5.39	46.5	31.89
Slope	1.01	0.91	0.89
P-value	0.85	0.61	0.13
RMSE	117.9	113.6	121.4
CCC	0.73	0.77	0.74
MSEP	13909	12914	22704
Mean bias %	0.50	0.02	4.5
Systematic bias %	0.01	1.52	1.7
Random errors %	99.5	98.5	93.81
Predicted mean			
Mean bias	-8.06	1.79	-25.7
P-value	0.58	0.89	0.09

[1]RMSE: Root of mean square errors; CCC: Concordance correlation coefficient; MSEP: Mean square error of prediction.

GENERAL RECOMMENDATIONS

- **Estimation of microbial contamination of roughage using *in situ* incubation*:***

$A_{CP}C = 1.99286 + 0.98256 \times A_{CP}NC$

$B_{CP}C = -17.2181 - 0.0344 \times B_{CP}NC + 0.65433 \times CP + 1.03787 \times NDF + 2.66010 \times NDIP - 0.85979 \times iNDF$

$kd_{CP}C = 0.04667 + 0.35139 \times kd_{CP}NC + 0.0020 \times CP - 0.00055839 \times NDF - 0.00336 \times NDIP + 0.00075089 \times iNDF$

$\%C = 79.21 \times (1 - e^{-0.0555 \times t}) \times e^{-0.0874 \times CP}$

- **Correction for MCP estimated from assays using single and double indicator system:**

MNcor (g/d) = 49.71 + 0.66 × MNsingle

MNcor (g/d) = 43.04 + 0.71 × MNdouble

- **Endogenous fraction of urinary purine derivatives in Zebu cattle:**

$0.30 \text{ mmol/BW}^{0.75}$

- **Daily excretion of urinary uric acid from daily excretion of urinary allantoin**

UA (mmol/d) = 0.1104 × ALA

- **Estimation of daily urinary creatinine excretion in cattle:**

$UCE \text{ (mg/d)} = 66.2158 \times BW^{0.8384}$

- **Prediction of MCP:**

$MCP = - 53.07 + 304.9 \times CPI + 90.8 \times TDNI - 3.13 \times TDNI^2$

$MCP = - 93.62 + 381.7 \times CPI + 90.7 \times tdOMI - 3.13 \times tdOMI^2$

$MCP = - 84.87 + 328.7 \times CPI + 28.3 \times MEI - 0.25 \times MEI^2$

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APPENDIXES

Appendix 3.1

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4

Prediction of the energy value of cattle diets based on the chemical composition of feeds

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The chemical composition of a feed/diet is the main determinant of its ability to supply nutrients to meet the demands for animal maintenance and production, especially regarding energy supply, which is obtained through digesting and metabolizing the organic components of feeds. Feed composition tables are reliable because they provide exact mean values for energy concentrations. However, there are variations in field conditions that cannot be properly contemplated by data tabulation. Thus, the use of chemical composition to predict the ability of a feed to supply energy can facilitate the work of nutritionists when formulating diets in specific situations, so they can be more exact and appropriate for each productive situation.

INTRODUCTION

Obtaining estimates of digestibility coefficients is a basic aspect for quantifying the energy value of feeds or diets, especially with regard to total digestive nutrients (TDN), and allows diets to be balanced adequately to meet animal requirements for maintenance and production.

Although it is a static digestive parameter that can be represented by a point estimate, the estimation of the digestibility coefficient of a whole feed or its individual chemical components is a troublesome and time-consuming process when carried out using classic *in vivo* methods (Detmann et al., 2006a).

Throughout the world, including Brazil, efforts have been made to compile data to build tables that can be used as a possible alternative for technicians and farmers who need to know the composition of feeds, including energy content. Those efforts were based on the fact that large size samples would tend to point with greater precision and accuracy to the populational mean of the characteristics of the feed (effect known as "law of large numbers") that, in thesis, would increase the accuracy of diets calculated based on these values (Detmann et al., 2008a).

Although the tabled feed energy values tend to be reliable from a statistical point of view, the feeds used in different production systems can differ from the average information; that is, they have a distribution, often normal, but with distinct deviations from the populational mean. Thus, diets calculated based on average composition will tend to give productions deviated from those initially planned at intensity similar to the deviation of the characteristics of the feed used compared to the populational mean (Detmann et al., 2008a).

This situation is particularly intense in the tropics, especially for forages, because the characteristics of the feeds produced reflect climatic and edaphic oscillations (e.g., temperature, precipitation, solar radiation and soil fertility) more strongly than in non-tropical regions.

These aspects influence feed energy content and substantial effort is required to reduce the current dependency on mean values derived from composition tables. Although studies with great contribution in this context were developed some decades ago (e.g., Conrad et al., 1984; Weiss et al., 1992), the main milestone is the seventh edition of the American tables for dairy cattle (NRC, 2001), in which tabulated data of energy content were not routinely used anymore, but rather alternatives to estimate the energy content of feeds on a "case-by-case" basis were suggested. Thus, deviations between the production characteristics foreseen in diet balancing and those effectively obtained in the field would be minimized (Detmann et al., 2008a).

The energy content prediction system for feeds offered to cattle adopted by the NRC (2001) is based on the influence of chemical

composition on the capacity to supply energy. The method is based on a system of summative equations in which, for each group of chemical compounds with potential for energy contribution (CP, crude protein; EE, ether extract; NFC, non-fibrous carbohydrates; and NDF, neutral detergent fiber) is given a sub-model responsible to estimate the fractions that are truly digestible, with later corrections regarding fecal metabolic losses and intake level.

Although it effectively accounts for the characteristics of feeds used in production systems (that is, laboratory analyses and not estimates of populational means) and has a theoretical base (Conrad et al., 1984; Weiss et al., 1992), the system adopted by the NRC (2001) did not present a satisfactory efficiency of prediction when applied to feeds obtained under tropical conditions (Rocha Jr. et al., 2003; Costa et al., 2005; Silva et al., 2007; Detmann et al., 2008b; Campos et al., 2010; Magalhães et al., 2010; Azevêdo et al., 2011; Sampaio et al., 2012), which constrained its effective application.

Due to this limitation, new sub-models to predict the digestible fractions of CP, EE, NFC, and NDF were developed and evaluated under tropical conditions (Detmann et al, 2004a; 2006a; 2006b; 2006c; 2007; 2008b; 2008c; 2010a). The unified assessment of these sub-models, that constitutes a new summative system, showed that they are capable of more exact prediction of the TDN content in diets offered to cattle in Brazil (Detmann et al., 2008b; Magalhães et al., 2010; Azevêdo et al., 2011; Sampaio et al., 2012), creating an alternative to applying the model adopted by the NRC (2001) and culminating in the adoption of the prediction system in the second edition of the BR-CORTE System (Detmann et al., 2010b).

However, because a few limitations were detected in the sub-models originally proposed, new information was generated from experimental assessments and/or meta-analyses and from new approaches to the assessment of feed chemical composition. Thus, the system for predicting the dietary TDN has been improved, that implies modifications to the model originally adopted in the second edition of the BR-CORTE System (Detmann et al., 2010b).

DESCRIPTION OF THE MODEL

Sub-models for EE and NFC

No significant theoretical or empirical alterations were made to the sub-models applied to the non-fibrous components EE and NFC in the second edition of the BR-CORTE System. They are based on the Lucas test (Lucas and Smart, 1959) to obtain the true digestibility coefficients, and on the assumptions of the factorial system (Blaxter and Mitchell, 1948; Lucas, 1960) to distinguish between the metabolic fecal fraction and the truly non-digestible fraction.

Under these assumptions, apparently undigested fecal matter can be defined for the non-fibrous components (EE or NFC) as follows:

$$F = U + M + E \quad (4.1),$$

where: F, fecal mass (g/day); U, truly undigested fraction (g/day); M, metabolic fecal fraction (g/day); and E, endogenous fecal fraction (g/day).

In this context, the metabolic fraction is defined as the fecal portion obtained from digestive tract secretions (Lucas, 1960) and microbial debris (Van Soest, 1994). Conversely, the endogenous fecal fraction corresponds to the fecal portion obtained by secretions of metabolic "waste" by cells of the gastrointestinal tract (Lucas, 1960).

Using these definitions, the identity exposed in (4.1) can be related to daily intake, as follows:

$$I - F = I - (U + M + E) \quad (4.2a),$$

$$I - F = I - U - M - E \quad (4.2b),$$

$$\frac{I-F}{I} = \frac{I-U-M-E}{I} \quad (4.2c),$$

$$Da = 1 - \frac{U}{I} - \frac{M}{I} - \frac{E}{I} \quad (4.2d),$$

where: I, intake (g/day); Da, apparent digestibility coefficient (g/g).

The endogenous fecal fraction can be represented by a mathematical function proportional to the metabolic mass of the animal (Blaxter and Mitchell, 1948; Lucas, 1960), given by:

$$\frac{E}{I} = \frac{\varepsilon \times W^{\frac{3}{4}}}{I} = \frac{\varepsilon}{I} \times W^{\frac{3}{4}} \quad (4.3),$$

where: W, animal weight (g); and ε, constant related to the endogenous release in the gastrointestinal tract per unit of metabolic mass (g/g × day^{-1}).

The ratio (ε/C) would only be considered significant if, and only if, intake assumes extremely small values (Lucas, 1960), possibly at feeding levels below maintenance. Thus under maintenance or production conditions, we have:

$$lim_{I \to I^{\circ}} \frac{\varepsilon}{I} \times W^{\frac{3}{4}} = 0 \quad (4.4),$$

where: I°, intake under maintenance or production (g/day).

In this way, the equation (4.2d) is rewritten as:

$$Da = (1 - \frac{U}{I}) - \frac{M}{I} \quad (4.5a),$$

$$Da = Dt - \frac{M}{I} \quad (4.5b),$$

where: Dt, true digestibility coefficient (g/g).

Multiplying both terms of the equation (4.5b) by intake, we have:

$$I \times Da = (I \times Dt) - M \quad (4.6),$$

We can obtain the Da value by deriving equation (4.6) in terms of intake as:

$$\frac{d(I \times Da)}{dI} = \frac{d(I \times Dt)}{dI} - \frac{dM}{dI} \therefore Da = Dt - \frac{dM}{dI} \quad (4.7).$$

Thus the apparent digestibility coefficient (Equation 4.7) can be represented by two different components: the first, which represents the constant true digestibility coefficient; and the second, which represents fecal metabolic fraction, which varies according to intake.

Converting equation (4.7) based on dietary content, we have:

$$R \times Da = (R \times Dt) - (R \times \frac{dM}{dI}) \quad (4.8a),$$

$$adR = tdR - MC \quad (4.8b),$$

where: R, dietary content (% DM); MC, fecal metabolic contribution, expressed as dietary content (% DM); adR, apparently digestible diet fraction (% DM); and tdR, truly digestible diet fraction (% DM).

Two datasets, obtained from experiments carried out with dairy cows or growing and finishing cattle under tropical conditions, were used to estimate the parameters described in equation (4.8b) for EE (n = 108) and NFC (n = 84) (Detmann et al., 2006a; 2006c). True digestibility coefficients were found similar between animal categories. Furthermore, the metabolic fecal contribution varied between animal categories (Detmann et al., 2006a; 2006c), which is consistent with the assumptions reported by Lucas and Smart (1959) and by those represented in equation (4.8).

The sub-models used to estimate the truly digestible fractions are:

$$tdEE = 0.86 \times EE \quad (4.9),$$

$$tdNFC = 0.95 \times NFC \quad (4.10),$$

where: tdEE, truly digestible EE (% DM); EE, diet content of EE (% DM); tdNFC, truly digestible NFC (% DM); NFC, diet content of NFC (% DM).

As there were no differences among animal categories regarding the true digestibility coefficient, equations (4.9) and (4.10) can be applied similarly to dairy cows and growing and finishing cattle. Thus, the differences between animal categories are based on the apparently digestible fraction, that is, by the fecal metabolic contribution, using the estimates shown in Table 4.1.

Table 4.1 - Fecal metabolic contribution (% dry matter) of ether extract (EE), non-fibrous carbohydrates (NFC) and crude protein (CP) for animals fed *ad libitum*

Component	Animal Category	
	Dairy Cows	Growing and Finishing Cattle
EE	0.21	0.18
NFC	5.72	5.11
CP	0.97	1.61
FM_{TDN}[1]	7.16	7.13
FM_{DE}[2]	0.314	0.322

[1]FM_{TDN}, total fecal metabolic fraction to estimate the TDN content (FM_{TDN} = CP + NFC + 2.25×EE). [2] FM_{DE}, fecal metabolic fraction to estimate the digestible energy content (Mcal/kg DM).

In the second edition of the BR-CORTE System, different fecal metabolic fractions were estimated for animals fed at maintenance and production conditions. However, starting in the third edition of the BR-CORTE System, estimates of dietary energy content for animals fed at maintenance level will no longer be considered, because of their limited application.

Individual validation procedures were previously carried out on the apparently digestible fractions of EE and NFC by using datasets independent of those used to fit the sub-models (Detmann et al., 2006a; 2006c; 2008b; Magalhães et al., 2010; Azevêdo et al., 2011; Sampaio et al., 2012). Those assessments showed that the sub-models adopted in the BR-CORTE System are more accurate and precise than those adopted by the NRC (2001).

Sub-model for NDF

In biological terms, the sub-model developed to estimate the digestible fraction of NDF kept its base by fractioning this component into potentially digestible and indigestible fractions, according to the equation:

$$dNDF = D \times pdNDF \quad (4.11a),$$

$$dNDF = D \times (NDFap - iNDF) \quad (4.11b),$$

where: dNDF, digestible NDF (% DM); pdNDF, potentially digestible NDF (% DM); D, digestibility coefficient of the pdNDF (g/g); and iNDF, indigestible NDF (% DM).

Both sub-models used to predict the digestible fraction of NDF in the second edition of the BR-CORTE System and in the NRC (2001) were based on chemical approximations and on a non-linear exponential relationship between lignin and iNDF, adapted from the assumptions of the Surface Law (Conrad et al., 1984; Weiss et al., 1992). For this relationship, the lignin constraint factor on NDF ruminal degradation is the base parameter (Detmann et al., 2004a). The mathematical structure of both models is given by:

$$dNDF = D \times \{(NDFap - L) \times [1 - (\frac{L}{NDFap})^F]\} \quad (4.12),$$

where: dNDF, digestible NDF (% DM); D, digestibility coefficient of pdNDF (g/g); NDFap, NDF content expressed with corrections for contaminant ash and protein (% DM)[1]; L, lignin content (% DM); and F, lignin constraint factor on NDF ruminal degradation.

The first constraint observed for equation (4.12) is the use of constant lignin constraint factor for NDF ruminal degradation [0.667, NRC (2001); 0.85, Detmann et al. (2010b)]. This assumption implies that the lignin would act homogeneously in determining the size of the iNDF fraction, and consequently the pdNDF fraction, in any feed. However, the lignin to iNDF ratio varies among forage types (Palmonari et al., 2016) and between forage and concentrates. Thus, this assumption compromises the accuracy of the digestible NDF estimates.

[1] In the sub-model adopted by the NRC (2001), the concentration of NDF is corrected only for the contaminant protein.

The pdNDF and iNDF fractions are asymptotic biological concepts; that is, they are defined when the time of exposure to the microbial enzymatic systems in the rumen tends toward infinity (Detmann et al., 2008a). In analytical terms, the accurate assessment of these fractions is only obtained by long-term biological trials (*in situ* ruminal incubation at times equal or greater than 240 hours; Casali et al., 2008; Valente et al., 2011). These analytical procedures demand a long time to obtain the estimates of iNDF and pdNDF and restrict the assessments because they demand the availability of fistulated animals. However, long term *in situ* ruminal incubation is the most accurate way to estimate the iNDF and pdNDF fractions and is the recommended procedure to insert values in the equation base of the sub-model (Equation 4.11b).

However, considering the limitations of the theoretical bases associated with equation (4.12) and presuming situations in which *in situ* ruminal incubations cannot be performed, an alternative to estimate iNDF content from chemical characteristics was developed by analyzing samples of feeds used in Brazil. With this approach, the association between iNDF and chemical characteristics of forages (n = 371) and concentrates (n = 65) was investigated. However, during the process of fitting the equations, stronger correlations with the chemical characteristics were observed for the pdNDF fraction compared to the iNDF fraction. Thus, to obtain more robust equations, they were fitted to estimate the pdNDF fraction, considering that it represents the complement of the iNDF fraction in relation to the total NDF. The basic characteristic for estimation was the direct association of pdNDF and the contents of NDF corrected for ash and protein (NDFap), for both forages (Figure 4.1) and concentrates (Figure 4.2), and in corrections for the pdNDF fraction size in function of other chemical characteristics of the feeds [acid detergent fiber (ADF) and lignin]. Different relationships were obtained for the different feed groups (forages and concentrates), that is an improvement compared to the homogeneous relationship previously assumed by the structure of Equation (4.12).

For forages and concentrates, the equations are, respectively:

$$pdNDF(F) = 3.38 + 0.883 \times NDFap - 0.834 \times ADF + 0.0065 \times ADF^2 - 0.197 \times L$$
($s_{XY} = 3.37$; $R^2 = 0.895$) (4.13),

$$pdNDF(C) = -1.19 - 10.16 \times D + 1.012 \times NDFap - 0.052 \times ADF$$
($s_{XY} = 0.71$; $R^2 = 0.998$) (4.14),

where: pdNDF(F) and pdNDF(C), pdNDF contents in forages and concentrates, respectively (% DM); NDFap, neutral detergent fiber corrected for contaminant ash and protein (% DM); ADF, acid detergent fiber without corrections for contaminant ash and protein (% DM); L, lignin content measured by the acid hydrolysis method (% DM); D, "dummy" variable associated with the concentrate type, where D = 1 for concentrates containing fiber with lesser potential degradation [cotton meal, cake and seed; sunflower meal and cake; wheat bran; and ground ear corn (GEC)] and D = 0 for the other concentrate feeds.

However, the estimates of iNDF or pdNDF fractions obtained by chemical approximations may present limitations, because simple chemical characteristics would not be able to reproduce or represent all the biological events associated with plant growth and with the establishment of physical and chemical interactions among the components of the cell wall responsible for establishing the sizes of these fractions.

The second constraint observed for Equation (4.12) is the use of constant values for the digestibility coefficient of pdNDF [0.75; NRC (2001)]. Although the sub-model used in the second edition of the BR-CORTE System took into account for differences between animal categories [0.67 for dairy cows, and 0.84 for growing and finishing cattle; Detmann et al., 2010b], the pdNDF digestibility coefficient is presumed as constant within animal categories, that, similarly to that adopted by the NRC (2001), does not consider all the influences from intake level, diet chemical composition, and feed type on the ruminal degradation of the potentially degradable fiber.

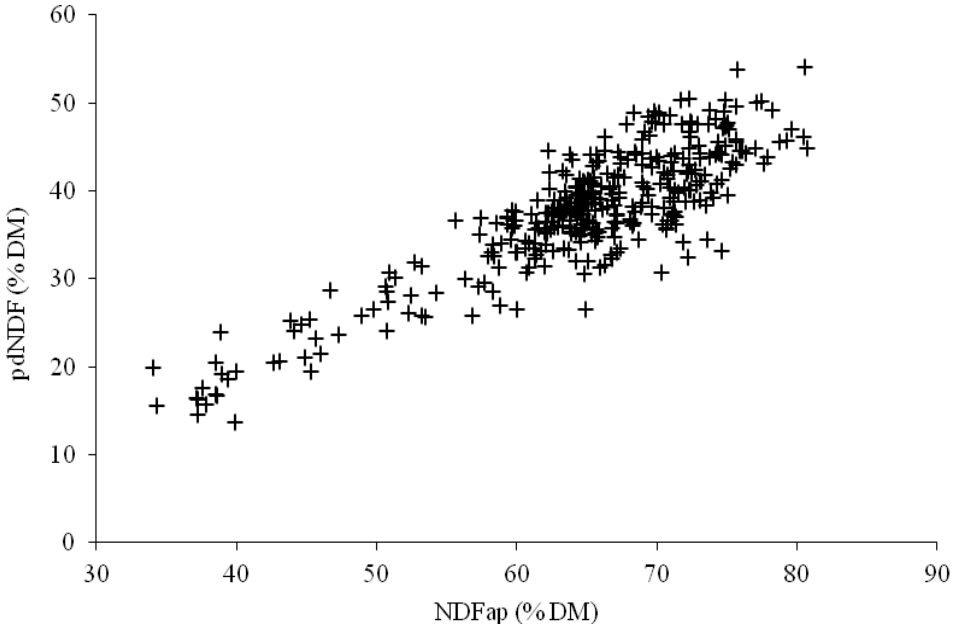


Figure 4.1 - Relationship between the contents of neutral detergent fiber corrected for ash and protein (NDFap) and potentially digestible neutral detergent fiber (pdNDF) in forage samples (n = 371).

To overcome this situation, a meta-analytical approach was performed with regard to the association between chemical composition, diet composition, and intake level, and the digestibility coefficient of pdNDF, using data from diets offered *ad libitum* to dairy cows (n = 45) and growing and finishing cattle (n = 213) in Brazil. The results showed different relationships for the animal categories and the equations are as follows:

$$D_{GF} = 80.21 \times FOR - 0.0166 \times DMI^2 + 2.658 \times iNDF + 3.691 \times CP + 0.0507 \times (DMI \times iNDF) - 2.9673 \times (FOR \times iNDF) - 3.9990 \times (FOR \times CP) \quad (4.15),$$

$$D_L = 249.32 + 1.180 \times CONC - 12.422 \times DMI + 0.2313 \times DMI^2 - 0.0475 \times (CONC \times DMI) \quad (4.16),$$

where: D_{GF} and D_L, digestibility coefficient of pdNDF for growing and finishing cattle and dairy cows, respectively (%); FOR, "dummy" variable associated with the forage type used, where FOR = 0 for corn and sorghum silages and FOR = 1 for grass forages and sugarcane; DMI, voluntary DM intake (g/kg body weight); iNDF, iNDF content in the diet (% DM); CP, CP content in the diet (% DM); and CONC, concentrate level in the diet (% DM).

It is emphasized that the equations presented a good fit (Figures 4.3 and 4.4) and allowed different aspects of the diet that effectively influence the ruminal utilization of potentially digestible fiber to be contemplated.

However, a limitation inherent to equations (4.15) and (4.16) is observed for the diet calculation, because estimates of some output parameters (i.e., forage:concentrate ratio, dietary content of CP and iNDF) are needed to perform the calculation itself, which makes it an iterative process. This could make the computer procedures difficult.

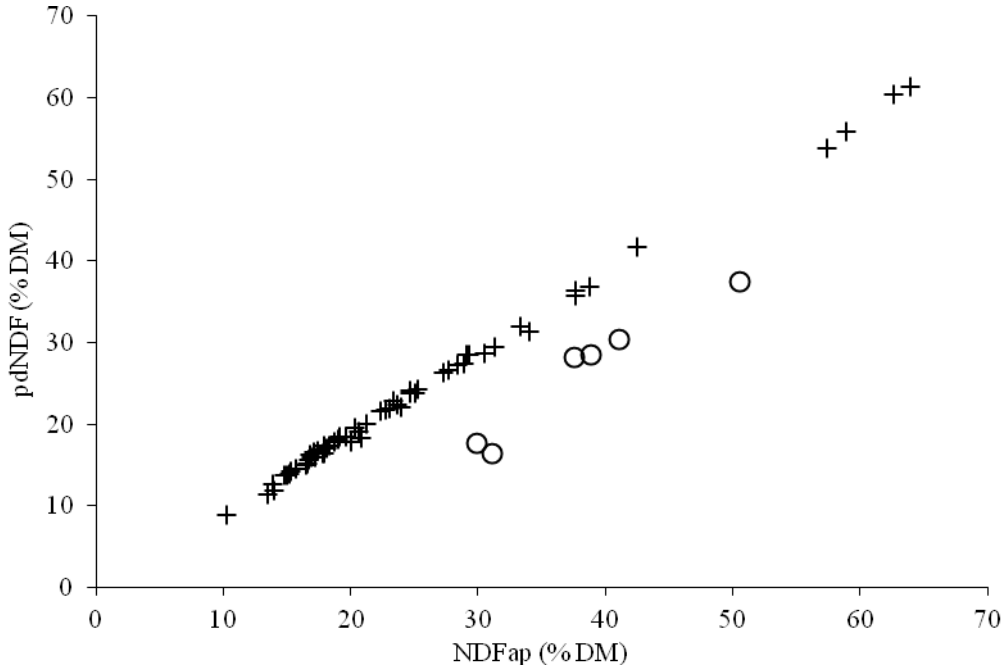


Figure 4.2 - Relationship between the contents of neutral detergent fiber corrected for ash and protein (NDFap) and potentially digestible neutral detergent fiber (pdNDF) in concentrate samples (n = 65; ○ = concentrates containing fiber with lesser potential degradation; + = other concentrate feeds).

Thus, an alternative system was developed based on assessing diets obtained from 60 animals fed exclusively on forage (i.e., corn silage, sugarcane, *Brachiaria* grass hay, *Cynodon* hay, grass silage), in which pdNDF passage and degradation rates were estimated based on rumen evacuation (Allen and Linton, 2007). The base model to quantify the digestible fraction of NDF is given by:

$$dNDF = [\frac{kd}{kd+kp} \times pdNDF] \times IAF \quad (4.17a),$$

$$dNDF = [\frac{kd}{kd+kp} \times (NDFap - iNDF)] \times IAF \quad (4.17b),$$

where: kd, pdNDF degradation rate (h^{-1}); kp, pdNDF ruminal passage rate (h^{-1}); and IAF, intestinal digestibility adjustment factor.

The models adopted to describe the pdNDF forage degradation and passage rates are given by (Figures 4.5 and 4.6):

$$kd = 0.00329 \times DMI \quad (s_{XY} = 0.0106) \quad (4.18),$$

$$kp(F) = \frac{0.287}{iNDF} \quad (s_{XY} = 0.0048) \quad (4.19a),$$

$$kp(F) = \frac{0.287}{(NDFap - pdNDF)} \quad (4.19b),$$

where: DMI, voluntary DM intake (g/kg body weight); kp(F), pdNDF passage rate for forage (h^{-1}); and iNDF, iNDF content in the forage (% DM).

Equation (4.19b) is suggested when equation (4.13) is used for estimating the pdNDF fraction.

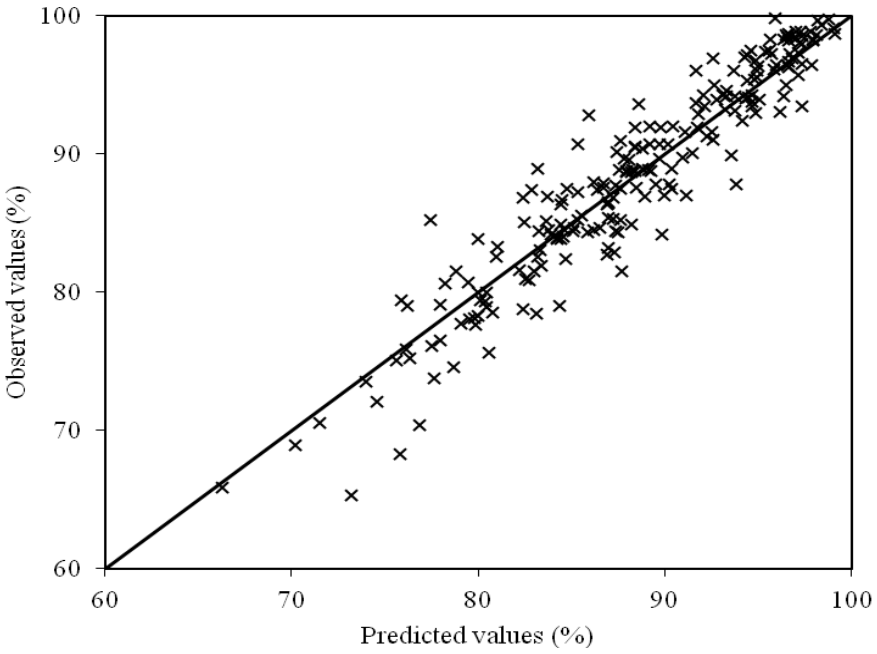


Figure 4.3 - Relationship between predicted and observed values for the digestibility coefficient of potentially digestible NDF in growing and finishing cattle (Equation 4.15; the continuous line represents the equality line; s_{XY} = 2.96; R^2 = 0.900; lack-of-fit: P>0.07).

The IAF was estimated from information available in the dataset, and no influence was observed for dietary characteristics on the proportion of pdNDF digested in the rumen and intestines. The mean proportion of the pdNDF digested in the rumen was 89±1.9%. Thus, IAF = 1.12 (IAF = 1/0.89).

The dataset used is limited because it is composed only of forage-based diets (without concentrate). Considering that concentrates present smaller particle size than those observed in forage, it is logical to suppose shorter retention time for concentrate fiber. The quantity of information that contrasts passage rates of fiber of forage and concentrates within a same experiment is limited for Brazilian conditions. Thus, an approximation was made from the experiment by Bürger et al. (2000), presuming that the ruminal passage rate of concentrate fiber is approximately 1.8 times that observed for forage fiber. Thus:

$$kp(C) = kp(F) \times 1.8 \quad (4.20),$$

where: kp(C), pdNDF passage rate for concentrates (h^{-1}).

As there is little information collected under Brazilian conditions on diets consisting exclusively of concentrates, it is suggested that the ruminal passage rate for this feeding condition be calculated according to the equation proposed by the NRC (2001):

$$kp = 0.02904 + 0.001375 \times DMI - 0.00020 \times CONC \quad (4.21),$$

where: DMI, voluntary DM intake (g/kg body weight); and CONC, concentrate level in the diet (% DM).

It is important to emphasize that equation (4.21) refers to the total concentrate DM and not to the pdNDF itself. However, considering that its application would be restricted to diets consisting only of concentrates, it is assumed that, in these circumstances, the pdNDF passage rate approximates the whole concentrate passage rate. However, this assumption still needs validation for Brazilian conditions.

Sub-model for CP

First, the sub-model used to evaluate the CP digestible fraction was based on the same assumptions adopted for EE and NFC (Detmann et al., 2006b), according to equations (4.1) to (4.8), resulting in:

$$tdCP = 0.78 \times CP \quad (4.22),$$

where: tdCP, truly digestible CP (% DM); and CP, diet content of CP (% DM).

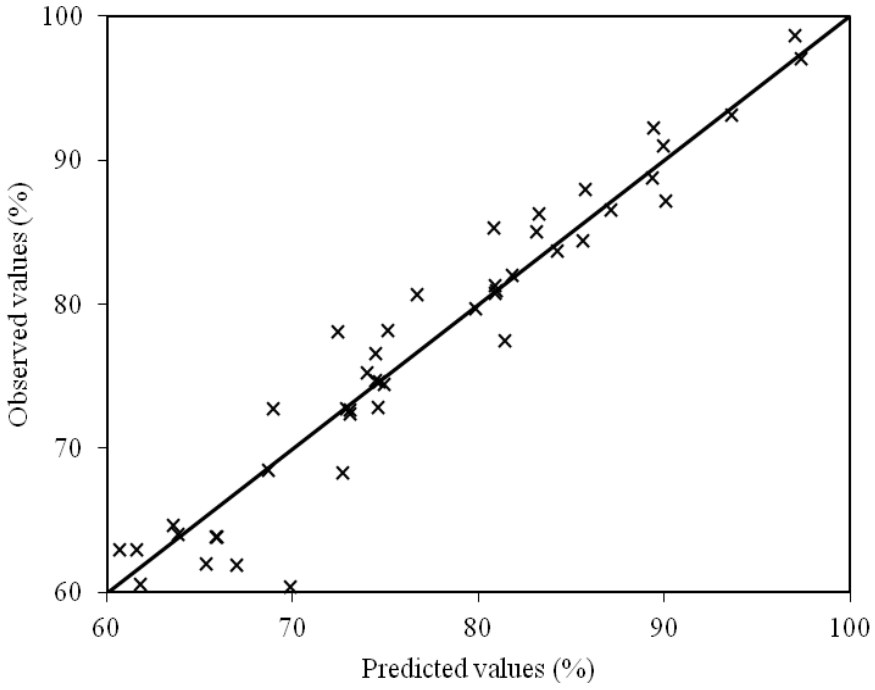


Figure 4.4 - Relationship between predicted and observed values for the digestibility coefficient of potentially digestible NDF in dairy cows (Equation 4.16; the continuous line represents the equality line; s_{XY} = 3.46; R^2 = 0.933; lack-of-fit: P>0.67).

In this case, conversion to the apparently digestible fraction (considering different animal categories) is performed by using the estimates of the corresponding fecal metabolic contribution (Table 4.1).

However, later observations showed that, because of the intense and complex association of nitrogen compounds and the insoluble fiber in tropical feeds, the CP could not be considered as a homogeneous nutritional entity (Detmann et al., 2008c). In spite of this, Azevêdo et al. (2011) observed that applying the uni-compartmental concept, in which the CP is presumed as a homogeneous nutritional entity, gave more accurate estimates when some agroindustry by-products and residues were assessed. Thus, although the concept represented by Equation (4.22) is not generally recommended, it could be used in the evaluation of energy content for agroindustry by-products.

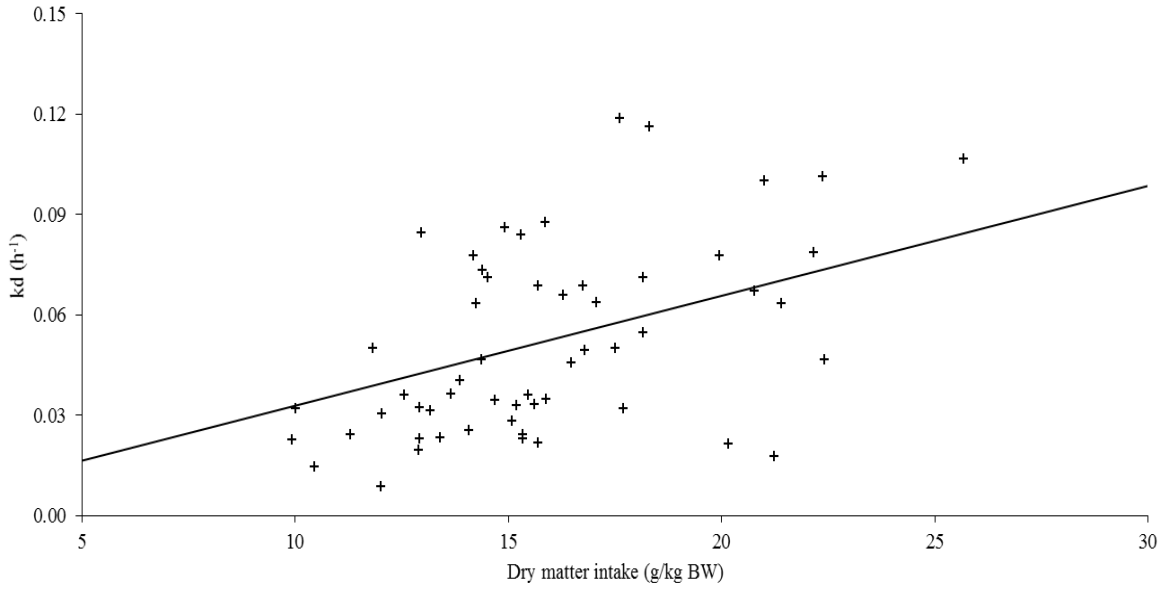


Figure 4.5 - Relationship between voluntary dry matter intake and degradation rate (kd) of potentially digestible neutral detergent fiber in forage-based diets (continuous line represents Equation 4.18).

Based on the evidence for the heterogeneous digestive pattern of the CP, a sub-model was developed considering two sub-compartments (Detmann et al., 2008c), whose chemical approximations are given by:

$$CCCP \cong CP - CWCP \quad (4.23a),$$

$$CWCP \cong NDIP \quad (4.23b),$$

where: CCCP, cell content CP; CWCP, cell wall CP; and NDIP, neutral detergent insoluble protein; all terms are expressed as % DM.

According to derivations by Detmann et al. (2008c), the CCCP would have a homogeneous digestive pattern similar to that of other non-fibrous components (EE and NFC) (Equation 4.8). On the other hand, by assumption, the digestion pattern of the CWCP would be similar to that observed for the NDF. In this way, the truly digestible fraction of the CP would be expressed, considering the chemical approximations represented in Equation (4.23), by:

$$tdCP = tD_{CCCP} \times CCCP + D_{pdCWCP} \times pdCWCP \quad (4.24a),$$

$$tdCP = tD_{CCCP} \times (CP - NDIP) + D_{pdCWCP} \times (NDIP - UNDIP) \quad (4.24b),$$

where: tdCP, truly digestible CP (% DM); tD_{CCCP}, true digestibility coefficient of the CCCP (g/g); pdCWCP, potentially digestible CWCP (% DM); D_{pdCWCP}, digestibility coefficient of the potentially digestible CWCP (g/g); and UNDIP, undegradable neutral detergent insoluble protein (% DM).

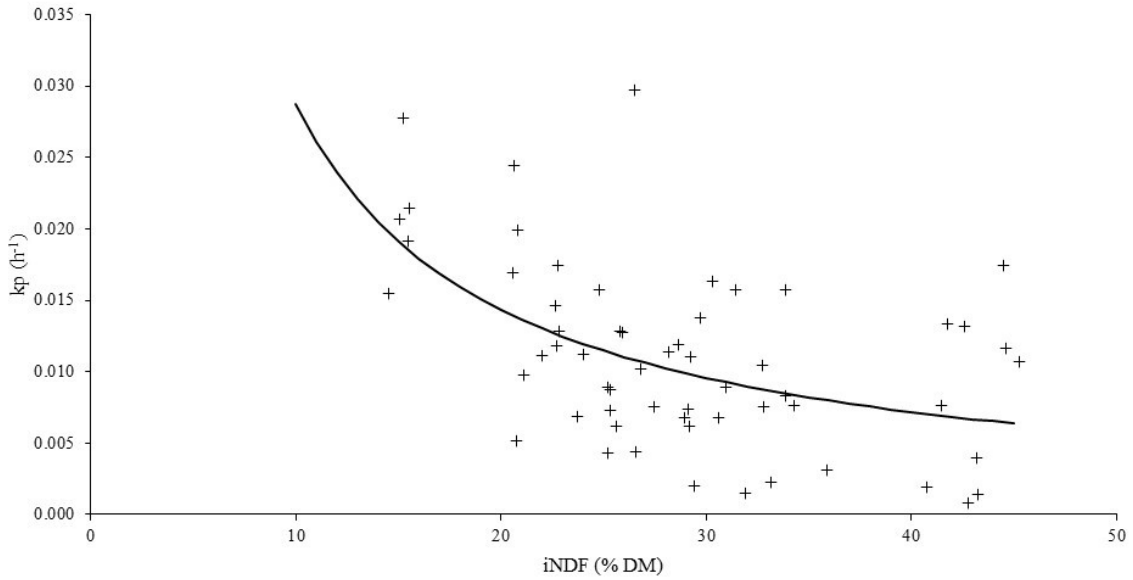


Figure 4.6 - Relationship between diet concentration of indigestible neutral detergent fiber (iNDF) and passage rate (kp) of potentially digestible neutral detergent fiber in forage-based diets (the continuous line represents Equation 4.19).

In the second edition of the BR-CORTE System, 0.98 g/g was used as the estimate for the true digestibility coefficient of CCCP (Van Soest, 1994; Detmann et al., 2006c; 2008c). However, for a better agreement to the estimates obtained from Brazilian data, this coefficient was altered to 0.95 g/g, similar to that one applied to estimate the truly digestible NFC (Equation 4.10). Following the assumptions adopted in the second edition of the BR-CORTE System, the digestibility coefficients of CWCP were presumed to be similar to those used for the fibrous portion of the feed/diet, which are no longer constant but vary in function of the diet and feeding conditions, as described in equations (4.15) to (4.21).

The analytical concept of UNDIP was defined by Detmann et al. (2004b) as an approaching to the parametric value of undegradable cell wall protein, which consists of the residual CP associated with the iNDF.

However, as pointed out previously, such an analytic approximation can be a hindrance in some situations, because fistulated animals may not be available. Thus, an alternative equation was developed to obtain the UNDIP value from the acid detergent insoluble protein (ADIP) using data from feeds produced under tropical conditions (Detmann et al., 2010a; n = 540), that is given by:

$$UNDIP = NDIP \times e^{-(0.8188+0.1676\times ADIP)} \quad (4.25),$$

where: ADIP, acid detergent insoluble protein (% DM), the other terms were previously defined (% DM).

When the chemical approximation for UNDIP is adopted, Equation (4.24b) can be rewritten as:

$$tdCP = 0.95 \text{ x } (CP - NDIP) + D_{pdCWCP} \text{ x } \{NDIP \text{ x } [1 - e^{-(0.8188 + 1.1676 \text{ x } ADIP)}]\} \quad (4.26).$$

The chemical approximation of UNDIP via ADIP has some limitations, because the UNDIP is a biological concept with high variability (Henriques et al., 2007; Detmann et al., 2010a). Thus, this solution should be used with caution; it is preferable, when feasible, to estimate the UNDIP by a biological method (i.e., long term incubation procedure). Sampaio et al. (2012) observed that estimating UNDIP by *in situ* incubations (protein associated with the iNDF) gave more exact and precise estimates of digestible CP compared to using the chemical approximation.

When using empirical approximation to calculate the digestibility coefficient of the pdNDF fractions (Equations 4.18 to 4.21), the truly digestible CP fraction should be

calculated separately for the forage and concentrate fractions of the diet by adapting Equation (4.26):

$$tdCP = 0.95 \times (CP - NDIP) + kd/(kd + kp) \times \{NDIP \times [1 - e^{-(0.8188 + 1.1676 \times ADIP)}]\} \quad (4.27).$$

In calculating the digestible CWCP, we chose not to adopt the correction factor for intestinal digestion, because intestinal digestion of the fiber was considered to take place primarily in the large intestine. In this case, the CWCP digested in this compartment would be basically used for microbial growth, with no contribution for total metabolizable protein.

Detmann et al. (2008c), Magalhães et al. (2010) and Sampaio et al. (2012) observed that the bi-compartmental concept produced more accurate estimates of the apparently digestible CP in diets based on tropical forage than did the uni-compartmental concept. Thus the use of the bi-compartmental concept is recommended, and the use of the single compartment model should be only recommended to evaluate agroindustry by-products.

Summative system for TDN and conversion to digestible and metabolizable energy

The TDN diet content (% DM) is obtained by the algebraic sum of the estimates produced for each sub-model for each digestible fraction, according to the animal category, from the following equation:

$$TDN = adCP + adNFC + dNDF + 2.25 \times adEE \quad (4.28a),$$

$$TDN = (tdCP - CM_{CP}) + (tdNFC - CM_{NFC}) + dNDF + 2.25 \times (tdEE - CM_{EE}) \quad (4.28b),$$

$$TDN = tdCP + tdNFC + dNDF + 2.25 \times tdEE - (CM_{CP} + CM_{NFC} + 2.25 \times CM_{EE}) \quad (4.28c),$$

$$TDN = tdCP + tdNFC + dNDF + 2.25 \times tdEE - FM_{TDN} \quad (4.28d),$$

where: TDN, dietary TDN (% DM); adCP, adNFC, adEE, apparent digestible fractions of CP, NFC and EE, respectively (% DM); tdCP, tdNFC, tdEE, truly digestible fractions of CP, NFC and EE, respectively (% DM); dNDF, digestible NDF (% DM); CMCP, CMNFC, CMEE, fecal metabolic contributions from CP, NFC and EE, respectively (% DM); FMTDN, total fecal metabolic fraction for the TDN calculation (% DM; Table 4.1); and 2.25. the Atwater's constant to equalize lipids and carbohydrates.

Digestible energy (DE) content is estimated by considering the specific energy contribution of each truly digestible fraction and discounting the energy of the fecal metabolic fraction:

$$DE = 0.056 \times tdCP + 0.042 \times tdNFC + 0.042 \times dNDF + 0.094 \times tdEE - FM_{DE} \quad (4.29),$$

where: DE, digestible energy (Mcal/kg DM); and $FM_{ED,}$ fecal metabolic fraction for the DE calculation (Mcal/kg DM; Table 4.1). The other terms were defined previously.

The DE is converted to metabolizable energy (ME) by using the equation developed in the Laboratory of Animal Metabolism and Calorimetry at the Veterinary Medicine College of the Federal University of Minas Gerais:

$$ME = 0.9455 \times DE - 0.3032 \quad (4.30),$$

where: ME, metabolizable energy (Mcal/kg DM).

RECOMMENDED CHEMICAL ANALYSIS METHODS

The methods for chemical analysis of feeds suggested to assess the DM, organic matter (OM), CP, EE, ADF, NDIP, ADIP, iNDF, UNDIP, and lignin contents are summarized in Table 4.2. Generally, the methods applied to chemical analysis follow the recommendations established in the book Methods for Feed Analysis (Métodos para Análise de Alimentos) of the National Institute of Animal Science and Technology (Instituto Nacional de Ciência e Tecnologia de Ciência Animal) (INCT-CA, Detmann et al., 2012), with some exceptions highlighted in the text. These exceptions are due to the absence of methods in the referred book or alterations already defined and that will be

established in the second edition that is still in preparation.

To assess the total nitrogen content or CP, the Kjeldhal method (method INCT-CA N-001/1) is recommended, with the following modification: use a 20:1 sodium sulfate-to-copper sulfate ratio in the digestion step (Silva et al., 2016). The same modifications should also be applied to the assessments of the nitrogenous compounds associated with the fibrous fractions (NDIP, ADIP, and UNDIP).

Table 4.2 - Summary of suggested methods to analyze feeds to predict the dietary TDN

Component	Method	General Description	Reference
DM	Pre-drying	55-60ºC/48-72 hours; equipment: forced ventilation oven	1
	Definitive drying	a. 105ºC/3 hours, for feeds with urea content higher than 10%; b. 105ºC/16 hours, for the other materials; equipment: non-ventilated oven, desiccator	2, 3
CP	Kjeldahl	Digestions in sulfuric acid (400ºC), distillation with sodium hydroxide, and titration with hydrochloric acid	4*
EE	Randall	Immersion time: 30 minutes; washing (dipping) time: 60 minutes; solvent condensation rate: 3-5 drops/sec; suggested extractor: petroleum ether	5
Ash	Calcination	600ºC/3-4 hours; equipment: furnace, desiccator	6
Organic Matter	By difference	OM = 100 – Ash	6
NDF, ADF	Detergent system	Contents assessed by conventional extractions under reflux (*Fibertech*) or by micro-extraction in autoclave	*
NDIP, ADIP	Detergent system	Assessment by the Kjeldahl method after extraction with the respective detergents	7*
NDIA	Detergent system	Assessment of the residual mineral matter in the NDF	8*
iNDF	*in situ* Incubation	*In situ* incubation for 288 hours using F57 (Ankom®) or non-woven textile (NWT, 100 g/m²) filter bags. Sample mass: 20 mg DM/cm² surface. Extract with neutral detergent	9
UNDIP	*in situ* incubation	Assessment of the protein associated with iNDF by the Kjeldahl method	9, 7*
Lignin	Sulfuric acid	Solubilization of cellulose by hydrolysis in H_2SO_4 (72% w/w) after prior treatment of the sample with acid detergent	10*

[1] Method INCT-CA G-001/1. [2] Method INCT-CA G-003/1. [3] Thiex and Richardson (2003). [4] Method INCT-CA N-001/1. [5] Method INCT-CA G-005/1. [6] Method INCT-CA M-001/1. [7] Method INCT-CA N-004/1 and N-005/1. [8] Method INCT-CA M-002/1. [9] Method INCT-CA F-008/1. [10] Method INCT-CA F-005/1. * See comments in the text.

The NDF and ADF content should be estimated by extractions using *Fibertech*-type equipment (Van Soest and Robertson, 1985; Mertens, 2002) or in an autoclave (Barbosa et al., 2015), according to the recommendations for reagents provided by INCT-CA (Detman et al., 2012). The NDF and ADF contents should be analyzed using filtering crucibles. For both cases, the use of *filter bags* should be regarded with caution because inaccuracies in the NDF contents have been observed (Gomes et al., 2011a; Barbosa et al., 2015). Consequent adaptations are also demanded for the analyses of NDIP, ADIP, neutral detergent insoluble ash (NDIA), and lignin. In particular, the NDF analysis should be carried out using a heat stable α-amylase (Mertens, 2002) with the proper correction for the NDIP and NDIA contents (Detmann and Valadares Filho, 2010). Using sodium sulfite is not

recommended because the solubilization of protein associated with fiber, lignin, and other compounds (Gomes et al., 2012). The ADF is analyzed sequentially to the NDF.

It is pointed out, however, that using filter bags and extractors adapted to this type of recipient (e.g., Ankom^{220}) is still recommended for the iNDF assessments. The extractor must function with a pressurized environment. Equipment adapted for use in atmospheric pressure leads to obtaining biased data (Gomes et al., 2011a).

The calculation of NDFap content is given by:

$$NDFap = NDF \times \frac{(100 - NDIP - NDIA)}{100} \quad (4.31),$$

where: NDFap, neutral detergent fiber corrected for contaminant ash and protein (% DM); NDF, neutral detergent fiber (% DM); NDIP, neutral detergent insoluble protein (% NDF); NDIA, neutral detergent insoluble ash (% NDF).

The NDF content (Equation 4.31) should be corrected so that the total NFC content of the feed is not underestimated and the energy contribution of the part of CP (NDIP) is not calculated in duplicate. On the other hand, correction avoids erroneous calculating of a part of mineral matter (NDIA) as an energetic component of feeds (Detmann et al., 2008b; Detmann and Valadares Filho, 2010).

In this context, the NFC content is obtained using the following equation (Detmann and Valadares Filho, 2010):

$$NFC = OM - [(CP - CPu + Ur) + EE + NDFap] \quad (4.32),$$

where: CPu, urea-derived CP (% DM); and Ur, urea content in the feeds (% DM).

DISCUSSION OF THE MAIN CHARACTERISTICS AND MODIFICATIONS TO THE MODEL

In comparison with the second edition of the BR-CORTE System (Detmann et al., 2010b), the structure of the sub-models used to predict the truly digestible fraction of the EE and NFC was maintained (Equations 4.9 and 4.10), because validation studies had confirmed its accuracy (Detmann et al., 2008b; Magalhães et al., 2010; Azevêdo et al., 2011; Sampaio et al., 2012), and confirmed the central hypothesis that both components could be treated as homogeneous nutritional entities and that their digestive pattern can be adequately interpreted by the Lucas test (Lucas and Smart, 1959; Lucas, 1960).

In addition, as reported in the second edition of the BR-CORTE System (Detmann et al., 2010b), the better performance of the summative system developed under Brazilian conditions can be partly attributed to the better adequacy of the fecal metabolic fractions (Table 4.1), which are necessary for proper conversion of the truly digestible fractions of EE, NFC, and CP to fractions compatible with apparent digestibility (the base used to calculate the TDN concentration). The fecal metabolic fraction is directly influenced by the nutrient flow to the large intestines, that implies alterations in cecal microbial activity (Ørskov, 1988), and by the level of fibrous components in the diet (Arroyo–Aguilu and Evans, 1972), which are notably different between animals fed under tropical and non-tropical conditions (Detmann et al., 2008b).

However, the sub-model initially proposed to assess the digestible NDF (Equation 4.12) presented low precision (Detmann et al., 2008b; Azevêdo et al., 2011; Sampaio et al., 2012), especially for growing and finishing cattle (Detmann et al., 2007).

The low prediction efficiency of this sub-model was attributed to two main factors. First, the use of a constant lignin constraint factor on NDF ruminal (parameter F; Equation 4.12), a characteristic also intrinsic to the sub-model adopted by the NRC (2001). The estimate of the parameter F adopted in the second edition of the BR-CORTE System was derived by Detmann et al. (2004a), who evaluated samples of tropical forages through the analysis of lignin by the method of oxidation in potassium permanganate. However, the set of samples used by these authors was somewhat restricted, because it did not include concentrate feeds and consisted largely of samples of tropical grasses under grazing (e.g., *Brachiaria* grass). It was understood, however, that the relationship between lignin and iNDF could not be considered homogeneous among feeds (Palmonari et al., 2016). Therefore, these facts were used to support the first modification in the theoretical assumptions to estimate the digestible fraction of NDF.

As previously emphasized, the iNDF fraction, and consequently the pdNDF fraction, is an asymptotic biological concept; that is, it is defined when there are no restrictions regarding the time when the feed is degraded by the rumen's microbial enzymatic systems (Detmann et al., 2008a). The high variability among samples for the iNDF concentration and consequently the pdNDF indicates that, although lignin is the main determining factor of the extension of fiber degradation (Van Soest, 1994), simple gravimetric analyses may not be capable of properly predicting all the determining factors of the asymptotic limits of the degradation (Detmann et al., 2008b). Thus, direct analysis of the iNDF by long term *in situ* rumen incubation trials would be a more plausible biological alternative for fractioning the NDF in feeds.

Nevertheless, there are limitations to carrying out such trials because animals fistulated in the rumen need to be available, and a long period of time is required (Casali et al., 2008; Valente et al., 2011). Thus, empirical prediction equations were developed by analyzing forage (n = 371) and concentrate samples (n = 65), and the results are expressed in equations (4.13) and (4.14), respectively (Figures 4.1 and 4.2). To fit these equations, associations with various feed components were properly investigated [i.e., NDF, NDFap, ADF, ADF corrected for contaminant ash and protein (ADFap), lignin assessed by acid hydrolysis and oxidation with permanganate]. One of the greatest advantages regarding the assumptions adopted in the second edition of the BR-CORTE System is the use of different models for forages and concentrates.

As previously pointed out, correlations between the different chemical characteristics considered and the iNDF fraction were weaker compared to those obtained for the pdNDF fraction (Table 4.3), which may reflect the greater proportion of pdNDF compared to iNDF in the total DM of the feeds. As these fractions are complementary to each other, better fits of the models were obtained considering the pdNDF fraction as the dependent variable. However, although complementary in relation to the total NDF, the pdNDF and iNDF fractions, expressed as DM percentage, were shown not to be correlated (Table 4.3) due, in most part, to the high variability of the NDF contents among feeds and to a lesser extent, to the high variability in the partitioning of the NDF into the potentially digestible and indigestible fractions among feeds.

The basic characteristic for fitting models for predicting the pdNDF fraction for forages and concentrates was the strong correlation observed with NDFap content (Table 4.3; Figures 4.1 and 4.2). This relationship seems to be logical, as, with rare exceptions, the pdNDF fraction corresponds to the most of the total NDF, thus showing a direct relationship of proportionality. These correlations were slightly stronger when compared with that for NDF (Table 4.3) possibly because of the small influence of cell wall protein and minerals on the potential of fiber degradation. In this sense, relations with other fiber characteristics were added to the models based on the NDFap concentration in order to incorporate discriminatory elements among feeds in function of the potential utilization of the fiber in the rumen.

Especially for forages, the linear and quadratic effects of the ADF and the linear effect of lignin concentration were added to the model to predict the pdNDF fraction (Equation 4.13).

Lignin plays a central role on the extent of fiber degradation in the rumen (Van Soest, 1994). The negative correlations between lignin and the pdNDF fraction for forages corroborate this statement, implying a negative regression coefficient in equation (4.13). Although evidence points to stronger correlations between the potential degradation of the tropical forage NDF and lignin analyzed by oxidation in permanganate (Gomes et al., 2011b), the set of samples assessed here showed a better association based on lignin contents assessed by the hydrolysis in sulfuric acid (Table 4.3). Thus the analysis methods were modified compared to the second edition of the BR-CORTE System (Table 4.2) and the recommendation of the method by oxidation in permanganate was removed. From a pragmatic point of view, this recommendation was shown to be advantageous, because the hydrolysis in sulfuric acid method requires less labor, has fewer analytical steps and lower cost compared to the method of oxidation in permanganate. However, it should be pointed out that the using hydrolysis method may lead to overestimation of the lignin concentration in feeds with a high cutin content, due to the joint consideration of these components (lignin and

cutin) in the residue assessed as lignin (Van Soest, 1994). For most feeds, the cutin contribution has little relevance. However, for cutin-rich feeds, such as castor seeds by-products (meal and cake) and cactus, the method of oxidation in permanganate may produce more reliable results for the lignin concentration.

Table 4.3 - Pearson's linear correlations coefficients for the concentrations of the pdNDF and iNDF fractions and different chemical characteristics in forages and concentrates

Characteristic[1]	Feed[2]			
	Forages		Concentrates	
	pdNDF	iNDF	pdNDF	iNDF
NDF	0.838 (<0.001)	0.541 (<0.001)	0.950 (<0.001)	0.427 (<0.001)
NDFap	0.868 (<0.001)	0.576 (<0.001)	0.967 (<0.001)	0.408 (<0.001)
ADF	0.539 (<0.001)	0.632 (<0.001)	0.811 (<0.001)	0.344 (0.004)
ADFap	0.534 (<0.001)	0.603 (<0.001)	0.803 (<0.001)	0.340 (0.005)
Lignin (H)	-0.553 (<0.001)	-0.106 (0.040)	0.059 (0.643)	0.911 (<0.001)
Lignin (Ox)	-0.505 (<0.001)	-0.080 (0.131)	0.502 (<0.001)	0.391 (0.001)
pdNDF × iNDF	0.095 (0.067)		0.163 (0.195)	

[1] NDF, neutral detergent fiber; NDFap, NDF corrected for contaminant ash and protein; ADF, acid detergent fiber; ADFap, ADF corrected for contaminant ash and protein; Lignin (H), lignin assessed by hydrolysis in sulfuric acid; Lignin (Ox), lignin assessed by oxidation in potassium permanganate. [2] Values in parenthesis represent the descriptive level of probability for H_0: $\rho = 0$.

Unlike that observed for NDF, the corrections for ash and protein did not improve the correlations between pdNDF and ADF (Table 4.3). Thus, the model (Equation 4.13) was based on the ADF concentrations without corrections. Although the ADIP is required to estimate the truly digestible fraction of the CP by using chemical approximation (Equations 4.26 and 4.27), excluding the use of the ADFap reduces the analytical labor, because it eliminates acid detergent insoluble ash (ADIA) analysis from the laboratory routine. It is pointed out that sequential ADF extraction removes a large part of the cell wall protein and biogenic silica (Van Soest, 1994), making the ADIP and ADIA participation lower than the NDIP and NDIA participation in the total DM of the sample, that seems to further justifies the correlations between pdNDF and ADFap being similar or weaker compared to the correlations between pdNDF and ADF.

Although the correlation between pdNDF and ADF was initially positive (Table 4.3), it was included in the model with a negative effect on pdNDF (Equation 4.13). This inversion in the direction of association reflects a limitation of the Pearson correlation coefficient when applied to a group of variables highly correlated, because the estimate of correlation for any pair of variables can hide the influence from the other variables assessed (Spiegel, 1971). However, in spite of the inversion in the direction of association, including the ADF in the model improved its fit and contributed significantly to the explanation of the relationship ($P \leq 0.04$). The quadratic pattern of Equation (4.13) suggests that there would be a minimum pdNDF content in function of the ADF, with subsequent increase. However, the effect of ADF on pdNDF is continually decreasing in the mathematical domain of its concentrations. The study of the partial derivative of the pdNDF concentration in function of the ADF concentration indicates that increases in pdNDF would only occur in limits within the field of the extrapolation and under biologically unlikely ADF concentrations (ADF≥64.2% DM).

The presence of ADF in the model (Equation 4.13) should be noted with caution, however. From a theoretical point of view, it must be emphasized that the ADF does not meet any correct definition of dietary fiber or insoluble

fiber (Mertens, 2003), and therefore should not be considered a valid or useful nutritional concept. Using ADF in equations to predict digestibility ignores the physiological basis that relates the fibrous components to digestibility. Digestion of all the insoluble fiber fractions is limited mainly by lignification. In this context, establishing relationships between ADF and digestion characteristics, mainly for insoluble fiber, are inconsistent from a nutritional point of view (Detmann, 2010) and represent only statistical associations. Biologically, negative correlations between ADF and insoluble fiber digestibility should be attributed to lignin rather than the ADF *per se* (Detmann, 2010). Thus, the negative effect of the ADF observed in the model, even in the presence of lignin (Equation 4.13), seems to reflect only the effect of the proportional participation of the different insoluble macro-components of the cell wall (cellulose, hemicellulose and lignin) in the forage NDF, that might influence its potential of degradation due to their different chemical bonds and physical interactions and the different participation of these components in the different plant tissues, that vary in participation in the plant depending on the species and stage of maturity.

For concentrate feeds, the linear negative effect of the ADF was added to the model to predict the pdNDF fraction (Equation 4.14). Although the lignin concentrations measured by oxidation correlated negatively with pdNDF (Table 4.3), its inclusion in the model did not make any significant contribution (P>0.46). As emphasized previously, the central effects on the NDF potential degradation should be attributed to lignin (Van Soest, 1994) and correlations between this characteristic and the ADF should be seen only as statistical associations. Thus, for concentrate feeds, the ADF seems to directly reflect lignin action, because lignin would be proportionally more representative in the acid detergent insoluble residue (cellulose + lignin) compared to the neutral detergent insoluble residue (hemicellulose + cellulose + lignin). On the other hand, assessing lignin in concentrates can present inherent difficulties due to its low concentration that decreases the precision of the gravimetric measurements. Thus, the advantage highlighted here for the ADF in concentrate feeds is due to the fact that lignin is contained in the ADF, allowing its quantification in a residue with greater mass, without needing a second chemical procedure to separate the cellulose, that also makes the analyses more practical, faster and cheaper.

A "dummy" variable was introduced in the model applicable to the pdNDF concentration in concentrates to correct the estimates for feeds with fiber with lesser potential degradation (Equation 4.14). This correction was incorporated only at intercept, because the slope of both the groups of concentrated feeds in function of the NDFap concentration was similar (Figure 4.2). Although the feed group with fiber with lesser potential degradation in the dataset includes only cotton by-products and wheat bran, subsequent assessment using the CQBAL 3.0 database (Valadares Filho et al., 2015) showed that correction by the dummy variable would also be applicable to sunflower by-products (meal and cake) and GEC.

The second factor that influences the low precision of the NDF digestible fraction in the sub-model adopted in the second edition of the BR-CORTE System is the adoption of fixed digestibility coefficients for the pdNDF fraction, a limitation pointed out previously by Detmann et al. (2010b). The pdNDF digestibility coefficient results from the integration between the dynamics of degradation and transit in the ruminant gastrointestinal tract and, consequently, all the factors with potential influence on these characteristics. Although the pdNDF digestibility coefficients previously adopted were different among animal categories, they were derived from the joint analysis of a small number of experiments (Detmann et al., 2007), that did not permit contemplation of the widely different dietary situations observed in Brazilian conditions. This question is particularly relevant for growing and finishing cattle, because the data originally used presented a great number of observations derived from experiments with animals managed on low-quality tropical pastures (Detmann et al., 2007), that, together with the problems reported previously for estimating the iNDF, seem to have implied a positive bias on the estimates of the digestible NDF for this animal category.

The first proposal to obtain estimates for the digestibility coefficient was based on a meta-analytical evaluation of diets (hereafter denoted as the meta-analytical approximation). The

integration of different studies by meta-analytical techniques has the obvious advantage of contemplating a wide range of dietary conditions, which would not be feasible to obtain in one or few experiments. Data from 45 diets with dairy cows and 213 diets with growing and finishing cattle (treatment means) were compiled. In principle, the objective was to fit a single equation to both animal categories, aiming at greater reliability due to the larger number of dietary conditions. However, the initial assessments showed that illogical associations from a biological point of view were being indicated by the equations (e.g., positive association between dietary EE and fiber digestion), a possible reflection of occurrence of the Simpson Paradox, that indicates the reversion of the direction of an association when data are combined from several groups to form a single group (Moore, 1995). In this way, different equations were fitted to each group. The backward regression method was adopted (Draper and Smith, 1966) and the regression parameters were adjusted for the random effects of the different experiments. However, a preselecting of the independent variables was done by inspecting the Pearson linear correlations.

For growing and finishing cattle, the strongest correlations with the pdNDF digestibility coefficient were observed for dietary CP ($r = 0.18$; $P<0.03$) and voluntary iNDF intake ($r = 0.25$; $P<0.01$). However, due to difficulties in obtaining estimates of the iNDF intake, this variable was replaced in the process of fit by voluntary DM intake (whose estimation can be obtained by the BR-CORTE System) and dietary iNDF, because the multiplication of both resulted in the iNDF intake. Distinction between different forage groups was necessary for the correct fit of the equation, and they were grouped in forages with high (i.e., corn and sorghum silages) and low (i.e., sugarcane, grass hay, grass silage, fresh grass) starch content (Equation 4.15; Figures 4.7 and 4.8).

The assessment of Equation (4.15) showed a positive effect of dietary iNDF content on pdNDF digestibility for low- (Figure 4.7) and high-starch (Figure 4.8) forages. This effect is associated with the fact that the indigestible fiber fraction has, proportionally, greater rumen fill effect compared to the potentially degradable fraction, because it is only removed from the rumen by passage (Waldo et al., 1972; Detmann et al., 2015). The increase in the rumen fill effect of the NDF with the greater participation of the iNDF fraction implies longer retention times, increasing the exposure time of the pdNDF fraction to the action of the rumen microorganisms. This effect of the dietary iNDF content was more prominent when high-starch forages were considered (Figure 4.8).

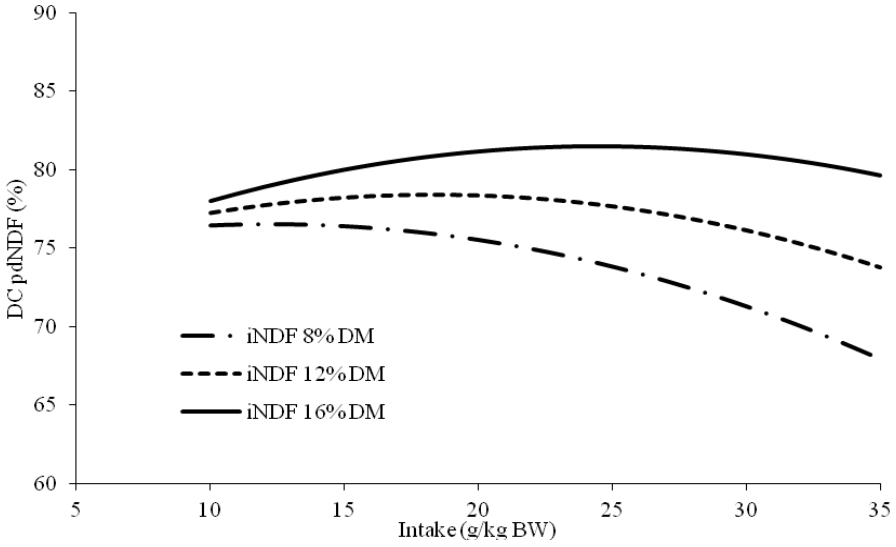


Figure 4.7 - Variations in the digestibility coefficient of potentially digestible neutral detergent fiber (DC pdNDF) according to voluntary dry matter intake and iNDF diet content for growing and finishing cattle fed forage with low starch content (Equation 4.15; presuming diet with 12% CP based on the DM).

Due to the effect of the interaction between forage type and dietary CP, positive effects associated with an increase in diet CP were only significant for high-starch forages (Equation 4.15). Clearly positive effects of nitrogenous compounds availability in the diet on effective fiber utilization in the rumen are normally observed when nitrogen deficient diets are offered to animals (Detmann et al., 2009), a characteristic little observed in the dataset used in the present study. However, with the increase in starch participation in the diet, deleterious effects on fiber utilization can be observed, that are attributed to falls in rumen pH to values below the adequate for fibrolytical activity or to an increased competition for substrates among fibrolytic and non-fibrolytic species (Mertens and Loften, 1980; Mould et al., 1983; Arroquy et al., 2005; Carvalho et al., 2011). However, results obtained in tropical conditions show that increase in diet availability of nitrogenous compounds can reduce competition between microbial species, reducing the deleterious effect of starch on ruminal fiber utilization (Costa et al., 2009; Lazzarini et al., 2016). This seems to justify the positive effect of the CP diet concentration on the pdNDF digestibility in high-starch forage (Equation 4.15).

Generally, for growing and finishing cattle, a negative effect of intake on pdNDF digestibility was observed (Girard and Dupuis, 1988; Figures 4.7 and 4.8). Under normal feeding conditions (without drastic imbalances) it is understood that the rumen passage rate is greatly influenced by intake (Pittroff and Kothmann, 1999). Thus, higher intakes are associated with higher passage rates and consequently lower rumen retention time and lower time for microbial action on the fiber. However, it was observed that the effect of intake on the pdNDF digestibility coefficient decreases as the quality of the diet decreases (increase in iNDF content), making the values practically stable in all range of the voluntary intake evaluated here (Figures 4.7 and 4.8). It is understood that voluntary intake by cattle is regulated by multiple mechanisms that act simultaneously. However, variations in the dietary conditions can make the regulating mechanisms alter in importance in the total sum of the influences that determine the voluntary intake (Detmann et al., 2014). In this sense, with a decreased diet quality, physical intake regulation mechanisms can become more prominent due to longer retention time of the digesta in the rumen, decreasing the influence of the intake level on passage rate and making the intake influence lesser evident regarding the pdNDF digestibility.

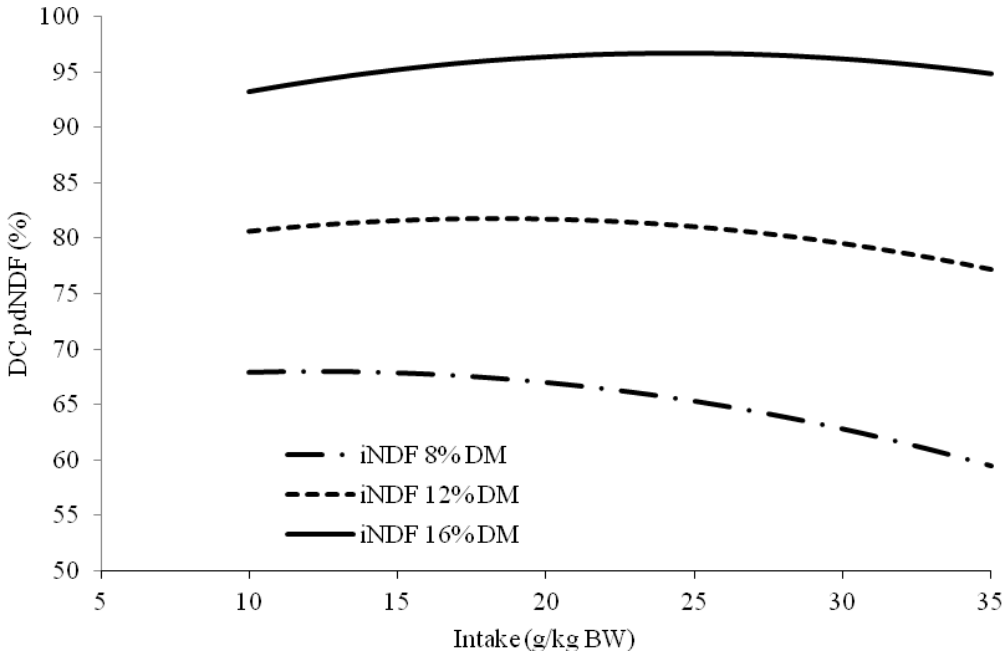


Figure 4.8 - Variations in the digestibility coefficient of the potentially digestible neutral detergent fiber (DC pdNDF) according to voluntary dry matter intake and iNDF diet content for growing cattle fed forage with high starch content (corn or sorghum silage; Equation 4.15; presuming diet with 12% CP based on the DM).

The model adopted for dairy cows was shown to be simpler compared to the model adopted for growing and finishing cattle (Equation 4.16; Figure 4.9). For this animal category, the pdNDF digestibility correlated negatively with the diet concentrate level ($r = -0.31$; $P<0.05$) and voluntary DM intake ($r = -0.36$; $P<0.04$). Negative correlation between the pdNDF digestibility coefficient and the CP concentration in the diet was also observed ($r = -0.47$; $P<0.01$). However, its inclusion did not result in a significant contribution to the fit of the equation, possibly because of the strong correlation between concentrate level and CP concentration in the diet ($r = 0.64$; $P<0.01$). In other words, the effects of the CP would be confounded with concentrate level in the diet. The greater simplicity of the model applicable to dairy cows is a possible reflection of the greater homogeneity of the diets offered to this animal category compared to those offered to growing and finishing cattle.

In general, increases in voluntary intake decreased pdNDF digestibility for reasons similar to those discussed for growing and finishing cattle (Figure 4.9). Similarly, the increase in concentrate content, expressed by an interaction with voluntary dry matter intake (Equation 4.16), has negative effects on fiber digestibility. However, these effects become larger as the level of concentrate and total intake increase. Higher concentrate and voluntary intake levels imply a greater NFC intake, compromising the conditions favorable to rumen fiber degradation due to the lower pH and greater competition between microbial species, as previously discussed.

The range of pdNDF digestibility coefficients obtained for dairy cows shows that the coefficient previously adopted for this animal category in the second edition of the BR-CORTE System (0.67) was underestimated for most dietary conditions.

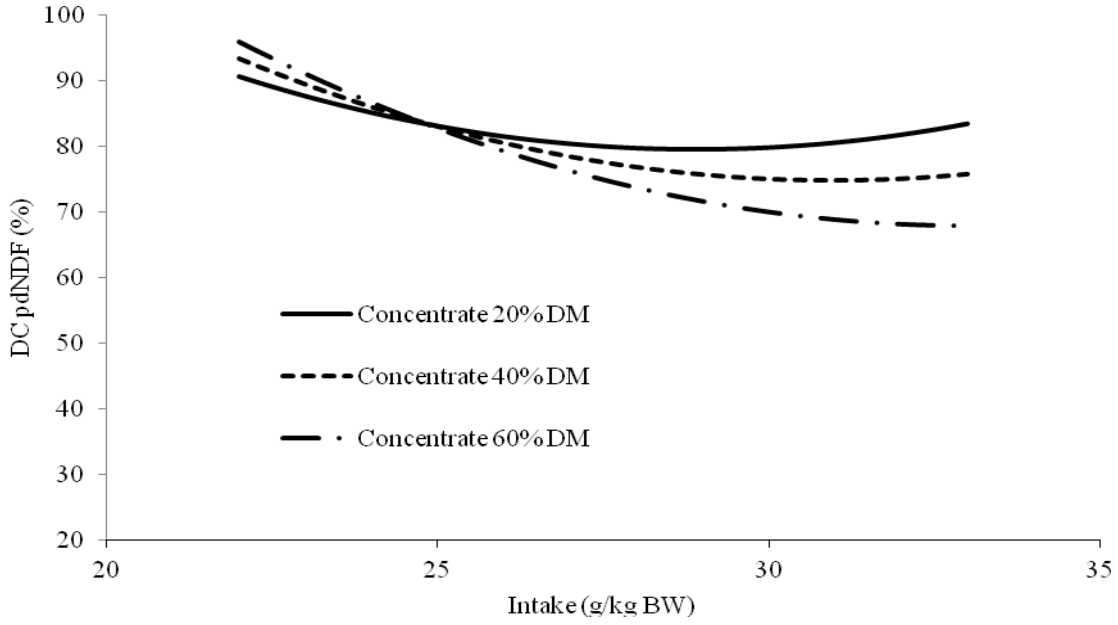


Figure 4.9 - Variations in the potentially digestible neutral detergent fiber digestibility coefficient (DC pdNDF) according to voluntary dry matter intake and concentrate level in diet for dairy cows (Equation 4.16).

Although equations (4.15) and (4.16) presented good fit (Figures 4.3 and 4.4), these models are based exclusively on experimental data and not on biological or theoretical bases. Therefore, even with good fit, the model should be considered specific for the conditions under which the data were obtained (Forbes and France, 1993) and their predictive value is restricted to the mathematical domain of the independent variables of each model. Thus, atypical diet combinations (e.g. diets containing corn silage with 22% iNDF and 15% CP for growing and finishing cattle) could produce biologically implausible pdNDF digestibility values. Especially for dairy cows, the conformation of the fitted model (Equation

4.16) indicates that it should not be applied for voluntary intakes greater than 32-34 g/kg body weight, because intakes greater than these were not observed in the dataset used for the meta-analytical assessments.

Although the meta-analytical approximation is based on the interpretation of empirical data, an intrinsic limitation is observed for this approximation. The fitted models require as input characteristics of the diet that are observed after their formulation (i.e., dietary contents of CP and iNDF, and concentrate levels in the diet). This makes the prediction process iterative, that is, the process of assessing the dietary energy starts from initial estimates for these variables supplied by the user. The output is assessed and used to back feed the model. The new solution obtained is again assessed and the cycle is repeated until the animal energy requirements and the energy supplied by the diet converge.

Thus, an alternative and more easily applied sub-model was developed (Equation 4.17) based on empirical information on the rumen dynamics of pdNDF assessed in cattle fed exclusively with forage (hereafter denoted as "empirical approximation"). Although data of animals fed with diets consisting of forage and concentrate are available, they were not used in order to develop a simplified sub-model that could be applied to individual feeds without needing information on the composition of the final diet. In addition, discrete adjustments regarding the animal categories were not contemplated in the empirical approximation, but were restricted to differences in the intake level and basal forage of the diet.

In this sense, the pdNDF degradation rate can be predicted from the voluntary DM intake (variable that can be estimated by the BR-CORTE System) by a positive and linear relationship. The positive association between the pdNDF degradation rate and voluntary intake (Equation 4.18; Figure 4.5) is based on the fact that the rumen fill effect of fiber, particularly its potentially degradable fraction, is negatively associated with its degradation rate in the rumen (Waldo et al., 1972; Detmann et al., 2015). Thus, it should be understood that the relationship expressed by Equation (4.18) is based on increase in diet quality.

The pdNDF passage rate of forage showed a simple, negative and curvilinear association with iNDF concentration in the basal forage of the diet, and this ratio was best described by a hyperbolic model (Equation 4.19; Figure 4.6). Although the iNDF and pdNDF fractions have different passage rates in the rumen (Lund et al., 2007), increase in the forage iNDF fraction increases the total rumen fill effect of NDF, because the iNDF fraction only disappears from the rumen by a single pathway (passage) and therefore, has lower turnover rate compared to the pdNDF fraction. In this way, both the equations fitted (Equations 4.18 and 4.19) present biological coherence with the idea of assessing pdNDF availability from integrating the rumen dynamics of transit and degradation (Equation 4.17).

However, the integration of transit and degradation refers only to the ruminal events and does not consider the possible utilization of pdNDF in the large intestine, which complements the total digestibility of this fraction. Thus, an intestinal digestibility adjustment factor (IAF) was adopted to compensate the post rumen digestive events. In the evaluated dataset, it was observed that, on average, 89% of the total pdNDF digestion took place in the rumen, that culminated in the adoption of IAF = 1.12 (1/0.89). This proportion was close to that suggested by other authors for non-tropical conditions (Huhtanen et al., 2010).

A limitation of the empirical approximation is the absence of data associated with the passage rate of concentrate pdNDF. This type of information is scarce in Brazil. Therefore, the fit for the concentrate passage rate was based on the pdNDF passage rate of the basal forage and on the rate of passages of fiber from concentrates and forages obtained by Bürger et al. (2000) (Equation 4.20). However, these adjustments may be modified as new information is obtained for Brazilian conditions.

As described previously for lactating cows (Figure 4.9), including concentrates in the diet can affect the digestibility coefficient of the pdNDF, particularly at the level of the rumen. This pattern shows there are effects associated with including concentrates that can affect the pdNDF degradation rate (NASEM, 2016). Alterations in the degradation rate can cause alterations in the fiber passage rate (Allen, 1996). However, such impacts are not

directly contemplated in the empirical approximation and their consideration in future approximations may increase the predictive capacity of the model.

As the pdNDF passage rate is estimated based on the iNDF concentration in basal forage, it would be impossible to obtain estimates for diets formulated exclusively with concentrates. As data of the rumen transit and degradation dynamics for this particular type of diet do not exist for Brazilian conditions, it was chosen to recommend the equation adopted by the NRC (2001) (Equation 4.21).

The structure of the sub-model adopted to estimate the truly digestible fraction of the CP was maintained in relation to the second edition of the BR-CORTE System (Equations 4.24 to 4.27). The only alterations made concerned the digestibility coefficients of the CP fraction associated with the cell content and cell wall. In the first case, for a better agreement to the estimates obtained with Brazilian data, this coefficient was altered from 0.98 to 0.95, converging to that which is applied to estimate the truly digestible NFC (Equation 4.10). Considering that the CP associated with the cell wall presents, by assumption, digestive pattern similar to that is observed for the fibrous portion of the feed/diet, its digestibility coefficients should be modified according to the sub-model used to estimate the pdNDF digestible fraction (Equations 4.15 to 4.21).

It is emphasized, however, that estimating the UNDIP from the ADIP was proposed to speed the prediction process (Detmann et al., 2010a). However, caution should still be maintained, because the UNDIP (biological analytical concept) and ADIP (chemical analytical concept) relationship is not very precise due to the high biological variability of the availability of nitrogen compounds associated with the fiber (Henriques et al., 2007; Detmann et al., 2010a). In this context, using the ADIP as predictive element should be understood only as chemical approximation, without any biological foundation being ascribed to its action on nitrogen compound digestibility.

To better understand the modifications in these sub-models regarding the second edition of the BR-CORTE System, a comparative assessment was performed using the chemical composition of forages (n = 16) and concentrates (n = 8) recorded in the CQBAL 3.0 dataset (Valadares Filho et al., 2015). The feeds were selected based on their routine use in cattle feeding, availability of all the items of chemical composition necessary to the estimation process, and the availability of observed TDN values. It is emphasized, however, that this validation process should be seen with caution, because the items regarding chemical composition can be derived from different sources and furthermore, the situations are not clear in which the TDN concentrations were assessed *in vivo*. The assessments are centered on the NDF and CP digestible fractions, because modifications were not established for the sub-models applied to estimate the EE and NFC digestible fractions.

Generally, marked differences were not observed among the meta-analytical and empirical approximations presented here or the sub-models adopted in the second edition of the BR-CORTE System for the NDF and CP digestible fraction values for concentrates. All the approximations produced TDN values close to those observed in the CQBAL 3.0 dataset (Figures 4.10 and 4.11).

However, marked differences were observed when forage samples were considered (Figure 4.10). The summative system adopted in the second edition of the BR-CORTE System tended to overestimate the TDN content in forages as a reflex of the higher estimates of the digestible NDF. As emphasized previously, the combination of using the fixed digestibility coefficient and a constant protection factor associated with lignin (Equation 4.12) tends to overestimate this fraction, especially in growing and finishing cattle. In this sense, the empirical approximation (Equations 4.17 to 4.20) produced lower NDF digestible fraction estimates (Figure 4.10), so that the TDN levels in forages were more similar to the values observed *in vivo* (Figure 4.11). On the other hand, the meta-analytical approximation (Equation 4.15) gave lower values of the digestible NDF, producing TDN values substantially lower than the values observed *in vivo*. Considering the similarity among all the approximations for the truly digestible fraction of the forage CP (Figure 4.10), the main

differences between approximations are in the process of estimating the NDF digestible fraction.

To better understand the differences between approximations, a simplified evaluation of the composition of prediction error was carried out based on derivations reported by Kobayashi and Salam (2000):

$$MSPE = \frac{1}{n}\sum_{i=1}^{n}(x_i - y_i)^2 \quad (4.33),$$

$$SB = (\bar{x} - \bar{y})^2 \quad (4.34),$$

$$MSV = MSPE - SB = \frac{1}{n}\sum_{i=1}^{n}[(x_i - \bar{x}) - (y_i - \bar{y})]^2 \quad (4.35),$$

where: MSPE, mean squared prediction error; x_i, predicted values (% DM); y_i, observed values (% DM); SB, squared bias; and MSV, mean squared variation.

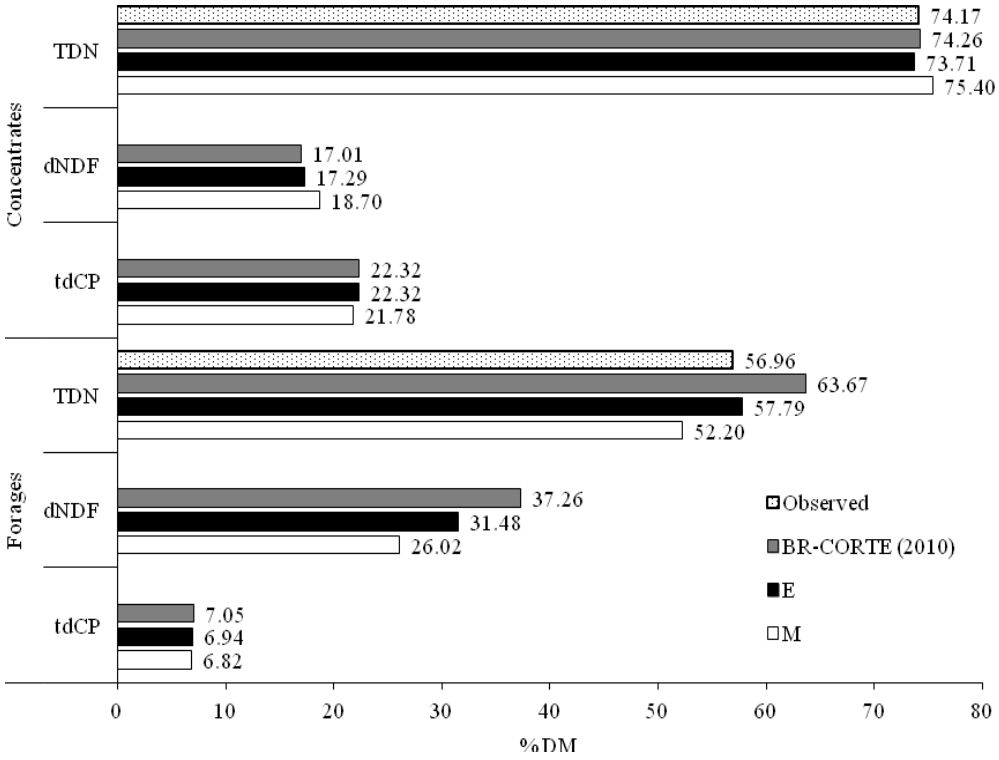


Figure 4.10 - Estimates of the truly digestible CP (tdCP), digestible NDF (dNDF) and the TDN content obtained by the sub-models adopted by the BR-CORTE (2010) and the meta-analytical (M) and empirical (E) approximations for growing and finishing cattle and TDN contents obtained from CQBAL 3.0 (forages, n = 16; concentrates, n = 8). The empirical and meta-analytical models considered intake of 22 g/kg body weight. For the meta-analytical model, a mean concentration was adopted of 12% CP and 14% iNDF in the diet. For the empirical and meta-analytical models applied to concentrates, corn silage was considered as the basal forage.

Due to the intrinsic limitation in the dataset obtained from the CQBAL 3.0, as previously mentioned, it was chosen not to carry out a more rigorous assessment of prediction error. The simplified partitioning used here (Equations 4.33 to 4.35) allowed the basic identification of the composition of the mean squared prediction error (MSPE) in relation to limitations in the accuracy (SB) or precision (MSV) of the models.

In this sense, the general assessment of the dataset showed that large gains in accuracy and precision were obtained only for forages because only a slight difference was observed regarding concentrate feeds (Figure 4.12).

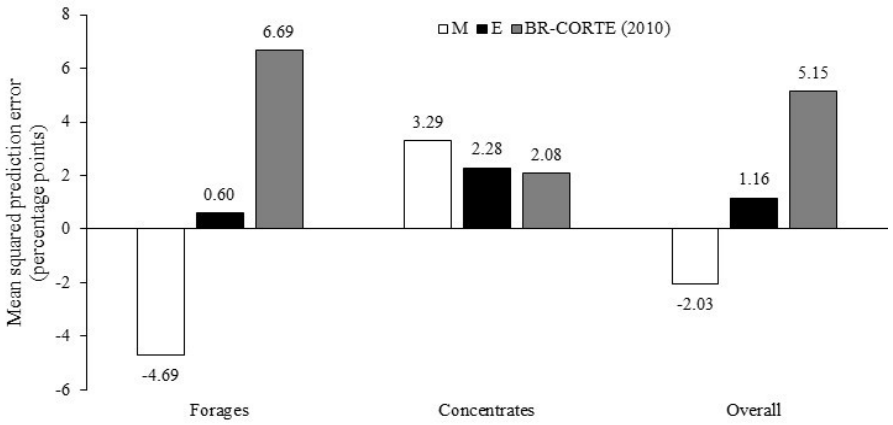


Figure 4.11 - Mean prediction error for TDN content (percentage points) in concentrate and forage feeds obtained by the sub-models adopted by the BR-CORTE (2010) and by the meta-analytical (M) and empirical (E) approximations for fiber and protein for growing and finishing cattle in relation to the mean TDN values observed according to data from CQBAL 3.0 (forages, n = 16; concentrates, n = 8). To verify the assumptions applied to each model, please consult Figure 4.10.

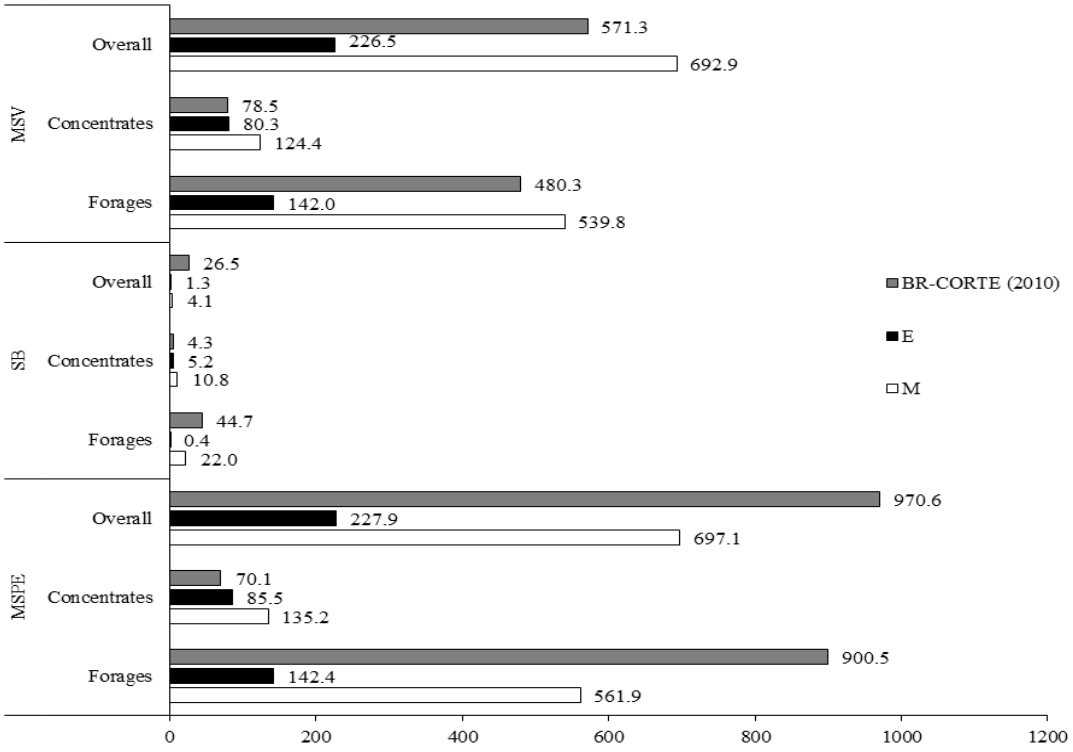


Figure 4.12 - Mean squared prediction error (MSPE), squared bias (SB) and mean squared variation (MSV) for the TDN contents in concentrate and forage feeds obtained by the sub-models adopted by the BR-CORTE (2010) and by the meta-analytical (M) and empirical (E) approximations for fiber and protein for growing and finishing cattle in relation to the mean TDN values observed according to data from CQBAL 3.0 (forages, n = 16; concentrates, n = 8). To verify the assumptions applied to each model, please consult Figure 4.10.

The empirical approximation produced more accurate estimates compared to the sub-models adopted in the second edition of the BR-CORTE System. The digestibility coefficient of the pdNDF for growing and finishing cattle previously adopted by the BR-CORTE System (0.84) was shown to be lower than the mean pdNDF digestibility for forage samples considering the empirical approximation (0.867). Even so, higher estimates were observed of the NDF digestible fraction, culminating in overestimation of the TDN concentration. This fact warns for the presence of positive biases in the pdNDF fraction estimation by Equation (4.12). However, the biggest gains were observed for the precision of the estimates, that, as emphasized previously, was the main limitation in the assessment of the digestible NDF (Detmann et al., 2007; 2008b; Azevêdo et al., 2011). Although the equations used for this approximation are relatively simple (Equations 4.17 to 4.20), considering the particularities of the basal forage (i.e., iNDF content) instead of constant coefficients for the pdNDF digestibility seems to have reflected in similar variations and stronger correlations with values observed *in vivo*. Thus, the empirical approximation was shown to be a more exact and precise alternative to replace the sub-model previously adopted by the BR-CORTE System to estimate the digestible NDF, with consequent applications on the CP digestible fraction.

Although developed from a large number of *in vivo* observations, the meta-analytical approximation showed limitations regarding accuracy (Figures 4.11 and 4.12) and precision (Figure 4.12) for TDN content in forage. This pattern could lead to its non-recommendation. However, it should be pointed out that the estimates of the digestible NDF and CP obtained by this approximation were based only on initial estimates for the end composition of the diet (Figures 4.10 and 4.11). As emphasized previously, using such approximation is an iterative process, in which sequential fits from the outputs are necessary to reach convergence between energy requirements and energy intake. Thus, it would be expected that the first output (obtained from initial values defined by the user) would produce low-precision estimates. In this way, the performance observed here for the meta-analytical approximation may not reflect its true characteristics. However, due to the lack of data, assessment procedures and mainly validation procedures of this approximation could not be developed, which would be recommended.

EXAMPLE OF APPLICATION

Productive Situation - growing and finishing Nellore cattle (feedlot).
Diet: forage:concentrate ratio 50:50 (dry matter basis), 12%CP.
Expected intake: 25 g DM/kg body weight.
Forage: corn silage.
Concentrate: mixture of corn grain (86.43% DM), soybean meal (10.07% DM), urea:ammonia sulfate (U:AS; 9:1) (1.5% DM) and mineral mixture (MM; 2.0% DM).

Table 4.4 - Chemical composition of the feeds and of the total diet (% DM)

Item	Silage	Ground corn	Soybean meal	U:AS	MM	Concentrate	Diet
DM	30.92	87.64	88.61	100	100	88.11	45.80
OM	94.74	97.60	92.85	100	0	95.20	94.97
CP	7.26	9.11	48.78	260	-	16.70	12.00
Ur	-	-	-	100	-	1.50	0.75
CPu	-	-	-	260	-	3.90	1.95
EE	3.16	4.07	1.71	-	-	3.69	3.43
NDFap	51.77	10.19	10.72	-	-	9.89	30.83
ADF	23.79	4.18	3.75			3.99	13.89
Lignin	4.97	1.16	1.33	-	-	1.14	3.06
NFC	32.55	74.23	31.64	-	-	67.34	49.95
NDIP	1.14	0.87	2.38	-	-	0.99	1.06
ADIP	0.57	0.35	1.34	-	-	0.44	0.51

Example A – meta-analytical approach to assess energy derived from NDF and CP

A.1. Calculation of the truly digestible EE fraction (Equation 4.9)

$$tdEE = 0.86 \times EE = 0.86 \times 3.43 = 2.95\%$$

A.2. Calculation of the truly digestible NFC fraction (Equation 4.10)

$$tdNFC = 0.95 \times NFC = 0.95 \times 49.95 = 47.45\%$$

A.3. Calculation of the digestible NDF fraction (Equations 4.11, 4.13, 4.14, and 4.15)

$$pdNDF(F) = 3.38 + 0.883 \times NDFap - 0.834 \times ADF + 0.0065 \times ADF^2 - 0.197 \times L$$
$$pdNDF(F) = 3.38 + 0.883 \times 51.77 - 0.834 \times 23.79 + 0.0065 \times (23.79^2) - 0.197 \times 4.97$$
$$pdNDF(F) = 31.95\%$$

$$pdNDF(C) = -1.19 - 10.16 \times D + 1.012 \times NDFap - 0.052 \times ADF$$
$$pdNDF(C) = -1.19 - 10.16 \times 0 + 1.012 \times 9.89 - 0.052 \times 3.99$$
$$pdNDF(C) = 8.61\%$$

$$pdNDF(Diet) = pdNDF(F) \times 0.5 + pdNDF(C) \times 0.5 = 31.95 \times 0.5 + 8.61 \times 0.5 = 20.28\%$$

iNDF(Diet) = NDFap – pdNDF = 30.83 – 20.28 = 10.55%

$$D_{GF} = 80.21 \times FOR - 0.0166 \times DMI^2 + 2.658 \times iNDF + 3.691 \times CP$$
$$+0.0507 \times (DMI \times iNDF) - 2.9673 \times (FOR \times iNDF) - 3.9990 \times (FOR \times CP)$$

D_{GF} = 80.21 x 0 – 0.0166 x 25^2 + 2.658 x 10.55 + 3.691 x 12 + 0.0507 x(25 x 10.55) – 2.9673 x (0 x 10.55) – 3.999x(0 x 12) = 75.33%

$$dNDF = D \times pdNDF$$
$$dNDF = 75.33\% \times 20.28 = 15.27\%$$

A.4. Calculation of the truly digestible CP fraction (Equations 4.15 and 4.26)

$$tdCP = tD_{CCCP} \times (CP - NDIP) + D_{pdCWCP} \times \{NDIP \times [1 - e^{-(0.8188 + 1.1676 \times ADIP)}]\}$$
$$tdCP = 0.95 \times (12.00 - 1.06) + 0.7533 \times \{1.06 \times [1 - e^{-(0.8188 + 1.1676 \times 0.51)}]\}$$
$$tdCP = 0.95 \times 10.94 + 0.7533 \times (1.06 \times 0.7569)$$
$$tdCP = 10.39 + 0.60 = 10.99\%$$

A.5. TDN Calculation (Equation 28d; Table 4.1)

$$TDN = tdCP + tdNFC + dNDF + 2.25 \times tdEE - FM_{TDN}$$
$$TDN = 10.99 + 47.45 + 15.27 + 2.25 \times 2.95 - 7.13$$
$$\boldsymbol{TDN = 80.35 - 7.13 = 73.22\%}$$

A.6. DE Calculation (Equation 4.29; Table 4.1)

$$DE = 0.056 \times tdCP + 0.042 \times tdNFC + 0.042 \times dNDF + 0.094 \times tdEE - FM_{DE}$$
$$DE = 0.056 \times 10.99 + 0.042 \times 47.45 + 0.042 \times 15.27 + 0.094 \times 2.95 - 0.322$$
$$= 3.205 \text{ Mcal/kg DM}$$

A.7. ME Calculation (Equation 4.30)

$$ME = 0.9422 \times DE - 0.303$$
$$ME = 0.9455 \times 3.205 - 0.303 = 2.727 \text{ Mcal/kg DM}$$

Example B – Empirical approach to assess the energy derived from NDF and CP

B.1. Calculation of the NDF digestible fraction (Equations 4.13, 4.14, 4.17, 4.18, 4.19b, and 4.20)

$$pdNDF(F) = 3.38 + 0.883 \times NDFap - 0.834 \times ADF + 0.0065 \times ADF^2 - 0.197 \times L$$
$$pdNDF(F) = 3.38 + 0.883 \times 51.77 - 0.834 \times 23.79 + 0.0065 \times (23.79^2) - 0.197 \times 4.97$$
$$pdNDF(F) = 31.95\%$$

$$pdNDF(C) = -1.19 - 10.16 \times D + 1.012 \times NDFap - 0.052 \times ADF$$
$$pdNDF(C) = -1.19 - 10.16 \times 0 + 1.012 \times 9.89 - 0.052 \times 3.99$$
$$pdNDF(C) = 8.61\%$$

$$kd = 0.00329 \times DMI = 0.00329 \times 25 = 0.0823$$

$$kp(F) = \frac{0.287}{iNDF(F)} = \frac{0.287}{(NDFap - pdNDF)} = \frac{0.287}{(51.77 - 31.95)} = 0.0145$$

$$kp(C) = kp(F) \times 1.8 = 0.0145 \times 1.8 = 0.0261$$

$$dNDF(F) = [(\frac{0.0823}{0.0823 + 0.0145}) \times 31.95] \times 1.12 = 30.42\%$$

$$dNDF(C) = [(\frac{0.0823}{0.0823 + 0.0261}) \times 8.61] \times 1.12 = 7.32\%$$

$$dNDF(Diet) = 0.5 \times dNDF(F) + 0.5 \times dNDF(C) = 0.5 \times 30.42 + 0.5 \times 7.32 = 18.87\%$$

B.2. Calculation of the truly digestible CP fraction (Equations 4.18, 4.19b, 4.20, and 4.27)

$$tdCP(F) = 0.95 \times (7.26 - 1.14) + \frac{0.0823}{0.0823 + 0.0145} \times \{1.14 \times [1 - e^{-(0.8188 + 1.1676 \times 0.57)}]\}$$
$$tdCP(F) = 0.95 \times 6.12 + 0.8502 \times (1.14 \times 0.7733)$$
$$tdCP(F) = 5.81 + 0.75 = 6.56\%$$
$$tdCP(C) = 0.95 \times (16.70 - 0.99) + \frac{0.0823}{0.0823 + 0.0261} \times \{0.99 \times [1 - e^{-(0.8188 + 1.1676 \times 0.44)}]\}$$
$$tdCP(C) = 0.95 \times 15.71 + 0.7592 \times (0.99 \times 0.7362)$$
$$tdCP(C) = 14.92 + 0.55 = 15.47\%$$

$$tdCP(Diet) = 0.5 \times tdCP(F) + 0.5 \times tdCP(C) = 0.5 \times 6.56 + 0.5 \times 15.47 = 11.02\%$$

B.3. TDN Calculation (Equation 4.28d; Table 4.1)

$$TDN = tdCP + tdNFC + dNDF + 2.25 \times tdEE - FM_{TDN}$$
$$TDN = 11.02 + 47.45 + 18.87 + 2.25 \times 2.95 - 7.13$$
$$\boldsymbol{TDN = 83.98 - 7.13 = 76.85\%}$$

B.4. DE Calculation (Equation 4.29; Table 4.1)

$$DE = 0.056 \times tdCP + 0.042 \times tdNFC + 0.042 \times dNDF + 0.094 \times tdEE - FM_{DE}$$
$$DE = 0.056 \times 11.02 + 0.042 \times 47.45 + 0.042 \times 18.87 + 0.094 \times 2.95 - 0.322$$
$$= 3.358 \text{ Mcal/kg DM}$$

B.5. ME Calculation (Equation 4.30)

$$ME = 0.9455 \times DE - 0.303$$
$$ME = 0.9455 \times 3.358 - 0.303 = 2.872 \text{ Mcal/kg DM}$$

FEED COMPOSITION TABLES

Tables of the chemical composition and energy content of selected feeds for growing and finishing cattle are presented below. The chemical composition data were taken from the CQBAL 3.0 dataset. The energy contents were estimated according to the equations described in Table 4.5.

Table 4.5 - Indication of equations used to estimate the energy content of the feeds listed in Tables 4.6 to 4.9

Fraction	Equations	Table
tdEE	9	-
tdNFC	10	-
NDFd	13, 14, 17, 18, 19b and 20	-
tdCP	18, 19b, 20 and 27	-
TDN	28d	4.1
DE	29	4.1
ME	30	-

To calculate the dNDF and tdCP fractions, a voluntary intake of 22 g DM/kg body weight was presumed. Specifically, for the calculation of these fractions in concentrate feeds, corn silage was considered as basal forage. In comparison, the TDN values were also calculated based on the second edition of the BR-CORTE System, but using the pdNDF digestibility coefficient suggested for dairy cows.

Due to the overestimation of TDN concentration caused by the sub-model applicable to the digestible NDF for growing and finishing cattle (Figures 4.10 and 4.11), the BR-CORTE System for dietary formulation (online version) uses the pdNDF digestibility coefficient for dairy cows as an alternative to obtain TDN values closer to those obtained *in vivo*. However, as emphasized before, the pdNDF digestibility coefficient for dairy cows adopted in the second edition of the BR-CORTE System (0.67) is underestimated, while the assessment of the pdNDF fraction from lignin using Equation (4.12) seems to generate overestimations. Thus the model would present negative bias for the digestibility coefficient and positive bias for pdNDF fraction size, that would indicate incoherence in its use.

Table 4.6 - Chemical composition and energy concentration in forages (*in natura* moist forages)

Items	Feeds											
	Alfalfa	Black oats	*Brachiaria brizantha* (0-30 d)	*Brachiaria brizantha* (91-120d)	*Brachiaria decumbens* (31-45 d)	*Brachiaria decumbens* (46-60 d)	Sugarcane	Coast cross	Cameroon elephant grass (61-90 d)	Tifton Grass 85	Tanzanian grass	Forage cactos
DM	25.30	19.43	17.15	27.72	22.39	27.14	28.77	32.62	16.68	26.96	23.31	11.30
OM	90.62	90.45	89.98	92.30	90.33	91.04	96.55	91.49	90.22	90.91	88.63	88.04
CP	90.97	18.78	12.32	4.80	11.66	9.39	2.76	12.03	8.89	12.91	9.45	4.24
EE	3.70	3.22	1.20	1.16	1.79	2.23	1.34	2.50	2.41	2.00	2.53	1.80
NFC	26.08	21.83	15.28	10.87	21.48	19.84	42.72	7.73	10.85	10.68	7.59	52.92
NDFap	39.87	46.62	61.18	75.47	55.40	59.58	49.73	69.23	68.07	65.32	69.06	29.08
ADF	26.63	27.41	34.68	42.87	28.19	36.76	33.52	35.78	43.91	36.91	41.58	18.61
Lig	7.47	4.06	4.44	6.41	3.82	5.18	5.86	6.13	7.10	7.49	5.89	4.93
ADIP	1.69	0.72	2.55	1.59	0.90	2.28	0.12	1.93	0.97	3.75	1.31	0.82
NDIP	4.99	5.28	3.00	3.87	5.14	3.38	0.46	5.81	2.56	6.81	3.30	1.40
TDN[1]	60.1	60.9	54.7	49.4	57.1	56.0	63.1	51.8	50.4	51.0	50.1	62.8
TDN[2]	62.2	60.5	55.5	54.0	58.2	56.8	63.0	56.7	53.4	55.5	52.7	63.2
DE[2]	2.86	2.75	2.47	2.30	2.56	2.48	2.66	2.51	2.33	2.47	2.31	2.68
ME[2]	2.39	2.29	2.02	1.88	2.12	2.04	2.21	2.07	1.90	2.03	1.88	2.23

[1] TDN calculated as described in BR-CORTE (2010) for dairy cows; [2] TDN, DE and ME calculated according to the new equation system (Table 4.5).

Table 4.7 - Chemical composition and energy concentration in conserved forages (hays and silages)

Items	Hays					Silages						
	Alfafa	Oats	*Brachiaria brizantha*	*Brachiaria decumbens*	Coast cross	Tifton 85	Sugarcane	Elephant grass	Corn	Soybean	Sorghum	Tifton (pre-dried)
DM	89.32	87.42	87.95	88.68	88.90	88.94	26.12	27.70	31.11	25.83	29.76	47.76
OM	88.38	91.82	93.30	93.26	92.91	92.20	95.14	90.29	94.23	91.78	93.59	91.12
CP	18.77	11.96	4.13	6.64	8.57	9.69	3.77	5.47	7.24	17.79	6.45	16.62
EE	2.85	1.77	1.22	1.77	1.48	1.55	1.71	2.23	2.84	9.45	2.53	2.41
NFC	23.77	27.93	8.82	6.64	10.14	9.92	27.64	15.32	33.81	15.43	26.02	10.60
NDFap	42.99	50.16	79.13	78.21	72.72	71.04	62.02	67.27	50.34	49.11	58.59	61.49
ADF	37.52	41.13	49.59	46.52	40.59	38.72	43.03	48.71	30.26	35.69	31.27	32.00
Lig	9.74	7.04	7.26	6.82	6.05	6.13	8.13	7.47	4.87	8.91	5.10	4.76
ADIP	2.14	2.15	0.36	0.80	1.75	1.16	0.38	0.76	0.87	1.95	0.93	1.14
NDIP	3.94	3.63	0.58	3.83	3.45	4.74	0.61	1.19	1.31	3.11	2.37	5.53
TDN[1]	54.0	56.8	49.2	49.3	51.8	51.0	55.5	50.5	63.3	62.8	59.2	55.4
TDN[2]	55.1	56.2	53.7	54.2	55.8	55.4	58.0	52.5	63.2	65.1	61.2	57.8
DE[2]	2.53	2.49	2.29	2.33	2.43	2.42	2.46	2.25	2.72	2.94	2.62	2.61
ME[2]	2.09	2.05	1.86	1.90	1.99	1.98	2.03	1.83	2.27	2.48	2.18	2.17

[1] TDN calculated as described in BR-CORTE (2010) for dairy cows; [2] TDN, DE and ME calculated according to the new equation system (Table 4.5).

Table 4.8 - Chemical composition and energy concentration in energy concentrates

Items	Feeds								
	Oats (grain)	Soybean hulls	Rice meal	Wheat bran	Millet (grain)	Corn (grain)	Sorghum (grain)	Citric pulp	Cassava scraps
DM	90.44	90.30	89.03	87.97	88.95	87.91	88.12	88.45	87.66
OM	93.59	94.18	89.17	93.32	94.19	97.54	97.87	91.72	95.83
CP	14.06	12.73	13.22	17.13	13.35	9.05	9.67	6.93	2.80
EE	3.82	2.20	16.32	3.51	4.49	4.02	2.94	3.11	0.45
NFC	48.09	15.88	39.02	33.07	53.95	72.48	73.90	60.36	78.97
NDFap	27.62	63.37	20.60	39.61	22.40	11.99	11.36	21.32	13.61
ADF	22.92	49.15	11.88	13.19	7.21	4.00	6.07	20.76	7.19
Lig	3.51	3.64	4.49	3.80	1.41	1.18	1.80	1.84	1.64
ADIP	0.14	2.29	0.55	0.94	1.40	0.18	0.05	0.08	0.47
NDIP	1.57	5.61	1.81	0.28	2.41	1.39	0.87	2.72	0.64
TDN[1]	72.2	69.5	83.7	68.5	77.7	83.8	82.8	76.1	79.7
TDN[2]	80.4	74.8	81.0	71.2	82.9	86.6	86.0	78.0	81.6
DE[2]	3.53	3.27	3.54	3.20	3.63	3.73	3.71	3.33	3.44
ME[2]	3.04	2.79	3.04	2.72	3.13	3.22	3.21	2.84	2.95

[1] TDN calculated as described in BR-CORTE (2010) for dairy cows; [2] TDN, DE and ME calculated according to the new equation system (Table 4.5).

Table 4.9 - Chemical concentration and energy concentration in protein concentrates

Items	Feeds								
	Cottonseed	Cotton meal 38%	Cotton cake	Sunflower meal	Gluten 21 meal	Glutenose	Peanut meal	Soybean meal	Soybean (grain)
DM	90.76	89.92	90.68	91.06	88.77	90.57	89.23	88.57	90.88
OM	95.78	91.07	95.14	93	92.20	96.81	92.47	92.89	93.71
CP	22.99	39.63	29.74	31.81	23.93	63.90	58.38	48.71	38.46
EE	19.32	1.43	9.43	1.94	2.78	2.73	0.40	1.86	19.05
NFC	7.71	20.55	10.05	10.76	29.79	23.93	11.50	28.86	20.78
NDFap	45.76	29.46	45.92	48.49	35.70	6.25	22.19	13.46	15.42
ADF	35.24	22.94	34.92	34.64	10.68	3.75	10.96	9.47	12.12
Lig	7.39	3.66	9.68	5.40	1.19	0.26	2.22	1.62	2.29
ADIP	2.06	1.05	1.67	0.91	0.25	2.13	1.12	0.39	2.67
NDIP	3.33	3.38	5.73	4.22	3.09	4.48	3.13	2.78	6.51
TDN[1]	84.9	67.0	71.04	67.5	70.2	85.75	74.0	76.86	94.99
TDN[2]	87.0	66.7	84.73	66.5	77.3	84.84	77.8	79.25	96.47
DE[2]	3.92	3.29	3.91	3.18	3.52	4.38	3.45	3.94	4.51
ME[2]	3.40	2.81	3.39	2.70	3.03	3.84	2.96	3.42	3.97

[1] TDN calculated as described in BR-CORTE (2010) for dairy cows; [2] TDN, DE and ME calculated according to the new equation system (Table 4.5).

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5

Prediction of body and carcass composition of beef cattle

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INTRODUCTION

The nutrients required by cattle depend on the animals' body composition. The methods utilized to predict body composition can be classified as direct and indirect. Direct methods consist of separating and dissecting all body components and then quantifying physical and chemical components. Thereby, experiments conducted using direct methods become extremely laborious, slow, and expensive due to the loss of at least half of the carcass besides the number of people and laboratory analyses involved. However, indirect methods predict body composition from simple parameters without the need for carcass dissection.

Several indirect methods have been developed. A method used to estimate body water and ether extract (EE) from specific gravity was developed by Kraybill et al. (1952) and, during the 1990´s, it was used by researchers in Brazil (Gonçalves et al., 1991; Peron et al., 1993; Lanna et al., 1995; Alleoni et al., 1997). However, this method did not result in adequate estimates for animals raised under Brazilian conditions (Lanna et al., 1995; Alleoni et al., 1997). Other techniques utilizing tools such as antipyrine, titrated water, N-acetyl-amine-antipyrine (Panaretto and Till, 1963), urea dilution (Preston and Kock, 1973) and ^{40}K (Clark et al., 1976) were not widely used in Brazil due to their complexity, high cost, and lack of equipment and/or experienced people. In this context, the most utilized indirect method in Brazil is that first proposed by Hankins and Howe (1946), which equations were developed to estimate carcass and empty body composition based on the composition of the section between the 9th and 11th ribs. This technique is widely used due to its ease of use, reduced cost involved, and speed of the process. Several groups reported positive results when this technique was used (Silva, 2001; Henrique et al., 2003; Paulino et al., 2005a).

THE USE OF THE SECTION BETWEEN THE 9th AND 11th RIBS

Studies during the 1920´s (Trowbridge and Haigh, 1921; Trowbridge and Haigh, 1922; Moulton, 1923; Lush, 1926) evaluated several carcass cuts to estimate carcass physical composition. It was concluded that the ribs region presented the best relationship with the carcass composition. Then, Hankins and Howe (1946) evaluated the use of different carcass cuts to predict the physical and chemical composition of cattle carcass and also developed a technique to obtain a carcass sample between the 9th and 11th ribs (HH section; Figure 5.1).

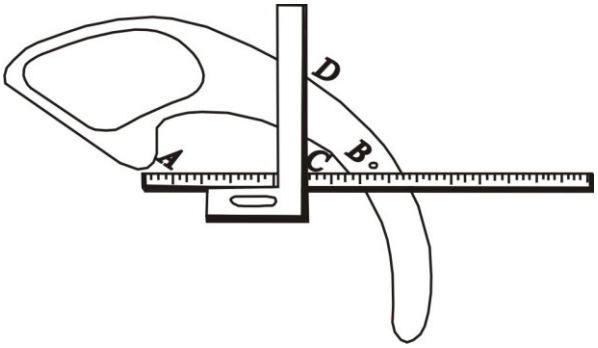


Figure 5.1 - Method developed by Hankins and Howe (1946) for collecting the section between the 9th and 11th ribs. The rib section can be obtained in carcasses hanging by transverse foramen located in the pelvis. First, a cut splitting the section between the 9th and 11th ribs is performed. Next, the distance between the split vertebra (point A) and the cartilage or "bottom" of the rib is measured (point B), and 61.5% of this distance is calculated (point C). Further, a perpendicular line is erected, and the separation is made where this line intersects the external circumference (point D).

CHEMICAL AND PHYSICAL COMPOSITION OF THE CARCASS AND EMPTY BODY CHEMICAL COMPOSITION

Prediction equations for carcass physical and chemical composition were first proposed by Hankins and Howe (1946) from the database of *Bos taurus taurus* steers and heifers. Thus, equations for each sex and a general equation were defined (Table 5.1).

Table 5.1 - Prediction equations for physical and chemical composition of carcass from the composition of the section between 9th and 11th ribs cut proposed by Hankins and Howe (1946)

Item	Sex	Equation[1]
Carcass physical composition		
Fat, %	General	% Fcarc = 3.06 + 0.82 × % F_{HH}
	Steers	% Fcarc = 3.54 + 0.80 × % F_{HH}
	Heifers	% Fcarc = 3.14 + 0.83 × % F_{HH}
Muscle, %	General	% Mcarc = 15.56 + 0.81 × % M_{HH}
	Steers	% Mcarc = 16.08 + 0.80 × % M_{HH}
	Heifers	% Mcarc = 16.09 + 0.79 × % M_{HH}
Bone, %	General	% Bcarc = 4.30 + 0.61 ×% B_{HH}
	Steers	% Bcarc = 5.52 + 0.57 × % B_{HH}
	Heifers	% Bcarc = 6.88 + 0.44 × % B_{HH}
Carcass chemical composition		
Ether extract, %	General	% EEcarc = 2.82 + 0.77 × % EE_{HH}
	Steers	% EEcarc = 3.49 + 0.74 × % EE_{HH}
	Heifers	% EEcarc = 2.73 + 0.78 × % EE_{HH}
Crude protein, %	General	% CPcarc = 5.98 + 0.66 × % CP_{HH}
	Steers	% CPcarc = 6.19 + 0.65 × % CP_{HH}
	Heifers	% CPcarc = 5.64 + 0.69 × % CP_{HH}
Water, %	General	% Wcarc = 14.90 + 0.78 × % W_{HH}
	Steers	% Wcarc = 16.83 + 0.75 × % W_{HH}
	Heifers	% Wcarc = 14.28 + 0.78 × % W_{HH}

[1]Fcarc = fat in the carcass; F_{HH} = fat in the HH section; Mcarc = muscle in the carcass; M_{HH} = muscle in the HH section; Bcarc = bone in the carcass; B_{HH} = bone in the HH section; EEcarc = ether extract in the carcass; EE_{HH} = ether extract in the HH section; CPcarc = crude protein in the carcass; CP_{HH} = crude protein in the HH section; Wcarc = water in the carcass; W_{HH} = water in the HH section.

Hankins and Howe (1946) equations have been widely used due to the ease of obtaining the HH section. Some studies (Cole et al., 1962; Powell and Huffman, 1973; Crouse and Dikeman, 1974; Nour and Thonney, 1994) evaluated these equations, however, presented distinct results. These differences may be related to the fact that the carcass chemical composition equations were developed from the soft tissue composition, while the bone composition was not considered.

Some researchers have tried to predict the chemical composition of the carcass and empty body of beef cattle from the chemical composition of the whole HH section (Peron et al., 1993; Jorge et al., 2000; Ferreira et al., 2001; Véras et al., 2001). In this case, samples of muscle, adipose, and bone tissues from the dissection of HH section were chemically analyzed and used to estimate the carcass chemical composition. However, the carcass physical composition was estimated from the equations proposed by Hankins and Howe (1946). Thereby, carcass chemical composition was estimated from the chemical composition of HH section, while the empty body composition was determined by the sum of carcass and non-carcass compositions. As the carcass is the main quantitative component of the empty body, most of these studies concluded that the chemical composition of the empty body could be predicted from the chemical composition of HH section.

Nevertheless, other studies (Silva, 2001; Paulino et al., 2005a; Costa e Silva et al., 2013) reported that this premise could not be completely accurate, mainly regarding the carcass content of EE. Thus, considerable efforts were made to establish more accurate predictive equations for carcass and empty body composition of beef cattle in the previous editions of this publication.

Equations to predict carcass and empty body chemical composition based on the HH section composition were developed for Zebu cattle in the first edition of the BR-CORTE (BR-CORTE, 2006). For this, a database composed of the chemical composition of the 66 animals from two studies was used (Paulino, 2002; Paulino, 2006; Table 5.2).

Table 5.2 - Equations based on the 9th to 11th rib section composition for estimating the chemical composition of the carcass and empty body of Zebu cattle, adapted from BR-CORTE (2006)

Item	Equation[1]	Standard error	R^2
Carcass chemical composition			
Ether extract	% EEcarc = 4.96 + 0.54 ×% EE_{HH}	2.22	0.80
Crude protein	% CPcarc = 4.05 + 0.78 ×% CP_{HH}	1.00	0.72
Ash	% Acarc = 2.88 + 0.50 ×% A_{HH}	0.66	0.40
Water	% Wcarc = 34.97 + 0.45 ×% W_{HH}	1.94	0.66
Empty body chemical composition			
Ether extract	% EE_{EBW} = 4.56 + 0.60 ×% EE_{HH}	2.37	0.81
Crude protein	% CP_{EBW} = 4.96 + 0.76 ×% CP_{HH}	0.90	0.75
Ash	% A_{EBW} = 2.54 + 0.39 ×% A_{HH}	0.47	0.45
Water	% W_{EBW} = 31.42 + 0.51 ×% W_{HH}	1.94	0.71

[1]EEcarc = ether extract in the carcass; CPcarc = crude protein in the carcass; Acarc = ash in the carcass; Wcarc = water in the carcass; EE_{HH} = ether extract in the HH section; CP_{HH} = crude protein in the HH section; A_{HH} = ash in the HH section; W_{HH} = water in the HH section; EE_{EBW} = ether extract in the empty body composition; CP_{EBW} = crude protein in the empty body composition; A_{EBW} = ash in the empty body composition; W_{EBW} = water in the empty body composition.

Marcondes et al. (2010; 2012) developed equations to predict chemical and physical compositions of the carcass and the empty body using the composition of the 9th to 11th rib section and other measurements of purebred (Nellore) and crossbred (Nellore × Angus and Nellore × Simmental) Zebu cattle (Tables 5.3 and 5.4), which were previously described in the second edition of the BR-CORTE (BR-CORTE, 2010). The database comprised the body composition of 247 bulls, steers, and heifers from six experiments conducted in feedlot.

According to Marcondes et al. (2012), the use of additional variables in models, as well as considering the effect of genetic group and sex provided better estimates of carcass and empty body compositions. It is noteworthy that the proportion of visceral fat (VF; composed by the mesenteric, renal, pelvic, and cardiac fat) was significant to predict most of the carcass and empty body constituents.

Body composition, mainly the fat fraction, and growth development, vary according to several factors, such as feeding level, genetic group, and sex. Although the feeding level influences body composition and growth (Prior et al., 1977; Ferrell et al., 1978; Nour et al., 1981; Williams et al., 1983; Nour and Thonney, 1987), its inclusion in the predictive equations is difficult and this information is not always available. According to Butterfield (1966), VF is correlated with animal metabolism and is relatively constant even during feeding challenges. Hence, it probably best represents body fat content. Thus, the use of VF along with other predictive variables in the equations might be very important for their applicability.

Table 5.3 - Prediction equations for physical and chemical composition of the carcass and chemical composition of empty body of purebred and crossbred Zebu cattle, adapted from Marcondes et al. (2010; 2012)

Variable	GG/Sex[1]	Equation[2]	R^2	RSME[3]
Carcass physical composition				
Fat*	-	% Fcarc = a + 0.30 × % F_{HH} + b × % VF	0.79	3.01
Muscle	Nellore	% Mcarc = 57.33 + 0.20 × % M_{HH} -1.39 × % VF	0.51	2.97
	Nellore × Simmental			
	Nellore × Angus	% Mcarc = 60.96 + 0.12 × % M_{HH} -1.39 × % VF		
Bone	Nellore	% Bcarc = 29.26 + 0.30 × % B_{HH} - 0.21 × HCY - 0.95 × % VF	0.77	1.43
	Nellore × Simmental			
	Nellore × Angus	% Bcarc = 29.26 + 0.30 × % B_{HH} - 0.21 × HCY - 1.01 × % VF		
Carcass chemical composition				
EE	-	% EEcarc = 4.31 + 0.31 × % EE_{HH} + 1.37 × % VF	0.83	2.13
CP	-	% CPcarc = 17.92 + 0.60 × % CP_{HH} - 0.17 × HCY	0.50	1.26
Water	Nellore	% Wcarc = 48.74 + 0.28 × % W_{HH} - 0.017 × EBW	0.67	2.27
	Nellore × Angus	% Wcarc = 38.06 + 0.48 × % W_{HH} - 0.017 × EBW		
	Nellore × Simmental	% Wcarc = 46.69 + 0.32 × % W_{HH} - 0.017 × EBW		
Empty body chemical composition				
EE	Bulls	% EE_{EBW} = 2.75 + 0.33 × % EE_{HH} + 1.80 × % VF	0.89	1.97
	Steers**	% EE_{EBW} = 1.84 + 0.33 × % EE_{HH} + 1.91 × % VF		
	Heifers	% EE_{EBW} = 4.77 + 0.33 × % EE_{HH} + 1.28 × % VF		
CP	-	% CP_{EBW} = 10.78 + 0.47 × % CP_{HH} - 0.21 × % VF	0.59	1.03
Water	Bulls	% W_{EBW} = 38.31 + 0.33 × % A_{HH} - 1.09 × % VF + 0.50 × % OV	0.82	1.96
	Steers**	% W_{EBW} = 45.67 + 0.25 × % A_{HH} - 1.89 × % VF + 0.50 × % OV		
	Heifers	% W_{EBW} = 31.61 + 0.47 × % A_{HH} - 1.06 × % VF + 0.50 × % OV		

[1]GG = genetic group; [2]Fcarc = fat in the carcass; F_{HH} = fat in the HH section; Mcarc = muscle in the carcass; M_{HH} = muscle in the HH section; Bcarc = bone in the carcass; B_{HH} = bone in the HH section; EEcarc = ether extract in the carcass; EE_{HH} = ether extract in the HH section; EE_{EBW} = ether extract in the empty body; % VF = percentage of mesenteric fat plus renal, pelvic, and cardiac fat in the empty body; CPcarc = crude protein in the carcass; CP_{HH} = crude protein in the HH section; HCY = hot carcass yield (%); CP_{EBW} = crude protein in the empty body; Wcarc = water in the carcass; W_{HH} = water in the HH section; EBW = empty body weight; W_{EBW} = water in the empty body; % OV = percentage of organs and viscera in the empty body; [3]RSME = root square mean of error.
*There was effect of sex for the intercept while there was interaction between sex and breed for the coefficient related to %VF where the deployment of this interaction can be seen in Table 5.4.
**The new equations for Nellore x Angus steers are presented in the section "Evaluation of the equations proposed by Hankins and Howe (1946), BR-CORTE (2006) and BR-CORTE (2010)".

Table 5.4 - Deployment of the effect of sex on the intercept and interaction between sex and breed on the coefficient related to the percentage of mesenteric fat plus renal, pelvic, and cardiac fat (VF)

Sex	Genetic group	Intercept	Coefficient related to VF
Bulls	Nellore	0.689	1.18
	Nellore × Angus		1.20
Steers	Nellore	5.259	0.38
	Nellore × Angus		0.43
	Nellore × Simmental		0.74
Heifers	Nellore	0.471	1.53
	Nellore × Angus		1.98
	Nellore × Simmental		2.34

EVALUATION OF THE EQUATIONS PROPOSED BY HANKINS AND HOWE (1946), BR-CORTE (2006), AND BR-CORTE (2010)

Body composition of Zebu bulls and crossbred beef cattle (bulls and steers)

Costa e Silva et al. (2013) concluded that the equations proposed by Marcondes et al. (2012) adequately estimate the carcass physical composition of Nellore bulls. Likewise, Fonseca et al. (2014) concluded that the equations proposed by Marcondes et al. (2012) estimated adequately the muscle and adipose tissues of F1 Nellore × Angus bulls and steers. However, Costa e Silva et al. (2013) did not recommend any of the equations proposed by Hankins and Howe

(1946) for predicting the carcass physical composition, whereas Fonseca et al. (2014) reported that none of the equations proposed by Hankins and Howe (1946) or Marcondes et al. (2012) correctly estimated the amount of bones of F1 Nellore × Angus cattle.

Moreover, some early studies conducted in Brazil concluded that the equations developed by Hankins and Howe (1946) were not fully applicable to predict carcass and empty body chemical composition of purebred (*Bos taurus indicus*) and crossbred (*Bos taurus indicus* × *Bos taurus taurus*) cattle (Lana et al., 1995; Silva, 2001; Paulino et al., 2005b).

Likewise, Costa e Silva et al. (2013) and Fonseca et al. (2014) evaluated whether the equations proposed by Hankins and Howe (1946), BR-CORTE (2006) and Marcondes et al. (2012) correctly estimate the carcass and empty body chemical composition of Zebu cattle and their crosses. Costa e Silva et al. (2013) did not recommend the use of the equations proposed by the BR-CORTE (2006) or Hankins and Howe (1946) for predicting carcass and empty body chemical composition of Nellore bulls, while reported that the equations proposed by Marcondes et al. (2012) presented accurate estimates.

Fonseca et al. (2014), utilizing data from F1 Nellore × Angus bulls and steers, verified that the equations proposed by Marcondes et al. (2012) showed superior estimates for carcass and empty body chemical composition, except for the water content in the empty body. As water is calculated by difference, this component is susceptible to the accumulation of errors from other analyses (Costa e Silva et al., 2013).

Fonseca et al. (2014) also observed that the EE content in empty body was correctly predicted by Marcondes et al. (2012) equations only when bulls and steers were analyzed separately. Additional evaluation performed by these authors showed that the equation did not require any adjustment for predicting the EE content in the empty body of bulls, whereas a reparameterization with fatter steers would improve the predictions of the EE content in the empty body for such animals.

As the equations proposed by Marcondes et al. (2012) were not sufficiently adjusted to estimate the EE and water contents in the empty body of crossbred beef steers (Fonseca et al., 2014), new equations for predicting the EE and water contents in such animals were developed and evaluated in the last edition of this publication (BR-CORTE, 2016). For this, a new database was built utilizing data from Marcondes et al. (2012) and Fonseca et al. (2014) to estimate the EE content, whereas the new equation for predicting the water content was derived from the same data used by Marcondes et al. (2012). Thus, the estimates of EE and water contents in the empty body of crossbred beef steers were readjusted using the cross-validation procedure (Duchesne and MacGregor, 2001). Twenty percent of the data from each study were randomly separated for validation of the EE equation, while an independent experiment was utilized for validation of the water equation. The equations proposed and validated can be seem below:

$$\% EE_{EBW} = 2.797 + 0.289 \times \% EE_{HH} + 2.056 \times \% VF$$
$$(R^2 = 0.84; RSME = 2.51),$$

where EE_{EBW} = ether extract content in the empty body, EE_{HH} = ether extract content in the 9^{th} to 11^{th} rib section, and VF = visceral fat (mesenteric, renal, pelvic, and cardiac fat).

$$\% W_{EBW} = 30.77 + 0.48 \times \% W_{HH} - 1.07 \times \% VF + 0.50 \times \% OV$$
$$(R^2 = 0.88; RSME = 2.42)$$

where W_{EBW} = water content in the empty body, W_{HH} = water content in the 9^{th} to 11^{th} rib section, VF = visceral fat (mesenteric, renal, pelvic, and cardiac fat), and OV = organs and viscera content in the empty body.

The inclusion of new predictive variables such as VF and organs and viscera (OV) improved the estimates of carcass and empty body chemical composition of purebred Zebu bulls and crossbred Zebu bulls and steers. Thus, the carcass and empty body equations recommended in the third edition of BR-CORTE (BR-CORTE, 2016) were kept in the current edition. It may avoid the complete dissection of the half-carcass and decrease the costs and labor involved in studies of nutrient requirements for beef cattle (Costa e Silva et al., 2013).

Body composition of Zebu cattle (steers and heifers)

The goodness of fit of the prediction equations suggested by Hankins and Howe (1946), BR-CORTE (2006), and BR-CORTE (2010) to predict the carcass and empty body chemical composition of Zebu steer and heifers was evaluated in the last edition of this publication (BR-CORTE, 2016). For this, individual information of 32 Nellore heifers and 18 Nellore steers from a study by Costa e Silva (2015) was utilized (Table 5.5).

Table 5.5 - Description of data utilized to evaluate the equations for body composition of Nellore steers (n = 18) and heifers (n = 32)

Item	Mean	SD[1]	Maximum	Minimum
Steers				
Empty body weight, kg	168	39.5	260	109
Carcass weight, kg	101	24.5	160	65.4
Organs + viscera, % EBW	14.1	1.56	17.5	11.7
VF[2], % EBW	3.02	0.93	4.63	1.73
Ether extract in the EBW, %	9.83	1.60	12.7	7.52
Crude protein in the EBW, %	18.7	0.78	20.0	17.0
Water in the EBW, %	67.7	1.16	69.6	65.5
Ether extract in the carcass, %	10.6	1.55	13.4	7.55
Crude protein in the carcass, %	18.5	0.94	20.3	16.9
Water in the carcass, %	66.2	1.61	68.8	62.0
Ether extract in the HH section, %	12.2	2.69	17.4	6.06
Crude protein in the HH section, %	18.9	1.77	21.8	15.8
Water in the HH section, %	64.1	1.52	65.8	58.8
Heifers				
Empty body weight, kg	190	40.4	266	104
Carcass weight, kg	116	24.8	162	62.6
Organs + viscera, % EBW	14.8	0.99	16.81	13.1
VF[2], % EBW	3.93	0.88	5.83	1.65
Ether extract in the EBW, %	13.1	2.38	18.9	7.45
Crude protein in the EBW, %	18.5	0.75	20.4	17.1
Water in the EBW, %	64.9	2.49	70.0	60.4
Ether extract in the carcass, %	13.0	2.36	18.1	8.23
Crude protein in the carcass, %	18.5	0.90	21.3	16.6
Water in the carcass, %	64.3	2.59	69.0	59.5
Ether extract in the HH section, %	15.2	2.91	20.4	9.12
Crude protein in the HH section, %	17.5	1.52	20.1	14.3
Water in the HH section, %	62.7	1.73	67.1	59.9

[1]SD = standard deviation; [2]VF = mesenteric fat plus renal, pelvic, and cardiac fat.

Briefly, all equations correctly estimated the crude protein (CP) content in the carcass, whereas only the equations recommended by the BR-CORTE (2010) correctly estimated the carcass contents of EE and water of Zebu steers and heifers (Table 5.6).

Furthermore, the BR-CORTE (2010) equations accurately and precisely estimated all chemical contents in the empty body evaluated, whereas the equations proposed by BR-CORTE (2006) presented inconsistencies in the intercept and/or slope of the linear regression (Table 5.7). Therefore, the predictive equations of carcass and empty body chemical compositions of Zebu steers and heifers first described in the second edition of BR-CORTE (BR-CORTE, 2010) were recommended in the last edition of this publication and kept in the current edition.

Table 5.6 - Means (kg) and descriptive statistics of the relationship between observed and predicted values of the carcass chemical composition of growing Nellore steers and heifers

Item	Crude protein				Ether extract				Water			
	Obs[1]	HH	B06	B10	Obs	HH	B06	B10	Obs	HH	B06	B10
Mean	19.9	19.3	19.4	19.7	14.0	15.7	14.2	15.5	71.1	70.0	69.6	69.4
Standard deviation	4.36	3.79	3.75	3.78	5.61	5.47	4.57	5.41	14.9	15.43	15.6	15.0
Maximum	28.7	27.4	27.5	28.1	29.4	25.0	22.1	27.8	104	103	101	99.3
Minimum	11.9	11.8	11.8	12.0	4.94	6.19	6.28	5.93	42.9	41.7	40.8	41.2
R	-	0.94	0.92	0.95	-	0.92	0.93	0.94	-	0.99	0.99	0.99
CCC[2]	-	0.92	0.90	0.94	-	0.87	0.91	0.90	-	0.99	0.98	0.98
Regression												
Intercept												
Estimate	-	-0.96	-0.92	-1.75	-	-0.84	-2.29	-1.09	-	4.25	5.26	2.67
Standard error	-	1.17	1.33	1.05	-	0.97	0.96	0.86	-	1.47	1.39	1.43
P value[3]	-	0.42	0.49	0.10	-	0.39	0.02	0.21	-	0.006	0.0004	0.07
Slope												
Estimate	-	1.08	1.07	1.10	-	0.94	1.14	0.97	-	0.96	0.95	0.99
Standard error	-	0.06	0.07	0.05	-	0.06	0.06	0.05	-	0.02	0.02	0.02
P value[4]	-	0.19	0.29	0.07	-	0.32	0.03	0.58	-	0.04	0.008	0.49
MSE[5]	-	2.67	3.11	1.88	-	8.02	4.54	6.19	-	6.41	7.26	7.09
Mean bias	-	0.34	0.23	0.03	-	3.11	0.07	2.38	-	1.33	2.29	2.88
Systematic bias	-	0.09	0.07	0.13	-	0.10	0.42	0.02	-	0.46	0.69	0.04
Random error	-	2.24	2.80	1.71	-	4.81	4.05	3.79	-	4.62	4.27	4.17

[1]Obs – observed values; HH – values predicted by equations from Hankins and Howe (1946); B06 – values predicted by equations from BR-CORTE (2006); B10 – values predicted by equations from BR-CORTE (2010). [2]CCC – concordance correlation coefficient; [3]H_0: $\beta_0=0$. [4]H_0: $\beta_1=1$. [5]MSE = mean square error.

Table 5.7 - Means (kg) and descriptive statistics of the relationship between observed and predicted values of empty body chemical composition from growing Nellore steers and heifers

Item	Crude protein			Ether extract			Water		
	Obs[1]	B06	B10	Obs	B06	B10	Obs	B06	B10
Mean	33.7	33.7	33.4	22.1	24.0	25.2	117	113	113
Standard deviation	6.10	5.49	5.50	8.73	7.80	9.06	23.1	23.8	23.2
Maximum	46.8	45.9	45.7	41.6	37.5	42.6	171	165	158
Minimum	19.9	20.3	20.2	7.77	10.4	8.93	72.9	68.4	70.1
R	-	0.95	0.97	-	0.94	0.96	-	0.99	0.98
CCC[2]	-	0.94	0.96	-	0.91	0.91	-	0.98	0.97
Regression									
Intercept									
Estimate	-	-1.79	-2.24	-	-3.14	-1.34	-	8.25	6.69
Standard error	-	1.94	1.47	-	1.41	1.02	-	2.19	3.38
P value[3]	-	0.36	0.14	-	0.03	0.19	-	0.001	0.053
Slope									
Estimate	-	1.05	1.08	-	1.05	0.93	-	0.96	0.98
Standard error	-	0.06	0.04	-	0.06	0.04	-	0.02	0.03
P value[4]	-	0.35	0.09	-	0.36	0.06	-	0.06	0.40
MSE[5]	-	3.79	2.43	-	12.6	16.0	-	26.8	35.7
Mean bias	-	0.0002	0.08	-	3.65	10.1	-	17.1	15.0
Systematic bias	-	0.08	0.17	-	0.16	0.42	-	0.74	0.33
Random error	-	3.70	2.17	-	8.75	5.44	-	9.04	20.4

[1]Obs – observed values; B06 – values predicted by the equations from BR-CORTE (2006); B10 – values predicted by the equations from BR-CORTE (2010). [2]CCC – concordance correlation coefficient; [3]H_0: $\beta_0=0$. [4]H_0: $\beta_1=1$. [5]MSE = mean square error.

CHEMICAL COMPOSITION OF CARCASS AND EMPTY BODY OF CROSSBRED DAIRY CATTLE

The carcass and empty body chemical composition described in the first and second editions of this publication (BR-CORTE, 2006 and 2010) were obtained from a database of Zebu (mainly Nellore) and beef crossbred cattle (Nellore × *Bos taurus taurus*), respectively.

Prados (2012), evaluating the suitability of these equations for predicting the body composition of crossbred dairy cattle (¼ Holstein × ¾ Zebu bulls), verified that the CP content in the empty body was adequately estimated by the BR-CORTE (2010) equation, whereas the equations proposed by the BR-CORTE (2006) correctly estimated the EE and water contents in the empty body. Likewise, Neves (2013) observed that the equations proposed by Hankins and Howe (1946) accurately estimated the CP content in the carcass and the CP and water contents in the empty body of Holstein × Zebu bulls. Also, this author concluded that equations proposed by the BR-CORTE (2010) were not adequate to estimate the carcass and empty body chemical composition of Holstein × Zebu bulls.

The presence of the Holstein breed in the genotype of the animals used in these studies, may have resulted in a different growth and conformation pattern when compared to breeds selected for beef production and their crossbreds. Thus, the prediction equations of carcass and empty body compositions presented reduced goodness of fit.

In this context, new predictive equations of body composition of crossbred dairy cattle were proposed in the last edition of this publication (BR-CORTE, 2016). For this, a database comprising individual information of 80 bulls, 56 steers, and 44 heifers from five experiments (Prados, 2012; Neves, 2013; Zanetti, 2014; Rodrigues, 2014; Silva, 2015) was utilized (Table 5.8).

Table 5.8 - Description of data used to generate equation for body composition for crossbred dairy cattle from the composition of the section between the 9th and the 11th rib cut

Item	Mean	SD[1]	Maximum	Minimum
Empty body weight, kg	311	82.5	529	118
Carcass weight, kg	188	51.8	345	68.3
Non-carcass component weight, kg	117	29.4	224	50.0
Organs and viscera, kg	59.3	21.0	124	20.9
VF[2], kg	16.4	7.59	46.2	2.25
Crude protein in the HH section, %	17.2	2.22	25.5	8.70
Ether extract in the HH section, %	19.8	6.54	36.5	3.01
Ash in the HH section, %	5.24	2.36	10.9	0.68
Water in the HH section, %	57.4	6.13	74.3	42.3
Crude protein in the carcass, %	17.3	1.96	21.7	12.1
Ether extract in the carcass, %	16.5	4.24	30.6	7.47
Ash in the carcass, %	4.43	1.27	7.90	1.60
Water in the carcass, %	61.7	3.45	69.6	54.6
Crude protein in the empty body, %	17.8	1.63	21.5	14.7
Ether extract in the empty body, %	16.1	4.27	28.0	4.84
Ash in the empty body, %	3.90	1.11	6.47	1.51
Water in the empty body, %	62.0	3.75	71.8	52.7

[1]SD = standard deviation; [2]VF = mesenteric fat plus renal, pelvic, and cardiac fat.

Using the *cross-validation* procedure (Duchesne and MacGregor, 2001), the effect of animal was considered in the statistical analyses which allowed the generation of a single equation for each component evaluated (CP, EE, and water). The equations developed are described in Table 5.9.

Table 5.9 - Prediction equations for carcass and empty body chemical composition for crossbred dairy cattle

Item	Equations[1]	R^2
Carcass chemical composition		
Ether extract	% EEcarc = 4.54 + 0.48 × % EE_{HH} + 0.12 × % OV	0.66
Crude protein	% CPcarc = 18.38 + 0.16 × % CP_{HH} – 0.20 × % OV	0.53
Water	% Wcarc = 55.67 + 0.21 × % W_{HH} – 0.021 × EBW	0.40
Empty body chemical composition		
Ether extract	% EE_{EBW} = 3.53 + 0.34 × % EE_{HH} + 0.80 × % VF + 0.10 × % OV	0.73
Crude protein	% CP_{EBW} = 19.92 + 0.086 × % CP_{HH} – 0.19 × % OV	0.58
Water	% W_{EBW} = 53.02 + 0.17 × % W_{HH} – 1.28 × % VF + 0.27 × % OV	0.47

[1]EEcarc = ether extract in the carcass; EE_{HH} = ether extract in the HH section; OV = percentage of organs and viscera in the empty body; CPcarc = crude protein in the carcass; VF = percentage of mesenteric fat plus renal, pelvic, and cardiac fat in the empty body; CP_{HH} = crude protein in the HH section; Wcarc = water in the carcass; W_{HH} = water in the HH section; EBW = empty body weight, kg; EE_{EBW} = ether extract in the empty body; CP_{EBW} = crude protein in the empty body; W_{EBW} = water in the empty body.

Silva et al. (2021) evaluated the goodness of fit of the prediction equations developed by Hankins and Howe (1946) and the BR-CORTE (2016) to predict the carcass and empty body chemical composition of crossbred dairy cattle. An independent database composed by 33 Holstein × Zebu steers were utilized. Briefly, CP and EE chemical contents in the carcass, and all chemical components in the empty body were precisely and accurately estimated by the BR-CORTE (2016) equations. However, water content in the carcass was better predicted by Hankins and Howe (1946) equation.

The BR-CORTE (2016) equations were developed using a database composed by Holstein × Zebu animals, which probably resulted in the best goodness of fit for CP and EE content in the carcass and the correct estimation of all chemical components in the empty body. Therefore, the BR-CORTE (2016) equations can be used to predict CP and EE in the carcass, as well as all chemical components in the empty body of Holstein × Zebu steers.

PREDICTION OF BODY MINERAL COMPOSITION

The equations recommended in the second edition of BR-CORTE (BR-CORTE, 2010) for predicting empty body mineral composition were based on Marcondes et al. (2009) study in which the mineral composition (calcium, phosphorus, sodium, potassium, and magnesium) of the section between the 9th and the 11th ribs was utilized as the predictive variable (Table 5.10).

Marcondes et al. (2009) verified a high correlation coefficient between the mineral composition of the HH section and the empty body (Table 5.10). However, Costa e Silva (2012) observed that the equations generated by Marcondes et al. (2009) did not correctly estimate the body macromineral composition (Ca, P, Mg, Na, and K) of Nellore bulls (Table 5.11).

In this way, a new database was developed in the last edition of this publication (BR-CORTE, 2016) aiming to develop new predictive equations of the mineral composition of the empty body of beef cattle (Table 5.12). Individual data of Zebu cattle were obtained from Marcondes et al. (2009) and Costa e Silva (2015), whereas the mineral composition of crossbred beef cattle were taken from Marcondes (2010) and Souza (2010) studies. Data from Rodrigues (2014) and Zanetti (2014) were utilized to estimate mineral composition for crossbred dairy cattle.

A meta-analysis was performed to develop equations for predicting the body macromineral composition (Ca, P, Mg, Na, and K) of Zebu, crossbred beef and dairy cattle (Table 5.13).

Table 5.10 - Prediction equations of macromineral composition in the empty body for beef cattle from the mineral composition of the section between the 9th and the 11th ribs (Adapted from Marcondes et al., 2009)

Item	Equation[1]	R^2
Calcium	$\% Ca_{EBW} = 0.7334 + 0.5029 \times \% Ca_{HH}$	0.71
Phosphorus	$\% P_{EBW} = 0.3822 + 0.4241 \times \% P_{HH}$	0.70
Magnesium	$\% Mg_{EBW} = 0.0096 + 0.6260 \times \% Mg_{HH}$	0.73
Sodium	$\% Na_{EBW} = 0.1111 + 0.2886 \times \% Na_{HH}$	0.31
Potassium	$\% K_{EBW} = 0.0357 + 0.6732 \times \% K_{HH}$	0.60

[1]Ca_{EBW} = calcium in the empty body; Ca_{HH} = calcium in the HH section; P_{EBW} = phosphorus in the empty body; P_{HH} = phosphorus in the HH section; Mg_{EBW} = magnesium in empty body; Mg_{HH} = magnesium in the HH section; Na_{EBW} = sodium in the empty body; Na_{HH} = sodium in the HH section; K_{EBW} = potassium in the empty body; K_{HH} = potassium in the HH section.

Table 5.11 - Means (kg) and descriptive statistics of the relationship between the observed and predicted values of mineral composition in the empty body of Nellore bulls

Item	Calcium		Phosphorus		Magnesium		Sodium		Potassium	
	Obs[1]	Predicted	Obs	Predicted	Obs	Predicted	Obs	Predicted	Obs	Predicted
Mean	4.37	3.00	2.83	2.91	0.12	0.14	0.42	0.39	0.60	0.41
Standard deviation	1.03	0.67	0.60	0.80	0.03	0.03	0.09	0.12	0.16	0.13
Maximum	7.15	4.66	4.25	5.47	0.17	0.20	0.61	0.68	0.90	0.71
Minimum	2.24	1.93	1.91	1.77	0.06	0.08	0.28	0.18	0.33	0.22
r	-	0.76	-	0.67	-	0.75	-	0.68	-	0.85
CCC[2]	-	0.31	-	0.64	-	0.62	-	0.62	-	0.46
Regression										
Intercept										
Estimate	-	0.85	-	1.35	-	0.03	-	0.22	-	0.19
Standard error	-	0.52	-	0.28	-	0.01	-	0.04	-	0.04
P-value[3]	-	0.11	-	< 0.001	-	0.03	-	< 0.001	-	< 0.001
Slope										
Estimate	-	1.17	-	0.51	-	0.63	-	0.53	-	1.01
Standard error	-	0.17	-	0.09	-	0.09	-	0.10	-	0.10
P-value[4]	-	0.32	-	< 0.001	-	< 0.001	-	< 0.001	-	0.92
MSE[5]	-	2.31	-	0.35	-	< 0.001	-	0.009	-	0.043
Mean bias	-	1.86	-	0.01	-	< 0.001	-	0.001	-	0.037
Systematic error	-	0.01	-	0.15	-	< 0.001	-	0.003	-	0.001
Random error	-	0.44	-	0.19	-	< 0.001	-	0.005	-	0.007

[1]Obs – observed values; [2]CCC – concordance correlation coefficient; [3]H_0: $\beta_0=0$. [4]H_0: $\beta_1=1$. [5]MSE = mean standard error.

Table 5.12 - Description of data used to generate equations to predict mineral composition of Zebu, crossbred beef and dairy cattle

Item	Mean	SD[1]	Maximum	Minimum
Zebu cattle (n=133)				
Empty body weight, kg	272	102	549	104
Ash in the HH section, %	5.56	1.63	10.3	2.74
Calcium in the empty body, %	2.23	0.90	4.75	0.89
Phosphorus in the empty body, %	0.77	0.18	1.26	0.41
Magnesium in the empty body, %	0.04	0.01	0.08	0.02
Sodium in the empty body, %	0.12	0.02	0.18	0.08
Potassium in the empty body, %	0.17	0.02	0.26	0.10
Crossbred beef cattle (n=117)				
Empty body weight, kg	344	82.6	506	192
Ash in the HH section, %	6.29	1.29	9.68	1.79
Calcium in the empty body, %	1.51	0.29	3.19	1.04
Phosphorus in the empty body, %	0.72	0.12	0.98	0.48
Magnesium in the empty body, %	0.04	0.01	0.07	0.03
Sodium in the empty body, %	0.13	0.03	0.21	0.08
Potassium in the empty body, %	0.21	0.03	0.41	0.14
Crossbred dairy cattle (n=80)				
Empty body weight, kg	318	67.9	510	195
Ash in the HH section, %	3.90	2.55	8.06	0.68
Calcium in the empty body, %	1.32	0.25	1.77	0.59
Phosphorus in the empty body, %	0.71	0.18	1.10	0.20
Magnesium in the empty body, %	0.03	0.01	0.05	0.02
Sodium in the empty body, %	0.14	0.02	0.17	0.10
Potassium in the empty body, %	0.20	0.05	0.28	0.11

Table 5.13 - Prediction equations for macromineral composition (Ca, P, Mg, Na, and K) in the empty body for Zebu, crossbred beef and dairy cattle

Item	Equation[1]	R^2
Zebu cattle		
Calcium	$\%\ Ca_{EBW} = 1.4557 + 0.2362 \times \%\ ASH_{HH} - 0.00223 \times EBW$	0.80
Phosphorus	$\%\ P_{EBW} = 1.0068 - 0.00099 \times EBW$	0.10
Magnesium	$\%\ Mg_{EBW} = 0.02859 + 0.001721 \times \%\ ASH_{HH} - 0.00001 \times EBW$	0.54
Sodium	$\%\ Na_{EBW} = 0.1213 + 0.002116 \times \%\ ASH_{HH} - 0.00002 \times EBW$	0.51
Potassium	$\%\ K_{EBW} = 0.1942 + 0.000833 \times \%\ ASH_{HH} - 0.0001 \times EBW$	0.22
Crossbred beef cattle		
Calcium	$\%\ Ca_{EBW} = 1.7028 + 0.04638 \times \%\ ASH_{HH} - 0.00142 \times EBW$	0.52
Phosphorus	$\%\ P_{EBW} = 0.4619 - 0.0404 \times \%\ ASH_{HH}$	0.49
Magnesium	$\%\ Mg_{EBW} = 0.02418 + 0.00196 \times \%\ ASH_{HH}$	0.34
Sodium	$\%\ Na_{EBW} = 0.1205 + 0.002747 \times \%\ ASH_{HH} - 0.00002 \times EBW$	0.56
Potassium	$\%\ K_{EBW} = 0.1636 + 0.007102 \times \%\ ASH_{HH}$	0.35
Crossbred dairy cattle		
Calcium	$\%\ Ca_{EBW} = 1.2445 + 0.0506 \times \%\ ASH_{HH} - 0.00035 \times EBW$	0.58
Phosphorus	$\%\ P_{EBW} = 0.7279 + 0.0333 \times \%\ ASH_{HH} - 0.00048 \times EBW$	0.58
Magnesium	$\%\ Mg_{EBW} = 0.0406 - 0.00106 \times \%\ ASH_{HH}$	0.06
Sodium	$\%\ Na_{EBW} = 0.1454 + 0.00064 \times \%\ ASH_{HH}$	0.05
Potassium	$\%\ K_{EBW} = 0.1411 + 0.01478 \times \%\ ASH_{HH}$	0.79

[1] Ca_{EBW} = calcium in the empty body; ASH_{HH} = ash in the HH section; EBW = empty body weight (kg); P_{EBW} = phosphorus in the empty body; Mg_{EBW} = magnesium in the empty body; Na_{EBW} = sodium in the empty body; K_{EBW} = potassium in the empty body.

The R^2 estimates for most minerals as a function of genetic group were considered satisfactory. However, the estimates of R^2 were close to zero for phosphorus and potassium in Zebu cattle, magnesium and potassium in crossbred beef cattle, and magnesium and sodium in crossbred dairy cattle, indicating that there is a tendency of constancy of these minerals in the empty body of such animals. However, it is important to highlight that these equations still need to be evaluated with an independent database to properly evaluate the effect of genetic group.

NON-CARCASS CHEMICAL COMPOSITION

As previously described, the prediction equations based on the composition of the 9th to 11th rib section for empty body chemical composition presented a better adjustment when compared with those for carcass chemical composition (Table 5.4). However, if the researcher utilizes the equations of carcass chemical composition or if the determination of the real carcass composition by dissection is required, the composition of the remaining body components (blood, hide, limbs, head, organs, and viscera) will need to be determined to ascertain the empty body chemical composition.

The determination of non-carcass chemical composition implicates, necessarily, in greater cost, time, and labor, once there are at least 4 more samples to be chemically analyzed (blood, hide, limbs + head, and organs + viscera) per animal. Carcass yield may range from 60 to 65% of the empty body weight (EBW; Costa et al., 2005; Missio et al., 2009). Thus, all non-carcass components would represent from 35 to 40% of the EBW. Hence, knowing the non-carcass chemical composition is important due to its contribution to the EBW composition.

In this context, Costa e Silva et al. (2012), aiming to reduce labor and experimental costs, developed predictive equations of the chemical composition of non-carcass components (blood, hide, limbs + head, and organs + viscera). A database composed of individual information of 335 Zebu, crossbred beef and dairy cattle were utilized. The study effect was accounted for, as well as the effects of genetic group and sex on the non-carcass components composition were evaluated during the statistical analysis.

Costa e Silva et al. (2012) observed that an adjustment for predicting the chemical composition of each non-carcass component (blood, hide, limbs, head, organs, and viscera) was necessary, and it would consequently result in too many predictive equations. Thus, to reduce the number of equations generated and simplify the estimates, the non-carcass components were grouped as head + limbs, hide + blood, and organs + viscera and new equations were generated, and previously described in the second edition of BR-CORTE (BR-CORTE, 2010).

The goodness of fit of prediction equations described by BR-CORTE (2010) were evaluated by Costa e Silva et al. (2013). These authors verified that the CP content of hide + blood was correctly estimated, whereas the EE and water equations presented adjustment problems (reproducibility and precision). In relation to head + limbs, the equations accurately estimated all chemical contents evaluated. Also, only the EE content in organs + viscera was correctly estimated. Thus, it was concluded that new equations should be developed, or so, instead of dividing the non-carcass components in three groups (hide + blood, head + limbs, and organs + viscera), a composite sample could be analyzed and generate a single equation for each chemical constituent.

In this sense, a database (Table 5.14) composed by the composition of non-carcass of 231 Zebu, 94 beef crossbred, and 180 dairy crossbred cattle (bulls, steers, and heifers) obtained from 19 thesis and dissertations (Moraes, 2006; Souza, 2009; Marcondes, 2007; Marcondes, 2010; Chizzotti, 2007; Porto, 2009; Gionbelli, 2010; Paixão, 2008; Paulino, 2006; Machado, 2009; Costa e Silva, 2011; Costa e Silva, 2015; Valente, 2013; Fonseca, 2013; Silva, 2015; Prados, 2012; Rodrigues, 2014; Zanetti, 2014; Neves, 2013) was utilized for developing new non-carcass equations in the last edition of this publication (BR-CORTE, 2016).

Table 5.14 - Description of data used to generate equations to predict non-carcass chemical composition of Zebu, crossbred beef and dairy cattle (n = 505)

Item[1]	Mean	SD[2]	Maximum	Minimum
Empty body weight, kg	302	92.2	549	80.7
Non-carcass component weight (NC), kg	112	34.0	224	31.6
Crude protein in the NC, kg	20.7	7.42	53.3	4.42
Ether extract in the NC, kg	20.4	12.5	69.9	1.89
Water in the NC, kg	65.4	17.5	134	22.5
Calcium in the NC, kg	0.80	0.62	3.57	0.04
Phosphorus in the NC, kg	0.31	0.26	1.76	0.02
Magnesium in the NC, g	16.5	8.28	50.0	2.37
Sodium in the NC, g	149	79.3	426	36.8
Potassium in the NC, g	134	62.8	324	31.4

[1]NC = non-carcass; [2]SD = standard deviation.

The prediction equations of non-carcass chemical composition were generated from the meta-analysis using the NLMIXED procedure, in which the dependent variables were regressed as a function of EBW. Also, the effects of sex and genetic group were tested, where only sex was significant for all constituents, except phosphorus and magnesium (Tables 5.15 and 5.16).

Nevertheless, they still need to be evaluated with an independent database to be widely and reliably adopted for predicting the non-carcass chemical composition for Zebu, crossbred beef and dairy cattle.

Table 5.15 - Prediction equations for non-carcass chemical composition for Zebu, crossbred beef and dairy cattle

Item	Sex	Equations[1]
Crude protein	Bulls	$CP_{NC} = 0.1675 \times EBW^{0.8434}$
	Steers	$CP_{NC} = 0.5263 \times EBW^{0.6452}$
	Heifers	$CP_{NC} = 1.2411 \times EBW^{0.4921}$
Ether extract	Bulls	$EE_{NC} = 3.7171 \times \exp^{(0.004936 \times EBW)}$
	Steers	$EE_{NC} = 4.8911 \times \exp^{(0.004671 \times EBW)}$
	Heifers	$EE_{NC} = 3.5533 \times \exp^{(0.006199 \times EBW)}$
Water	Bulls	$W_{NC} = 1.5768 \times EBW^{0.6547}$
	Steers	$W_{NC} = 3.1486 \times EBW^{0.5242}$
	Heifers	$W_{NC} = 7.3003 \times EBW^{0.3865}$

[1]CP_{NC} = crude protein in the non-carcass components (kg); EBW = empty body weight (kg); EE_{NC} = ether extract in the non-carcass components (kg); W_{NC} = water in the non-carcass components (kg).

Table 5.16 - Prediction equations for macromineral composition of non-carcass components for Zebu, crossbred beef and dairy cattle

Item	Sex	Equations
Calcium	Bulls	$Ca_{NC} = 43.71 \times EBW^{0.3510}$
	Steers	$Ca_{NC} = 5.176 \times EBW^{0.8772}$
	Heifers	$Ca_{NC} = 69.36 \times EBW^{0.4342}$
Phosphorus	-	$P_{NC} = 2.262 \times EBW^{0.4522}$
Magnesium	-	$Mg_{NC} = 10.99 \times EBW^{0.1736}$
Sodium	Bulls	$Na_{NC} = 73.65 \times EBW^{0.1181}$
	Steers	$Na_{NC} = 3.264 \times EBW^{0.6916}$
	Heifers	$Na_{NC} = 23.04 \times EBW^{0.3544}$
Potassium	Bulls	$K_{NC} = 96.43 \times EBW^{0.0673}$
	Steers	$K_{NC} = 5.147 \times EBW^{0.5781}$
	Heifers	$K_{NC} = 31.54 \times EBW^{0.2821}$

[1]Ca_{NC} = calcium in the non-carcass components (g); EBW = empty body weight (kg); P_{NC} = phosphorus in the non-carcass components (g); Mg_{NC} = magnesium in the non-carcass components (g); Na_{NC} = sodium in the non-carcass components (g); K_{NC} = potassium in the non-carcass components (g).

RELATIONSHIP BETWEEN FAT-FREE DRY MATTER AND BODY COMPOSITION

Reid et al. (1955) suggested that body EE content could be estimated from the body water content. The authors also indicated that the protein to ash ratio (protein:ash) in the body would be constant in the fat-free dry matter, being only influenced by the animal age. In this context, Marcondes et al. (2010) studied the relationship between fat-free dry matter and EBW composition utilizing a database with 272 cattle. As there were no effects of genetic group or sex on the regression parameters, Marcondes et al. (2010) proposed the following equation to estimate EE in the empty body based on water content:

$$\%EE_{EBW} = 236.21 - 126.25 \times \log (W_{EBW}) + 1.114 \times \%VF$$
$$(R^2 = 0.96; RSME = 1.26),$$

where EE_{EBW} = ether extract content in the empty body, W_{EBW} = water content in the empty body, VF = mesenteric fat, plus renal, pelvic, and cardiac fat content in the empty body.

Knowing the proportion of fat in the empty body, the protein concentration in the fat-free dry matter can be estimated as a function of the empty body mass. However, differently to Reid et al. (1955) that correlated protein:ash with age, Marcondes et al. (2010) correlated protein:ash with EBW. This happened because age can be a relative measurement of body composition, as different nutritional plans can result in different body composition at the same age. Thus, the following equation suggested by Marcondes et al. (2010) can alternatively be utilized:

$$\%\ CPFFDM_{EBW} = 74.09 + 0.0098 \times EBW,$$

where $CPFFDM_{EBW}$ = crude protein content in the empty body on a fat-free dry matter basis and EBW = empty body weight (kg). The ash content (%) in the empty body on a fat-free dry matter basis can be estimated as 100 – CP.

NEW METHODS TO PREDICT BODY COMPOSITION OF CATTLE

Techniques that do not require slaughtering the animal to obtain its body composition have been studied. Such techniques may be useful for cattle sorting in feedlots, reducing differences within pens regarding nutrient requirements or carcass standard, as well as to define the best time for slaughter.

Composition obtained from DXA

The use of dual energy X-ray absorptiometry (DXA) is an alternative technique to indirectly determine cattle body composition. Its application is common in human medicine aiming to evaluate the mineral composition of bone as well as fat and muscle mass. Thus, some studies have evaluated its usefulness for indirect determination of cattle carcasses composition.

In this way, Prados et al. (2016), utilizing a database with 116 observations (96 Nellore bulls and 20 Nellore × Angus bulls), developed equations (Table 5.17) to estimate the composition of the section between the 9th and the 11th ribs based on DXA measurements (GE Lunar Prodigy Advance Dxa System, GE Healthcare, Madison, Wisconsin, USA). After scanning, the rib sections were dissected, and their chemical compositions were compared to the DXA parameters.

Table 5.17 - Prediction equations of the chemical composition of the section between the 9th and the 11th ribs using dual-energy X-ray absorptiometry (DXA)

Variable[1]	Equations[2]	R^2
Ether extract	$EE_{HH} = 122.40 + 1.12 \times F_{DXA}$	0.86
Fat free tissue	$FF_{HH} = 103.22 + 0.87 \times FF_{DXA}$	0.93
Lean tissue	$LT_{HH} = 37.08 + 0.91 \times LT_{DXA}$	0.95
Ash	$A_{HH} = 18.72 + 1.02 \times BMC_{DXA}$	0.39

[1]EE_{HH} = ether extract in the HH section; F_{DXA} = fat measured by DXA; Fat free tissue = lean tissue added with ash content in the bone, FF_{HH} = fat free in the HH section (water + protein + ash); FF_{DXA} = fat free measured by DXA (LT_{DXA} + BMC_{DXA}); LT_{HH} = lean tissue in the HH section; LT_{DXA} = lean tissue measured by DXA; A_{HH} = ash in the HH section; BMC_{DXA} = bone mineral content measured by DXA; [2]All variables in grams. (Adapted from Prados et al., 2016).

Prados et al. (2016) concluded that the equations generated were accurate and are recommended for predicting the chemical composition of the section between the 9th and the11th ribs of Nellore and Nellore × Angus cattle. However, the authors also highlighted that more studies would be needed to evaluate the use of DXA to estimate carcass composition.

More recently, Godoi (2021) developed equations for predicting carcass and empty body composition based on the composition of different carcass sections and DXA measurements. For this, the half-carcass of 15 Nellore heifers was divided into seven sections (S1 to S7): S1 - longitudinal cut after the second rib; S2 - longitudinal cut after the section eighth rib; S3 - section between the 9th and 11th ribs (Hankins and Howe, 1946); S4 - the remaining section after the removal of S3; S5 - twelfth rib; S6 - longitudinal cut after the sacrum; and S7 - the remaining section after the removal of S1 to S6 (Figure 5.1).

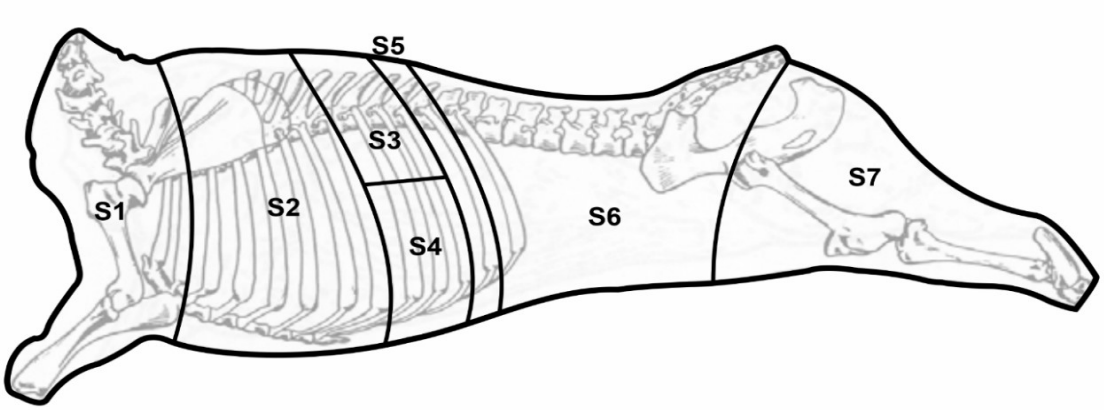


Figure 5.1 - Description of the carcass sections evaluated for predicting carcass and empty body composition of Nellore heifers, adapted from Godoi (2021).

After the scanning and obtention of DXA parameters (DXA lean mass, DXA fat mass, and DXA bone mineral content (BMC), each section was dissected into muscle, fat, and bones, and its physical composition was recorded. The muscle, fat and bones of all sections were summed to obtain the carcass physical composition. The muscle + fat and bone samples of each section were analyzed for CP, EE, and MM to obtain their chemical composition. After that, the full carcass chemical composition was calculated based on the chemical composition of each section and its relative proportions on each carcass. Samples of non-carcass components were obtained and chemically analyzed to, along with the carcass chemical composition, determine the empty body chemical composition.

Statistical procedures were performed using the SAS (Inst. Inc., Cary, NC), with the animal being the experimental unit. The physical and chemical composition of each carcass section (S1 to S7), as well as their DXA parameters (DXA lean mass, DXA fat mass, and DXA BMC) were used to predict the physical and chemical composition of the carcass and the chemical composition of the body. The Akaike's information criterion (AIC), and Swarz Bayesian information criteria (BIC) were used to determine the predictive variables that would be included in the prediction equation. The leave-one-out cross-validation method was used to develop linear predictive equations using PROC REG in the SAS (9.4) software. More details can be obtained in Godoi (2021).

The prediction equations proposed by Godoi (2021) to get the carcass physical composition of Nellore heifers using the physical composition of carcass sections are presented in Table 5.18, whereas the predictive equations of carcass physical composition based on DXA measurements can be seen in Table 5.19. S2 and S6 equations for fat content, S6 and S7 equations for muscle content, and S2 and S7 equations for bone content have shown AIC and BIC lower than the prediction equations based on other sections.

Table 5.18 - Prediction equations for the carcass physical composition of Nellore heifers using the physical composition of carcass sections, adapted from Godoi (2021)

Variable	Section	Equation[1]	R^2	RMSE[2]	AIC[3]	BIC[4]
Fat, kg	1	$Fat_{carc} = -1.599 + 4.227 \times Fat_S$	0.93	1.87	20.6	22.9
	2	$Fat_{carc} = 1.936 + 4.792 \times Fat_S$	0.97	1.22	7.72	9.67
	3	$Fat_{carc} = 3.999 + 16.96 \times Fat_S$	0.91	2.14	24.7	27.5
	4	$Fat_{carc} = 4.181 + 14.18 \times Fat_S$	0.84	2.88	33.6	36.2
	5	$Fat_{carc} = 5.013 + 20.646 \times Fat_S$	0.88	2.51	29.4	32.4
	6	$Fat_{carc} = 1.728 + 4.004 \times Fat_S$	0.98	0.91	-0.85	0.34
	7	$Fat_{carc} = -1.139 + 5.448 \times Fat_S$	0.95	1.64	16.7	19.7
Muscle, kg	1	$Musc_{carc} = -1.386 + 3.897 \times Musc_S$	0.92	2.98	34.6	36.7
	2	$Musc_{carc} = 8.867 + 4.74 \times Musc_S$	0.95	2.29	26.7	28.8
	3	$Musc_{carc} = 13.171 + 23.029 \times Musc_S$	0.79	4.86	49.3	51.6
	4	$Musc_{carc} = 14.893 + 24.93 \times Musc_S$	0.76	5.19	51.3	51.7
	5	$Musc_{carc} = 16.261 + 34.558 \times Musc_S$	0.84	4.19	44.8	47.4
	6	$Musc_{carc} = 2.775 + 5.452 \times Musc_S$	0.98	1.54	14.7	17.8
	7	$Musc_{carc} = -3.064 + 3.35 \times Musc_S$	0.99	1.22	7.83	10.6
Bone, kg	1	$Bone_{carc} = 1.169 + 2.805 \times Bone_S$	0.84	0.77	-5.99	-7.35
	2	$Bone_{carc} = 3.585 + 3.941 \times Bone_S$	0.89	0.65	-11.3	-8.25
	3	$Bone_{carc} = 4.942 + 15.774 \times Bone_S$	0.66	1.13	5.51	7.65
	4	$Bone_{carc} = 6.544 + 20.665 \times Bone_S$	0.45	1.45	12.9	13.1
	5	$Bone_{carc} = 5.06 + 38.604 \times Bone_S$	0.65	1.14	5.79	6.84
	6	$Bone_{carc} = 3.453 + 5.652 \times Bone_S$	0.77	0.92	-0.64	0.54
	7	$Bone_{carc} = -1.385 + 3.659 \times Bone_S$	0.94	0.47	-21.1	-18.6

[1]Fat_{carc}= fat in half carcass (kg); Fat_S = fat in each section (kg); $Musc_{carc}$= muscle in half carcass (kg); $Musc_S$ = Muscle in each section; $Bone_{carc}$= bones in half carcass (kg); $Bone_S$ = Bone in each section (kg);
[2]RMSE = root mean square error.
[3]AIC = Akaike's information criterion.
[4]BIC = Swarz Bayesian information criteria.

When DXA measurements were used to estimate the physical composition of the carcass, the S1 and S7 equations for fat and bone contents showed lower AIC and BIC values than those equations based on the other sections evaluated. Nevertheless, lower AIC and BIC values were observed for S2 and S7 equations for muscle content when compared to the predictive equations based on other sections. Furthermore, is it noteworthy that S7 equations presented the lowest predictive errors (RMSE) for all physical constituents evaluated using both techniques (physical composition of carcass sections and DXA measurements), except for the bone predictive equation based on the DXA measurements.

Therefore, results suggested that the carcass physical composition (fat, muscle, and bone contents) of Nellore heifers were generally better predicted by S7 equations whether by the physical composition or DXA measurements of carcass sections.

Table 5.19- Prediction equations for carcass physical composition of Nellore heifers using dual energy X-ray absorptiometry (DXA) of carcass sections, adapted from Godoi (2021)

Variable	Section	Equation[1]	R^2	RMSE[2]	AIC[3]	BIC[4]
Fat, kg	1	$Fat_{carc} = 1.954 + 4.571 \times DXAFat_S$	0.96	1.52	14.5	16.5
	2	$Fat_{carc} = 4.931 + 4.262 \times DXAFat_S$	0.91	2.19	25.4	25.6
	3	$Fat_{carc} = 3.644 + 11.983 \times DXAFat_S$	0.80	3.30	37.7	38.6
	4	$Fat_{carc} = 2.521 + 14.995 \times DXAFat_S$	0.82	3.11	35.9	37.1
	5	$Fat_{carc} = 6.801 + 13.269 \times DXAFat_S$	0.69	4.09	44.1	44.5
	6	$Fat_{carc} = 3.061 + 3.471 \times DXAFat_S$	0.91	2.15	24.8	24.9
	7	$Fat_{carc} = -1.345 + 5.148 \times DXAFat_S$	0.98	0.94	-0.10	1.84
Muscle, kg	1	$Muscle_{carc} = -7.294 + 3.374 \times DXALean_S$	0.92	3.03	35.1	37.7
	2	$Muscle_{carc} = 6.226 + 4.089 \times DXALean_S$	0.95	2.44	28.6	28.9
	3	$Muscle_{carc} = 19.313 + 21.106 \times DXALean_S$	0.44	7.96	64.1	62.7
	4	$Muscle_{carc} = 20.758 + 18.033 \times DXALean_S$	0.72	5.62	53.7	53.3
	5	$Muscle_{carc} = 26.373 + 26.327 \times DXALean_S$	0.54	7.17	60.9	59.6
	6	$Muscle_{carc} = 5.431 + 4.661 \times DXALean_S$	0.87	3.74	41.4	40.4
	7	$Muscle_{carc} = -6.644 + 3.129 \times DXALean_S$	0.96	1.99	22.5	24.6
Bone, kg	1	$Bone_{carc} = 2.956 + 8.865 \times DXABMC_S$	0.90	0.61	-12.8	-11.1
	2	$Bone_{carc} = 5.339 + 12.375 \times DXABMC_S$	0.81	0.85	-2.98	-0.32
	3	$Bone_{carc} = 7.718 + 23.153 \times DXABMC_S$	0.58	1.27	9.10	11.2
	4	$Bone_{carc} = 7.933 + 56.493 \times DXABMC_S$	0.43	1.48	13.5	13.7
	5	$Bone_{carc} = 8.107 + 55.587 \times DXABMC_S$	0.52	1.29	9.41	10.1
	6	$Bone_{carc} = 6.817 + 11.219 \times DXABMC_S$	0.66	1.12	5.26	6.46
	7	$Bone_{carc} = 2.518 + 9.267 \times DXABMC_S$	0.81	0.85	-3.17	-0.74

[1]Fat_{carc}= fat in half carcass (kg); $DXAFat_S$ = fat mass in each section; $Muscle_{carc}$= muscle in half carcass (kg); $DXALean_S$ = Lean mass in each section; $Bone_{carc}$= bones in half carcass (kg); $DXABMC_S$ = Bone mineral content in each section.
[2]RMSE = root mean square error.
[3]AIC = Akaike's information criterion.
[4]BIC = Swarz Bayesian information criteria.

The predictive equations of the carcass chemical composition (EE, CP, and ash) based on the chemical composition of carcass sections of Nellore heifers proposed by Godoi (2021) are shown in Table 5.20.

S1 and S2 equations for EE and CP and S1 and S7 equations for ash have shown lower values of AIC and BIC when compared to the equations based on the other sections compositions.

Table 5.20 - Prediction equations for the carcass chemical composition of Nellore heifers using the chemical composition of carcass sections, adapted from Godoi (2021)

Variable	Section	Equation[1]	R^2	RMSE[2]	AIC[3]	BIC[4]
Ether extract, kg	1	$EE_{carc} = -1.596 + 4.309 \times EE_S$	0.98	0.99	1.47	4.48
	2	$EE_{carc} = 1.372 + 4.686 \times EE_S$	0.97	1.16	6.20	8.75
	3	$EE_{carc} = 2.899 + 17.82 \times EE_S$	0.95	1.49	13.7	16.2
	4	$EE_{carc} = 2.710 + 17.686 \times EE_S$	0.91	1.99	22.4	24.7
	5	$EE_{carc} = 4.134 + 22.946 \times EE_S$	0.92	1.77	19.0	21.9
	6	$EE_{carc} = 2.500 + 4.036 \times EE_S$	0.97	1.18	6.89	8.54
	7	$EE_{carc} = -1.989 + 5.227 \times EE_S$	0.95	1.46	13.2	16.1
Crude Protein, kg	1	$CP_{carc} = 0.216 + 3.562 \times CP_S$	0.91	0.82	-4.07	-3.64
	2	$CP_{carc} = 3.120 + 4.408 \times CP_S$	0.93	0.71	-8.31	-5.92
	3	$CP_{carc} = 3.993 + 20.311 \times CP_S$	0.73	1.39	11.8	13.6
	4	$CP_{carc} = 4.290 + 22.054 \times CP_S$	0.85	1.07	3.74	6.20
	5	$CP_{carc} = 4.857 + 30.464 \times CP_S$	0.87	0.92	-0.71	2.36
	6	$CP_{carc} = 2.720 + 4.533 \times CP_S$	0.88	0.94	-0.14	0.93
	7	$CP_{carc} = -0.433 + 3.478 \times CP_S$	0.83	1.12	5.30	4.57
Ash, kg	1	$Ash_{carc} = 0.359 + 3.010 \times Ash_S$	0.88	0.28	-36.0	-35.3
	2	$Ash_{carc} = 0.871 + 4.586 \times Ash_S$	0.85	0.31	-33.4	-31.2
	3	$Ash_{carc} = 0.811 + 19.929 \times Ash_S$	0.61	0.50	-19.0	-17.3
	4	$Ash_{carc} = 1.152 + 31.700 \times Ash_S$	0.59	0.52	-18.0	-16.8
	5	$Ash_{carc} = 1.656 + 33.258 \times Ash_S$	0.51	0.55	-16.0	-15.8
	6	$Ash_{carc} = 0.957 + 5.617 \times Ash_S$	0.67	0.46	-21.6	-20.5
	7	$Ash_{carc} = 0.483 + 2.570 \times Ash_S$	0.87	0.29	-35.0	-35.9

[1]EE_{carc}= ether extract in half carcass (kg); EE_S = ether extract in each section (kg); CP_{carc}= crude protein in half carcass (kg); CP_S = crude protein in each section (kg); Ash_{carc}= Ash in half carcass (kg); Ash_S = ash in each section (kg).
[2]RMSE = root mean square error.
[3]AIC = Akaike's information criterion.
[4]BIC = Swarz Bayesian information criteria.

Similarly, the equations generated from S1 and S7 DXA measurements showed lower values of AIC and BIC for all chemical constituents evaluated (EE, CP, and ash) in relation to those equations built from other sections of DXA data (Table 5.21). Moreover, it is important to highlight that S1 equations presented the lowest RMSE for all carcass chemical constituents evaluated using both techniques (chemical composition of carcass sections or DXA measurements), except for the CP equation based on the chemical composition of its section and EE equation based on DXA measurements.

Table 5.21 - Prediction equations for carcass chemical composition of Nellore heifers using dual energy X-ray absorptiometry (DXA) of carcass sections, adapted from Godoi (2021)

Variable	Section	Equation[1]	R^2	RMSE[2]	AIC[3]	BIC[4]
Ether extract, kg	1	$EE_{carc} = 1.406 + 4.08 \times DXAFat_S$	0.95	1.51	14.3	17.0
	2	$EE_{carc} = 3.997 + 3.825 \times DXAFat_S$	0.91	1.95	21.9	21.9
	3	$EE_{carc} = 2.679 + 10.888 \times DXAFat_S$	0.81	2.83	33.0	33.6
	4	$EE_{carc} = 1.722 + 13.534 \times DXAFat_S$	0.83	2.69	31.5	32.6
	5	$EE_{carc} = 5.474 + 12.146 \times DXAFat_S$	0.71	3.50	39.4	40.1
	6	$EE_{carc} = 2.121 + 3.159 \times DXAFat_S$	0.94	1.59	15.8	14.9
	7	$EE_{carc} = -1.533 + 4.593 \times DXAFat_S$	0.97	1.08	4.05	6.98
Crude protein, kg	1	$CP_{carc} = -0.886 + 0.872 \times DXALean_S$	0.93	0.70	-8.98	-6.57
	2	$CP_{carc} = 3.144 + 1.000 \times DXALean_S$	0.86	1.01	2.01	0.69
	3	$CP_{carc} = 6.307 + 5.193 \times DXALean_S$	0.40	2.09	24.0	22.8
	4	$CP_{carc} = 6.793 + 4.337 \times DXALean_S$	0.63	1.64	16.7	16.0
	5	$CP_{carc} = 7.771 + 6.875 \times DXALean_S$	0.56	1.80	19.4	16.7
	6	$CP_{carc} = 2.916 + 1.144 \times DXALean_S$	0.80	1.21	7.46	6.26
	7	$CP_{carc} = -0.226 + 0.779 \times DXALean_S$	0.91	0.81	-4.49	-4.21
Ash, kg	1	$Ash_{carc} = -0.162 + 3.635 \times DXABMC_S$	0.89	0.27	-37.8	-35.9
	2	$Ash_{carc} = 0.703 + 5.29 \times DXABMC_S$	0.86	0.30	-34.6	-32.7
	3	$Ash_{carc} = 1.717 + 9.917 \times DXABMC_S$	0.62	0.50	-19.2	-17.7
	4	$Ash_{carc} = 1.778 + 24.665 \times DXABMC_S$	0.48	0.59	-14.6	-14.7
	5	$Ash_{carc} = 1.900 + 23.564 \times DXABMC_S$	0.55	0.54	-16.9	-16.9
	6	$Ash_{carc} = 1.426 + 4.591 \times DXABMC_S$	0.65	0.48	-20.4	-19.8
	7	$Ash_{carc} = -0.499 + 3.598 \times DXABMC_S$	0.87	0.29	-35.5	-32.9

[1]EE_{carc}= ether extract in half carcass (kg); $DXAFat_S$ = fat mass in each section; CP_{carc}= crude protein in half carcass (kg); $DXALean_S$ = Lean mass in each section; Ash_{carc}= ash in half carcass (kg); $DXABMC_S$ = Bone mineral content in each section.
[2]RMSE = root mean square error.
[3]AIC = Akaike's information criterion.
[4]BIC = Swarz Bayesian information criteria.

The prediction equations proposed by Godoi (2021) for the empty body chemical composition of Nellore heifers using the chemical composition of carcass sections or DXA measurements are presented in Table 5.22 and 5.23, respectively. The lowest values of AIC and BIC were observed for S1 and S2 equations when using the chemical composition of carcass sections for predicting the contents of EE, CP, and ash in the empty body, whereas S1 and S7 presented the lowest AIC and BIC values when DXA measurements were used for predicting the same chemical components in the empty body.

Table 5.22 - Prediction equations for the empty body chemical composition of Nellore heifers using the chemical composition of carcass sections, adapted from Godoi (2021)

Variable	Section	Equation[1]	R^2	RMSE[2]	AIC[3]	BIC[4]
Ether extract, kg	1	$EE_{EBW} = 0.249 + 12.717 \times EE_S$	0.94	4.75	48.6	51.4
	2	$EE_{EBW} = 8.089 + 14.122 \times EE_S$	0.97	3.22	36.9	38.3
	3	$EE_{EBW} = 13.562 + 52.524 \times EE_S$	0.91	5.91	55.2	57.0
	4	$EE_{EBW} = 12.12 + 53.302 \times EE_S$	0.91	5.79	54.5	57.7
	5	$EE_{EBW} = 17.113 + 67.93 \times EE_S$	0.90	6.33	57.2	59.6
	6	$EE_{EBW} = 12.239 + 11.938 \times EE_S$	0.94	4.99	50.0	52.2
	7	$EE_{EBW} = -0.978 + 15.444 \times EE_S$	0.92	5.66	53.8	56.3
Crude Protein, kg	1	$CP_{EBW} = -2.258 + 12.68 \times CP_S$	0.86	3.73	41.3	42.7
	2	$CP_{EBW} = 7.967 + 15.744 \times CP_S$	0.88	3.41	38.6	39.6
	3	$CP_{EBW} = 10.124 + 74.84 \times CP_S$	0.74	4.98	50.0	51.8
	4	$CP_{EBW} = 12.648 + 77.433 \times CP_S$	0.78	4.51	47.1	49.7
	5	$CP_{EBW} = 14.32 + 108.439 \times CP_S$	0.81	4.29	45.5	48.4
	6	$CP_{EBW} = 6.473 + 16.221 \times CP_S$	0.84	3.95	43.1	44.3
	7	$CP_{EBW} = -3.991 + 12.225 \times CP_S$	0.76	4.84	49.2	47.0
Ash, kg	1	$Ash_{EBW} = 4.198 + 6.238 \times Ash_S$	0.70	1.01	2.10	3.14
	2	$Ash_{EBW} = 5.134 + 9.726 \times Ash_S$	0.72	0.97	1.08	3.47
	3	$Ash_{EBW} = 4.67 + 44.782 \times Ash_S$	0.58	1.18	6.83	9.12
	4	$Ash_{EBW} = 5.594 + 69.094 \times Ash_S$	0.52	1.18	6.88	8.85
	5	$Ash_{EBW} = 6.359 + 78.81 \times Ash_S$	0.52	1.27	9.09	9.66
	6	$Ash_{EBW} = 5.076 + 12.45 \times Ash_S$	0.62	1.15	6.07	7.14
	7	$Ash_{EBW} = 4.51 + 5.279 \times Ash_S$	0.69	1.04	2.94	2.62

[1]EE_{EBW}= ether extract in empty body (kg); EE_S = ether extract in each section (kg); CP_{EBW}= crude protein in empty body (kg); CP_S = crude protein in each section (kg); Ash_{EBW}= ash in empty body (kg); Ash_S = ash in each section (kg).
[2]RMSE = root mean square error.
[3]AIC = Akaike's information criterion.
[4]BIC = Swarz Bayesian information criteria.

Therefore, the results of Godoi (2021) suggested that S1 equations, built from the chemical composition and DXA measurements of carcass section, generally better estimated all chemical components of the carcass and the empty body of Nellore heifers when compared to the other sections evaluated.

Although S1 equations did not exhibit the lowest values of AIC and BIC for most of carcass physical components among the other sections evaluated, they have shown good precision with values of R^2 between 84.3% and 95.6%, suggesting that perhaps it would also be reasonable to estimate the carcass physical composition of Nellore heifers through this section equations.

Table 5.23 - Prediction equations for the empty body chemical composition of Nellore heifers using dual energy X-ray absorptiometry (DXA) of carcass sections, adapted from Godoi (2021)

Variable	Section	Equation[1]	R^2	RMSE[2]	AIC[3]	BIC[4]
Ether extract, kg	1	$EE_{EBW} = 8.305 + 12.264 \times DXAFat_S$	0.95	4.57	47.4	49.7
	2	$EE_{EBW} = 16.301 + 11.431 \times DXAFat_S$	0.90	6.21	56.6	55.0
	3	$EE_{EBW} = 11.804 + 32.993 \times DXAFat_S$	0.83	8.22	65.1	65.4
	4	$EE_{EBW} = 8.974 + 40.948 \times DXAFat_S$	0.84	7.79	63.4	63.4
	5	$EE_{EBW} = 21.198 + 35.742 \times DXAFat_S$	0.68	11.0	73.8	73.8
	6	$EE_{EBW} = 11.311 + 9.301 \times DXAFat_S$	0.90	6.16	56.4	54.5
	7	$EE_{EBW} = -0.462 + 13.789 \times DXAFat_S$	0.97	3.41	38.6	40.7
Crude protein, kg	1	$CP_{EBW} = -8.92 + 3.283 \times DXALean_S$	0.99	1.23	8.07	10.8
	2	$CP_{EBW} = 7.014 + 3.683 \times DXALean_S$	0.87	3.57	30.0	39.9
	3	$CP_{EBW} = 16.539 + 20.902 \times DXALean_S$	0.48	7.12	60.7	59.8
	4	$CP_{EBW} = 19.301 + 16.844 \times DXALean_S$	0.71	5.36	52.2	52.1
	5	$CP_{EBW} = 24.387 + 24.845 \times DXALean_S$	0.54	6.68	58.8	57.3
	6	$CP_{EBW} = 5.163 + 4.333 \times DXALean_S$	0.86	3.75	41.5	41.1
	7	$CP_{EBW} = -5.5946 + 2.88 \times DXALean_S$	0.93	2.70	31.7	32.2
Ash, kg	1	$Ash_{EBW} = 2.252 + 8.403 \times DXABMC_S$	0.89	0.61	-13.0	-10.0
	2	$Ash_{EBW} = 4.478 + 11.793 \times DXABMC_S$	0.81	0.82	-4.19	-1.77
	3	$Ash_{EBW} = 6.946 + 20.936 \times DXABMC_S$	0.52	1.27	9.04	10.5
	4	$Ash_{EBW} = 6.202 + 64.855 \times DXABMC_S$	0.62	1.12	5.15	6.79
	5	$Ash_{EBW} = 7.075 + 53.605 \times DXABMC_S$	0.54	1.21	7.56	7.08
	6	$Ash_{EBW} = 5.694 + 11.129 \times DXABMC_S$	0.71	0.97	1.01	2.82
	7	$Ash_{carc} = 1.216 + 9.407 \times DXABMC_S$	0.92	0.50	-18.8	-15.9

[1]EE_{EBW}= ether extract in empty body (kg); $DXAFat_S$ = fat mass in each section; CP_{EBW}= crude protein in empty body (kg); $DXALean_S$ = Lean mass in each section; Ash_{EBW}= ash in empty body (kg); $DXABMC_S$ = Bone mineral content in each section.
[2]RMSE = root mean square error.
[3]AIC = Akaike's information criterion.
[4]BIC = Swarz Bayesian information criteria.

Nevertheless, it is important to highlight that most of the predictive equations generated for the physical and chemical composition of the carcass and chemical composition of the empty body presented high R^2 values whether built from carcass sections compositions or DXA measurements. Thus, based on the R^2 values, the physical and chemical composition of the carcass and the empty body chemical composition could be estimated by any of the evaluated carcass sections (S1 to S7), allowing the choice of the section according to the needs of each study. However, it is worth mentioning that the precision and accuracy of the estimates may vary depending on the carcass section chosen.

FINAL CONSIDERATIONS

The equations proposed in the last editions of this publication (BR-CORTE, 2010; BR-CORTE, 2016) were validated, and thus, are recommended for predicting the carcass and empty body composition of Zebu and crossbred beef and dairy cattle as a replacement for carcass dissection, resulting in reduced costs and labor.

Furthermore, the use of prediction equations for non-carcass components seems to be an accurate approach. Also, new methods, such as DXA, represent promising alternatives to predict body composition of cattle. However, more studies should be conducted to increase accuracy and to evaluate these equations using an independent database before being widely and reliably adopted.

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6

Prediction of carcass weight, backfat thickness, and body weight loss during the transport of beef cattle

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INTRODUCTION

Regardless of the type of operation (cow-calf, stocker/backgrounding, finishing, or whole production cycle), the beef cattle producer's ultimate goal is meat production. Thus, their participation in the beef supply chain usually ends when the animal is slaughtered, with payment based on carcass weight (CW). However, the expected carcass yield (CY) often generates disagreements between producers and slaughterhouses.

Producers often complain about the large variations in CY observed for cattle of similar type that were weighted under the same conditions at the farm prior to transportation, as well as regarding the disparities in CY obtained in different slaughterhouses. For most producers, the lower CY obtained in some slaughterhouses would be related to carcass dressing practices and/or problems with carcass weighing. On the other hand, slaughterhouses argue that lower CY may be due to on-farm weighing errors, management, and transport problems (e.g., long distance transport and bruising), lower finishing grade (carcass backfat), and cattle type (e.g., dairy crossbred).

In general, the carcass consists of muscle, bone, and fat after the removal of the head, hide, internal organs, peri-renal and inguinal fat, legs, tail, genitals, mammary gland (females), tissue damaged by exsanguination, spinal cord, and diaphragm (Pascoal et al., 2011; MAPA, 1989). Moreover, in some slaughter plants, there is also the removal of other carcass constituents such as the hump (when present) and tissues associated to the penis insertion in males, influencing the final CW and, consequently, the CY. Thus, the large variations in CY reported by producers may also be related to specific dressing procedures performed at different slaughter plants. In this context, several factors can affect CY, such as genotype, gender, nutrition, slaughter body weight (BW), and pre-slaughter management and transportation.

Minimal requirements of slaughterhouses regarding carcass quality include CW above 180 kg for females and 225 kg for bulls and steers (Assis, 2021). Nevertheless, carcasses with better quality traits (e.g., greater finishing grade and marbling) may be directed to specific markets and generate greater remuneration to producers. In many countries, beef carcasses are usually commercialized based on CW and cattle genotype, gender, and age at slaughter. Other factors such as conformation, meat and fat color, finishing grade, marbling, and pH may also be considered when defining carcass quality and its respective remuneration (Costa et al., 2002; Arboitte et al., 2004; Gomide et al., 2014).

In this context, the backfat thickness (BFT), typically measured between the 12th and the 13th ribs, is an important indicator of carcass quality, and it is positively correlated with CY and carcass adiposity and fat finishing grade (Berg and Butterfield, 1976; Tarouco et al., 2005; Silva et al., 2006). Moreover, adequate BFT is necessary to prevent CW losses, fast drop in carcass temperature, and meat darkening during the chilling process, allowing a better visual presentation of meat cuts and their sensorial characteristics (Luchiari Filho, 2000; Vaz and Restle, 2000; Moreira et al., 2018). On the other hand, excess of backfat is also detrimental to carcass quality, as excessive backfat deposition is usually associated with reduced beef cuts yield and increased operational costs due to the severe trimming required (Abraham et al., 1968; Costa et al., 2002; Neto et al., 2010). Thus, BFT of 3 to 6 mm is usually required by slaughterhouses (Luchiari Filho, 2000). In

general, beef carcasses that do not meet the required BFT may be subject to pricing penalties.

However, CW, and consequently CY, as well as BFT are usually measured after slaughtering the animals, not allowing management adjustments within the productive cycle. In this sense, providing alternative methods for predicting these characteristics *in vivo* may enable producers to better define management strategies and the correct slaughter point aiming to produce carcasses of greater quality and remuneration, as well as with reduced production costs. Therefore, the committee of the current edition of the BR-CORTE proposed a new chapter to discuss the main factors that influence cattle CY and composition. Subsequently, equations for predicting CW and BFT are presented, as well as a study regarding the body weight loss during transport of beef cattle.

FACTORS INFLUENCING CARCASS YIELD AND COMPOSITION

Genotype and gender

Cattle from different genotypes and genderes present differences regarding their potential for meat production, body weight at maturity (matBW), BW gain rate, and composition of weight gain (Berg and Butterfield, 1976; Valadares Filho et al., 2016). In general, continental *Bos taurus taurus* breeds (e.g., Simmental and Charolais) present large frame and mature size (late precocity), *Bos taurus indicus* breeds (e.g, Nellore) present medium frame size and intermediate precocity, and British *Bos taurus taurus* breeds (e.g, Angus and Hereford) present small frame size and early precocity.

At the same BW, late maturity-breed cattle usually present greater BW gain rates and proportionally deposit more muscle and less fat in the carcass compared to early maturity-breed cattle (Nour et al., 1983; Hassen et al., 1998; Williams et al., 2010). In this sense, differences in CY among genotypes are commonly observed when the time of slaughter is determined by the carcass finishing degree, as larger frame size cattle present desired finishing grade at higher BW and, consequently, have greater CY (Camfield et al., 1996; Euclides Filho et al., 1997; Clímaco et al., 2011).

In relation to the genetic composition, the breed can also interfere in CY. At the same BW, beef cattle carcasses (such as Angus) have greater soft tissue to bone ratio, and proportionally more fat than dairy cattle carcasses (such as Holstein; Nour et al., 1981; Nour et al., 1983). These differences are likely because genetic selection in dairy cattle has been focused on milk production rather than tissue deposition. Thus, cattle from breeds that were genetically selected for beef production, at same BW, have greater CY than those selected for milk production (Nour et al., 1981; Bertrand et al., 1983; Nour et al., 1983).

The association of desirable characteristics from two or more breeds (heterosis) through crossbreeding also modifies the growth and conformation pattern of crossbred cattle when compared to those from the purebreds. The benefits of crossing taurine and zebu beef purebreds have been reported in the literature (Fitzhugh et al., 1975; Gray et al., 1978; Williams et al., 2010) and include greater productive performance and better carcass traits.

In this context, greater CW and, sometimes CY, is expected in crossbred cattle (taurine and zebu beef breeds) when compared to zebu purebred cattle, as the presence of taurine breeds in the genotype of these crossbred animals usually result in greater BW gain rates and carcass fat deposition (Crouse et al., 1989; Plasse et al., 1995; Yar et al., 2022). Greater CW and backfat thickness have been reported in Simmental × Nellore e Angus × Nellore steers (Oliveira et al., 2011) and heifers (Lage et al., 2012) in relation to Nellore steers and heifers, respectively. Similarly, Amaral et al. (2018) have described greater carcass gain and subcutaneous fat thickness in Angus × Nellore bulls when compared to Nellore.

On the other hand, crossbred dairy cattle (Holstein × Zebu) are also commonly raised for beef production in Brazil. However, the presence of the Holstein breed in the genotype of the crossbred dairy animals usually lead to a different growth and conformation pattern when compared to breeds selected for beef production and their crossbreds. Several studies available in the

literature described lower CY in crossbred dairy cattle in relation to those from breeds selected for beef production (e.g., Nellore and Angus) and their crossbreds (Jorge et al., 1999; Fernandes et al., 2004; Rocha Junior et al., 2010). Nonetheless, some studies did not find differences in CY of dairy crossbred (Holstein × Zebu) and Zebu beef breeds cattle (Alves et al., 2004; Costa et al., 2007).

Gender also influences the weight gain rate, composition of gain, and consequently, body composition and carcass traits (Berg and Butterfield, 1976; Valadares Filho et al., 2016). Bulls usually present greater growth rate, with higher protein and less fat content in the gain when compared to steers and heifers within a contemporary group (Berg and Butterfield, 1976; Fortin et al., 1980; Paulino et al., 2009).

However, females deposit more udder and internal organs fat (Paulino et al., 2009). Moreover, steers typically deposit more abdominal and renal fat than bulls at similar BW (Paulino et al., 2009). Therefore, at the same BW, the CW, and frequently the CY, are greater in bulls and lower in heifers, whereas steers usually present intermediate values (Hassen et al., 1998; Vittori et al., 2006; Paulino et al., 2008). Vaz et al. (2010) reported that, even at young ages, steers present greater CY when compared to heifers, as heifers have greater weight of the digestive tract.

Slaughter body weight

Slaughter BW is an important factor to determine CW and CY of cattle. Body weight is positively correlated to CW (Lôbo et al., 2002; Silva et al., 2003; Cruz et al., 2004). Furthermore, CY linearly increases with increasing slaughter BW (May et al., 1992; Bruns et al., 2004; Restle et al., 2005). Carcass yield increases with increasing BW due to the increased carcass fat deposition and reduced proportion of BW that consists of the digestive tract and its content (Berg and Butterfield, 1976; Waldo et al., 1990; Owens et al., 1993). May et al. (1992), evaluating the carcass traits of Angus × Hereford steers serially slaughtered 0 to 196 d on feed, and Arboitte et al. (2004) assessing the carcass traits of 5/8 Nellore × 3/8 Charolais steers finished in feedlot and slaughtered at 425, 467, and 510 kg, observed a linear increase in CY and BFT of such animals. In addition, Restle et al. (2005) observed a decreasing contribution of internal organs to slaughter BW (kg/100 kg slaughter BW) as the slaughter BW of 5/8 Nellore × 3/8 Charolais steers increased from 425 to 510 kg.

Nonetheless, Hicks et al. (1987) and Bruns et al. (2004) have reported a quadratic increase in BFT with increasing BW at slaughter. Differences regarding the duration of studies and, consequently, the BW range evaluated may be responsible for the different patterns of BFT deposition in the carcass described among the studies.

Nutritional strategies

The diet offered to cattle may affect their CY (Berg and Butterfield, 1976; Owens et al., 1993). The gastrointestinal tract content and the relative weight of its compartments is greater when forage diets are fed to cattle in relation to concentrate diets (ARC, 1980; Owens et al., 1993; Véras et al., 2001). In addition, the greater nutrient supply (and energy) obtained from concentrate diets usually results in greater weight gain and carcass rates, carcass fat deposition, and CW (Nour et al., 1983; Oliveira et al., 2009; Marcondes et al., 2011). Several studies have demonstrated that CY linearly increases with increasing diet concentrate content (Gesualdi Júnior et al., 2000; Ribeiro et al., 2001; Leme et al., 2003; Oliveira et al., 2011). In this context, the greater the diet concentrate content, the greater the expected CY.

Transport and management

Beef cattle are transported at least once in their lives when they are shipped for slaughter. Handling, loading/unloading, commingling, vehicle accelerations and vibrations, exposure to new environments, and extreme temperatures during transportation can cause stress (Schwartzkopf-Genswein et al., 2016). As a result, animals often experience BW loss (shrink), carcass injuries, and alteration of meat quality (Bhatt et al., 2021).

In Brazil, BW loss may be the most important economic effect, because of BW or CW- based trading of cattle. This effect usually occurs mostly due to the lack of feed and water (Marques et al., 2012), but also because of

increased transpiration, defecation, and urination. However, Schwartzkopf-Genswein et al. (2016) reported in a review that transportation related to BW loss was not only attributed to loss of gut fill but also to tissue loss, which can exceed 60% of BW losses depending on the length of the fasting period. Jones et al. (1988), evaluating the effects of fasting, mixing, transportation, and resting, mimicking what cattle would be exposed to during specific transport scenarios, concluded that the main effect of fasting and transportation in beef cattle was a loss in CW and gut fill, which was greater for a 72-hour journey compared to a 48-hour journey. Also, high ambient temperature and extra and rough handling of cattle usually increase weight loss (Coffey et al., 2001; González et al., 2012; van Engen and Coetzee, 2018).

Poor cattle management, especially pre-slaughter handling process, can also cause bruises and limit cattle well-being (Paranhos da Costa et al., 2012; Mendonça et al., 2019). Bruising can be defined as a tissue injury with rupture of blood vessels and accumulation of blood and serum beneath the skin (Strappini et al., 2012), which usually depreciates the commercial value of carcasses as the affected parts may need to be discarded. Bruises can cause carcass loss and consequently, negatively affect CY and the economic output.

Two studies conducted in Uruguay (Huertas et al., 2010; Huertas et al., 2015) found that 60% of the total beef carcass assessed had at least one bruise. Moreover, the occurrence of bruises on the carcasses resulted in an average removal of 2.0 and 1.6 kg of meat per lesion in the studies of Huertas et al. (2010) and Huertas et al. (2015), respectively. However, Zanardi et al. (2022) and Strappini et al. (2010) observed a relatively low prevalence of bruises in slaughterhouses in Italy and Chile slaughterhouses, where approximately 20% of cattle presented at least one bruise.

Several studies have been performed to evaluate the effects of pre-slaughter management (e.g, handling procedures and duration of transportation and vehicle type), genotype and gender predispositions to bruises occurrence (Strappini et al., 2010; Mendonça et al., 2016; Bethancourt-Garcia et al., 2019; Mendonça et al., 2019). Results from these studies have indicated that the occurrence of bruises on cattle carcasses are related to the distance traveled, where cattle transported for long distances presented more bruises than those transported for shorter journeys. Also, trucks with larger load capacities caused a greater number of severe bruises. Furthermore, carcass bruises were greater for females (cows, mainly) when compared to male cattle, as well as the presence of horned animals within cattle groups increased the risk of bruising.

Dressing procedure

The CW utilized for calculating the CY in commercial slaughterhouses is usually obtained after the slaughter, dressing, and cleaning processes, which differ among countries and slaughter plants. In this context, whether the carcass is weighed hot (hot carcass weight; HCW) or after cooling (cold carcass weight; CCW), is washed or not, and contains or not the kidneys attached will affect the CW obtained. Moreover, the removal of bruises, abscesses (e.g., resulted from vaccination against foot and mouth disease), or fat excess , known as trimming, may also decrease CW and, consequently, the CY.

In 2014, a survey performed in 28 Brazilian slaughter plants (Scot Consultoria company) showed mean CY values of 52 and 54% for male cattle raised in pasture and feedlots, respectively, and values between 48 and 49% for cows. In addition, mean values of CY of 50 e 51% were reported for heifers raised in pasture and feedlots, respectively. However, experimental results from comparative slaughter trials, in which carcasses were not trimmed, often describe greater CY, reach about 60%.

Differences between experimental and commercial CY may be also related to the experimental fasting period of 12 to 16 h to obtain the shrunk body weight (SBW) in trials, while in farming conditions normally they weight the animals without a fasting period, recording the full BW of animals. .

Comparisons between experimental and commercial CY values may often lead to producers distrust regarding the procedures for obtaining the CY by the slaughterhouses.

Thus, CY obtained in experiments should not be compared with those observed in commercial conditions without adjustments. In

this sense, to compare experimental and commercial data, it would be necessary to establish the fasting effect and the dressing/trimming effect on CY.

In addition, the biological efficiency has been currently used as an indicator of feedlot production efficiency. This indicator is calculated as the amount of feed necessary to produce 1 or 15 kg of carcass (15 kg of carcass is a metric for CW called "*arroba*" utilized in Brazil). In this case, the production process efficiency is calculated after slaughtering the animals, which do not allow adjustments or modifications during the productive cycle. Therefore, estimating the CW from cattle's BW would enable nutritionists to make more precise adjustments on nutrition and management during the production cycle, as well as to assist on the definition of the best time for slaughter. Hence, linear and non-linear equations to predict CW from BW will be proposed.

ESTIMATION OF CARCASS WEIGHT

Linear equations

In a recent study, Benedeti et al. (2021) proposed a linear equation to predict CW of feedlot cattle according to the variables slaughter condition, gender, genotype, and shrunk body weight (SBW). A database composed by 1112 animals (Table 6.1) encompassing bulls, steers, and heifers of different genotype (Zebu, beef crossbred, and dairy crossbred), and slaughtered at two types of slaughter procedure (experimental and commercial) was used to develop a linear CW predictive equation (Eq.6.1).

Table 6.1 - Descriptive statistics of the data used to develop the linear model to predict carcass weight of beef cattle, adapted from Benedeti et al. (2021)

Item	n	Shrunk body weight, kg	Carcass weight, kg
Studies	30		
Animals	1112	429	234
Gender			
Bull	785	462	255
Steer	186	393	215
Heifer	141	297	158
Genotype			
Zebu	776	433	235
Crossbred beef cattle	164	419	230
Crossbred dairy cattle	171	423	234
Slaughter procedure[*]			
Commercial	636	503**	280
Experimental	476	374	208

[*]Experimental = data from animals slaughtered in an experimental procedure without dressing or trimming the carcasses; Commercial = data from animals slaughtered in a commercial slaughter house.
[**]Shrunk body weight of commercial animals was estimated according to Gionbelli et al. (2016); $SBW = 0.880 \times BW^{1.0175}$.

Authors found significant effects ($P < 0.05$) of the slaughter procedure only on the intercept and significant effects ($P < 0.05$) of gender, genotype, and SBW on the slope of the linear regression of the CW; thus, the following CW predictive equation was suggested:

$$CW\ (kg) = -11.03 + P + (0.6094 + G + B) \times SBW \quad \text{Eq.6.1,}$$

where CW = carcass weight (kg), P = slaughter procedure (if commercial = -10.98, if experimental = 0), G = gender effect (if steer = 0, if bull = 0.008169, and if heifer = -0.00612), B = genotype effect (if Zebu = 0, if crossbred beef cattle = -0.01595, and if crossbred dairy cattle = -0.03301), and SBW = shrunk body weight (kg).

Therefore, at the same SBW, greater CW estimations will be observed for cattle slaughtered in experimental when compared to commercial conditions, due to the absence of dressing or trimming process, which decrease CY. Furthermore, the estimated CW will be

heavier for bulls, followed by steers and heifers, respectively, when considering animals with the same SBW. Regarding the genotype effect, the dairy crossbred, and beef crossbred decreases the CW estimation in relation to Zebu genotype, probably reflecting a greater dry matter intake of the crossbred cattle.

The validation analysis of the linear CW equation was performed using an independent database containing cattle slaughtered in experimental and commercial slaughter plants (Table 6.2). The experimental data set was composed by 70 observations, encompassing only bulls from two genotypes (Zebu and beef crossbred). Commercial data set was composed by 10 means from 746 cattle, encompassing Zebu and crossbred beef bulls and heifers.

Table 6.2 - Descriptive statistics of the data used to validate the linear model (Eq. 6.1) to predict carcass weight of Zebu beef cattle, adapted from Benedeti et al. (2021)

Item	Dataset*	
	Experimental	Commercial
Studies, n	2	-
Animals, n	70	10**
Gender, %		
Bull	100	92.2
Heifer	-	7.77
Genotype, %		
Zebu	65.7	79.4
Crossbred beef cattle	34.3	20.6
Shrunk body weight, kg	452 ± 67.4	471 ± 33.6***

*Experimental = independent data from animals slaughtered in an experimental plant; Commercial = independent data from animals slaughtered in a commercial abattoir.
**10 means from 746 animals.
***Shrunk body weight of commercial animals was estimated according to Gionbelli et al. (2016); SBW = 0.8800 × $BW^{1.0175}$.

The observed and predicted values were compared based on the following regression model: Y = β0 + β1 × X, where X = predicted values, Y = observed values, β0 = intercept of the equation, and β1 = slope of the equation. The regression was evaluated according to the following statistical hypothesis: H0: β0 = 0 and H0: β1 = 1, and Ha: not H0. If the null hypothesis was not rejected, it was concluded that the linear equation accurately and precisely estimated CW of feedlot cattle. Estimates were also evaluated using the mean squared error of prediction (MSEP), and its components (Bibby and Toutenburg, 1977): MSEP = SB + MaF + MoF = $1/n \sum_{i=1}(x_i - y_i)^2$; SB = $(x_i - y_i)^2$; MaF = $(s_x - s_y)^2$; Mof = $2s_x s_y(1 - r)$; where x are the predicted values; y are the observed values; MSEP is the mean squared error of prediction; SB is the squared bias; MoF is the component relative to the model of random fluctuation; MaF is the component relative to the magnitude of random fluctuation; s_x and s_y are the standard deviations of the predicted and observed values, respectively, and r is the Pearson linear correlation coefficient between the predicted and observed values. The prediction of efficiency was determined by estimating the correlation and concordance coefficient or reproducibility index (CCC), as described by Tedeschi (2006). All calculations were obtained using the Model Evaluation System (MES; Tedeschi, 2006). For comparisons, 0.05 was established as the critical level of probability for type I error. More details regarding this study can be found in Benedeti et al. (2021).

Briefly, the validation analysis demonstrated that the linear equation accurately and precisely estimated CW of beef cattle in either experimental or commercial slaughter conditions (Table 6.3), as the null hypothesis of a respective intercept and slope equal to 0 and 1 (P > 0.05) were not rejected; and CCC was close to 1 (CCC of 0.979 and 0.961 for experimental and commercial conditions, respectively). However, the commercial validation presented the lowest

MSEP. The MSEP partitioning showed that the proportions of SB were 12.7 and 78.2%, while proportions of MaF were 0.006, and 8.31% in the experimental and commercial evaluations, respectively.

Table 6.3 - Validation statistic of the relationship between the observed and predicted carcass weight* of Zebu beef cattle by the linear model, adapted from Benedeti et al. (2021)

Item**	Experimental***		Commercial***	
	Observed	Predicted	Observed	Predicted
Mean, kg	268	265	258	264
Standard deviation, kg	40.4	39.7	23.0	24.8
Maximum, kg	322	327	285	298
Minimum, kg	105	117	215	217
R	-	0.982	-	0.994
CCC	-	0.979	-	0.961
Regression				
Intercept				
Estimate	-	3.33	-	15.6
Standard error	-	6.23	-	9.75
P-value (H_0: a=0)	-	0.595	-	0.148
Slope				
Estimate	-	1.00	-	0.919
Standard error	-	0.023	-	0.037
P-value (H_0: b=1)	-	0.943	-	0.058
MSEP	-	65.4	-	44.5
SB	-	8.32	-	34.8
MaF	-	0.004	-	3.68
MoF	-	57.1	-	6.01

*Developed equation: CW, kg = -11.03 + P + ((0.6094 + G + B) × SBW), R^2 = 0.98.
**P = Slaughter plant effect, if commercial = -10.98, if experimental =0; G = gender effect, if steer = 0, if bull = 0.008169 and if heifer = - 0.00612; B = genotype effect, if Zebu = 0, if Dairy crossbreds = -0.03301 and if Beef crossbreds = -0.01595; SBW = shrunk body weight; R = determination coefficient; CCC = correlation and concordance coefficient; MSEP = mean square error of prediction; SB = squared bias; MaF = magnitude of random fluctuation; MoF = model of random fluctuation.
***Experimental = independent data of animals slaughtered in an experimental plant; Commercial = independent data of animals slaughtered in a commercial slaughterhouse.

Thus, although experimental evaluation presented greater MSEP, it had the lowest SB, meaning that this validation analysis had a greater capacity to simulate variation around the mean. Such results may be related to differences on the validation experimental and commercial databases. Experimental data set had only bulls, while commercial had bulls and heifers. Nevertheless, the linear equation can be considered adequate to estimate CW of feedlot cattle due to its good precision and accuracy.

Non- linear equations

Carcass weight is affected by factors such as BW, weight gain rate and composition, body and carcass composition, and the contribution of the digestive tract size and fill to BW (Berg and Butterfield, 1976; Owens et al., 1993), as well as specific dressing procedures performed at different slaughter plants, which should be taken in account in predictive equations. Benedeti et al. (2021) have successfully considered such effects on CW when utilizing, besides the SBW, gender, genotype, and slaughter plant as dummy predictive variables in the linear equation described in the previous section. However, the consideration of many influencing factors may lead to overparameterization of CW prediction, increasing the complexity of calculations. In addition, Benedeti et al (2021) utilized a fixed adjustment factor for slaughter plant on CW prediction, not accounting for differences on dressing process among different animals and slaughterhouses.

Most of influencing factors (rate of gain and its composition, body composition, gut fill, etc.) of CW are correlated with BW and/or BW gain (Valadares Filho et al., 2016). Moreover, it is well known that the cattle growth curve, such as BW and tissues deposition, has been well described by simple non-linear models such as allometric equations (NASEM, 2016; Valadares Filho et al., 2016; Domínguez-Viveros et al., 2020), which could also be used to predict the optimal slaughter moment. Thus, aiming to provide a simpler and more accurate calculation of the CW for cattle of different genotype and gender, slaughtered at different conditions, authors conducted a study aiming: 1) to develop a non-linear equation to predict cattle experimental CW (eCW); 2) to evaluate the contribution of each component removed during the dressing procedure to obtain the commercial CW (cCW), as well as to develop a equation to predict cCW from eCW; and 3) to evaluate the goodness of fit of the equations generated to predict eCW and cCW of beef cattle.

Experimental carcass weight

A metanalysis was performed using data from 19 studies performed at the Universidade Federal de Viçosa (UFV), totalizing 682 feedlot cattle encompassing bulls, steers, and heifers of different genotypes (Zebu, beef crossbred, and dairy crossbred). The dataset contained individual information on SBW and CW of cattle obtained in experimental conditions (eCW), with no dressing procedures performed before weighing the carcass (Table 6.4).

Table 6.4 - Descriptive statistics of the data used to develop the non-linear model to predict experimental carcass weight of beef cattle

Item	n	Shrunk body weight, kg	Carcass weight, kg
Studies	19	-	-
Animals	682	380 ± 94.9	221 ± 58.9
Gender			
Bull	472	401 ± 83.9	237 ± 52.5
Steer	95	368 ± 103.6	204 ± 56.5
Heifer	115	303 ± 88.9	168 ± 50.3
Genotype			
Zebu	477	376 ± 93.3	222 ± 59.2
Crossbred beef cattle	52	397 ± 105.9	231 ± 65.7
Crossbred Dairy cattle	153	388 ± 95.4	214 ± 55

Before slaughter, animals were fasted for 12 to 16 h but with free access to water. Pre-boarding handling of animals was conducted in accordance with good animal welfare practices in Brazil. Experimental slaughter was performed via stunning and jugular cutting for total bleeding. Additional details regarding the experimental slaughter procedures can be obtained in Silva et al. (2021).

Data were coded for gender (bull, steer, and heifer) and genotype (Zebu, beef crossbred, and dairy crossbred). Initially, data were tested for normality. Further, a mixed model including the fixed effects of SBW, genotype, and gender, and random effects of study was used to evaluate linear and non-linear models with or without the intercept that best fits the relationship between eCW and SBW based on Akaike's Information Criteria (AIC). These analyses were performed with the MIXED procedure of the SAS (version 9.4, Inst. Inc., Cary, NC), and the 0.05 was established as the critical level of probability for a type I error.

A non-linear equation with intercept had the lowest AIC for predicting eCW. Moreover, there were significant effects ($P<0.05$) of genotype and gender on the exponent but not ($P>0.05$) on the intercept of the non-linear eCW model. Thus, the following non-linear equation to estimate experimental eCW was suggested:

$$eCW\ (kg) = 0.41764 \times SBW^{\beta 1} \quad \text{Eq.6.2,}$$

where eCW = experimental carcass weight (kg); SBW = shrunk body weight (kg); β1 =

genotype and sex effect, if Zebu bull = 1.0583, if crossbred beef bull = 1.0561, if crossbred dairy bull = 1.0479, if Zebu steer = 1.0549, if crossbred beef steer = 1.0527, if crossbred dairy steer = 1.0445, if Zebu heifer = 1.0533, if crossbred beef heifer = 1.0511, and if crossbred dairy heifer = 1.0429 (Table 6.5).

Table 6.5 - Coefficients for the non-linear predictive equation of experimental carcass weight (Eq.6.2)

Genotype	Gender	β1
Zebu	Bull	1.0583
	Steer	1.0549
	Heifer	1.0533
Crossbred beef cattle	Bull	1.0561
	Steer	1.0527
	Heifer	1.0511
Crossbred Dairy cattle	Bull	1.0479
	Steer	1.0445
	Heifer	1.0429

The carcass gain rates according to genotype and gender can be accessed by the exponent (β1) of the generated equation to estimate eCW from SBW. The exponents greater than 1 observed in the current study indicated carcass gain in a greater rate than the cattle shrunk weight gain (SWG), regardless of cattle genotype and gender. However, values of β1 were greater for Zebu and lower for crossbred dairy cattle while crossbred beef cattle were intermediate within each gender. These results indicated that, within each gender, Zebu and crossbred dairy cattle presented the greatest and lowest proportions of SWG in carcass tissues, respectively, when compared to crossbred beef cattle.

In addition, estimated eCW will be higher for bulls, followed by steers and heifers respectively, when considering cattle with equal SBW within each genotype evaluated. As previously discussed, at the same SBW, bulls present greater proportion of protein and lower fat deposition than steers and heifers. Steers typically deposit more abdominal and renal fat than bulls at similar BW. Also, heifers tend to deposit more fat in udder and internal organs, which usually results in proportionally less deposition of carcass tissues in relation to bulls. Therefore, at the same BW, CW are greater in bulls and lower in heifers, whereas steers usually present intermediate CW.

These results corroborate with the discussion previously held, where: 1) purebred and crossbred beef cattle, at same SBW, usually present greater CW when compared to crossbred dairy cattle; e 2) At the same SBW, CW is usually greater in bulls and lower in heifers, whereas steers commonly stay in an intermediate position.

Commercial carcass weight

A database composed by 5 studies (Alhadas et al., 2021; Andrade, 2021; Lage, unpublished; Matos, unpublished; Pacheco, unpublished; Silva, unpublished) performed at UFV, totalizing 192 animals encompassing Zebu and crossbred beef bulls and heifers were utilized to evaluate the contribution of the dressing procedure on commercial CW (cCW), as well as to develop an equation for predicting cCW of beef cattle (Table 6.6) from eCW. Slaughter was performed similarly to that described previously for the estimative of eCW. Nevertheless, all carcasses were weighted before and after the dressing procedure, and the weight of each carcass constituent removed during this process was individually recorded. Thus, the dataset contained individual information on CW before (eCW) and after the dressing procedure (cCW), as well as the weight of each carcass component usually removed during the commercial dressing procedure, which were: the tissues damaged by exsanguination, nuchal ligament, lymph nodes, spinal cord, tissues associated to penis insertion (when present),

and the trimming of fat excess and all damaged or contaminated parts (additional dressing). Further, the sum of all carcass components removed during the dressing procedure (total dressing) was calculated and included in the dataset.

Table 6.6 - Descriptive statistics of the data used to develop the equation to estimate the commercial carcass weight of beef cattle

Item	Total data set	Gender		Genotype	
		Bull	Heifer	Zebu	Crossbred beef
Studies, n	5	4	1	4	1
Animals, n	192	170	22	143	49
Shrunk body weight, kg	422 ± 85.5	424 ± 88.3	412 ± 60.1	400 ± 74.0	488 ± 83.6
Carcass weight before dressing, kg	252 ± 52.4	254 ± 53.7	237 ± 38.3	238 ± 45.2	292 ± 51.4
Carcass weight after dressing, kg	237 ± 49.8	239 ± 51.2	222 ± 34.7	223 ± 41.8	279 ± 48.6
Dressing					
Tissues damaged by exsanguination; kg	2.26 ± 1.162	2.22 ± 1.206	1.58 ± 0.669	2.59 ± 1.126	1.31 ± 0.613
Nuchal ligament, kg	0.63 ± 0.233	0.66 ± 0.233	0.44 ± 0.097	0.72 ± 0.193	0.37 ± 0.114
Lymph nodes, kg	0.95 ± 0.510	0.95 ± 0.527	0.90 ± 0.360	1.12 ± 0.480	0.45 ± 0.122
Spinal cord, kg	0.34 ± 0.136	0.34 ± 0.141	0.32 ± 0.088	0.38 ± 0.126	0.22 ± 0.086
Tissues associated to penis insertion, kg	0.48 ± 0.400	0.48 ± 0.400	-	0.51 ± 0.460	0.42 ± 0.161
Trimming*, kg	9.62 ± 3.488	9.49 ± 3.442	10.6 ± 3.76	9.35 ± 3.707	10.4 ± 2.63
Total dressing, kg	14.2 ± 4.33	14.1 ± 4.34	14.8 ± 4.31	14.6 ± 4.63	13.2 ± 3.10

*Trimming of fat excess and all damaged or contaminated parts.

Data were coded for genotype (Zebu and beef crossbred) and gender (bull and heifer). Initially, data were tested for normality. Subsequently, the fixed effects of genotype and gender on the total dressing (kg) were tested using a mixed model, accounting for the random variation among studies. Further, a mixed model including the fixed effects of genotype, and gender, and random effects of the study were used to evaluate linear (Eq.6.1) and non-linear (Eq.6.4) models with or without the intercept, that best fit the relationship between cCW and eCW based on Akaike's Information Criteria (AIC). These analyses were performed with the MIXED procedure of SAS (version 9.4, Inst. Inc., Cary, NC), and 0.05 was established as the critical level of probability for a type I error.

There were no effect of genotype or gender ($P>0.05$) on the total dressing (kg). In addition, a linear equation without intercept had the lowest AIC for predicting cCW from eCW. Further, no effect of genotype or gender ($P>0.05$) was observed on the slope of the equation. Therefore, the developed equation for estimating cCW was:

$$cCW\ (kg) = 0.9391 \times eCW \qquad \text{Eq.6.3,}$$

where cCW = commmercial carcass weight (kg) and eCW = experimental carcass weight (kg).

Thus, after replacing eCW in Eq.6.3, the cCW can be calculated as follows:

$$cCW\ (kg) = 0.9391 \times (0.41764 \times SBW^{\beta 1}) \qquad \text{Eq.6.4}$$

where cCW = commercial carcass weight (kg); SBW = shrunk body weight (kg); $\beta 1$ = shown in Table 6.5.

The resulted cCW equation corroborate with the results on dressing procedure, where no effects of genotype or gender were observed for total dressing and slope of cCW equation. Although numerical differences in the contribution of some individual carcass component removed during the dressing procedure can be observed, Zebu and crossbred

beef bulls and heifers presented similar total dressing in cCW (14.2 kg, on average).

Validation of the predictive equation of commercial carcass weight

An independent database containing cattle slaughtered in experimental and commercial conditions was used to validate the cCW equation (Table 6.7). The experimental data set was composed of 1196 observations from 10 studies, encompassing Zebu and crossbred beef bulls and heifers. In this case, the removal of the same carcass components described for the dressing procedure in the previous section was performed to obtain the observed cCW values at experimental conditions. Commercial data set was composed of 30 means from 1431 animals, encompassing Zebu and crossbred beef bulls, steers, and heifers. The data set used in the validation analysis was not included in the data set used to adjust the tested equation.

Table 6.7 - Descriptive statistics of the data used to validate the non-linear model to predict commercial carcass weight of beef cattle

Item	Data set	
	Experimental	Commercial
Studies, n	10	-
Animals, n	1196	1431
Gender, %		
Bull	99.0	70.4
Steer	-	4.2
Heifer	1.0	25.4
Genotype, %		
Zebu	90.7	47.9
Crossbred beef cattle	9.3	52.1
Shrunk body weight, kg	488 $\pm$ 53.5	454 $\pm$ 52.5

Validation analysis was performed as previously described for the evaluation of Eq.6.1.

Validation analysis demonstrated that Eq.6.4 accurately and precisely estimated the cCW, as the null hypothesis of a respective intercept, and slope equal to 0 and 1 were not rejected ($P>0.05$) and values of R and CCC were close to 1 for either experimental or commercial slaughter plants data sets (Table 6.8; Figure 6.1).

However, a superior goodness of fit was observed when cCW was validated with the experimental data set, which presented the greatest R^2 and CCC values and the lowest MSEP. Furthermore, the MSEP partitioning showed that the proportions of SB were 0.01 and 18.3%, whereas proportions of MoF were 99.8 and 67.9% in the experimental and commercial data set comparisons, respectively.

Table 6.8 - Validation statistics of the relationship between the observed and predicted commercial carcass weight of beef cattle by the non-linear model

Item*	Slaughter procedure			
	Experimental		Commercial	
	Observed	Predicted	Observed	Predicted
Mean, kg	275	274	254	250
Standard deviation, kg	33.6	32.8	20.6	21.1
Maximum, kg	378	373	278	291
Minimum, kg	138	138	215	205
R^2	-	0.94	-	0.89
CCC	-	0.97	-	0.92
Regression				
Intercept				
Estimate	-	1.64	-	23.7
Standard error	-	1.922	-	15.23
P-value	-	0.394	-	0.131
Slope				
Estimate	-	0.99	-	0.92
Standard error	-	0.007	-	0.061
P-value	-	0.424	-	0.212
MSEP	-	64.8	-	65.4
SB	-	0.01	-	18.3
MaF	-	0.03	-	2.59
MoF	-	64.7	-	44.4

*R^2 = determination coefficient; CCC = correlation and concordance coefficient; MSEP = mean square error of prediction; SB = squared bias; MaF = magnitude of random fluctuation; MoF = model of random fluctuation.

The greatest R^2 and CCC and the lowest MSEP indicated a superior accuracy and reproducibility in the experimental evaluation. Moreover, prediction errors for cCW were less associated with central tendency (SB) in experimental than commercial conditions.

Thus, prediction errors for cCW in experimental conditions had a lower proportion associated with the model than those for commercial conditions.

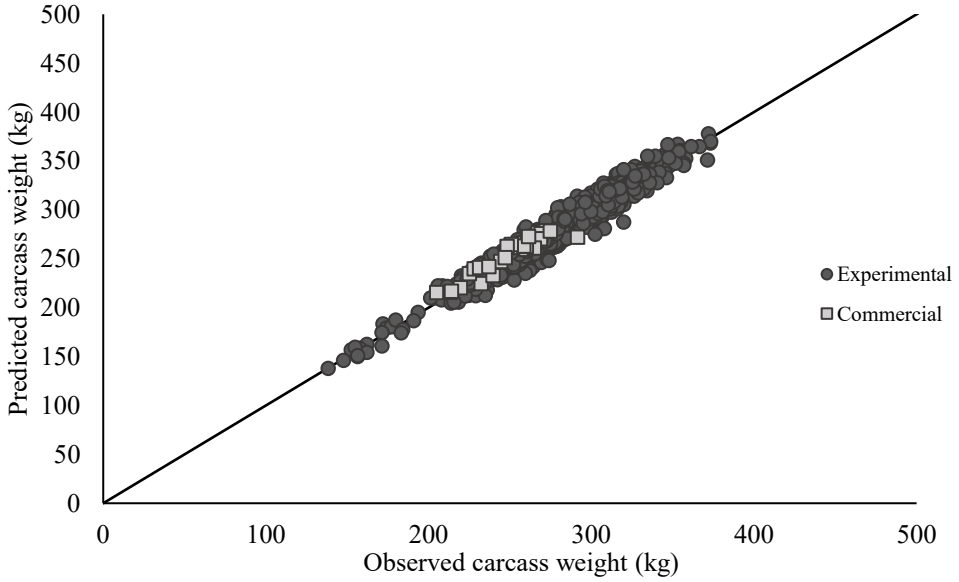


Figure 6.1 - Relationship between the observed and predicted commercial carcass weight of beef cattle by the non-linear model.

The goodness of fit of equations might be reduced when they are applied to estimate variables in different conditions than the ones used to generate the equation. Although the equation was proposed for predicting cCW, all data used to generate this equation was obtained in experimental conditions, in which the dressing procedure usually performed in commercial slaughter plants was reproduced to estimate cCW from eCW. Moreover, cattle were not transported, as the experimental slaughterhouse was located near the experimental feedlot. As previously discussed, there are differences on dressing procedures among different slaughterhouses, which might affect the CW. Unlike the dressing procedure performed in the current study, the hump muscle can also be removed during the dressing procedure of some slaughterhouses, for example. Moreover, cattle transport to commercial slaughter plants may lead to carcass losses due to bruising and/or shrink, whose incidence and/or severity seem to be dependent on the distance traveled, type of vehicle, animal genotype and gender (Schwartzkopf-Genswein et al., 2016). Thus, variations on the specific management and dressing procedure performed in commercial validation database and those in the database utilized for generating the equation could have contributed to reduced goodness of fit when predicting cCW in commercial conditions.

Furthermore, experimental database included bulls (99%) and heifers (1.0%), while the commercial included bulls (70.4%), steers (4.2%), and heifers (25.4%). Also, experimental database utilized in the validation was composed mostly by cattle from Zebu genotype (90.7%), whereas most cattle in the commercial database were beef crossbred (52.1%). This may also explain the better performance of the models for cattle slaughtered under experimental procedures, since bulls and Zebu cattle represented 88.5 and 74.5% of the data used to develop the proposed cCW equation, respectively. Moreover, there were no steers in the data set used to generate the cCW equation. Nevertheless, the cCW equation can be considered adequate to estimate cCW due to its good precision and accuracy in both experimental and commercial conditions.

ESTIMATION OF BACKFAT THICKNESS

Assis (2021) proposed an equation for predicting BFT of beef cattle. Then, a metanalysis was performed using data of 744 cattle from 21 studies encompassing bulls, steers, and heifers of different genotypes (Zebu, beef crossbred, and dairy crossbred), slaughtered in experimental and commercial conditions (Table 6.9). The database contained individual information on SBW, CW, BFT measured between the 12th and the 13th ribs, and average daily gain (ADG) during the finishing phase.

Table 6.9 - Descriptive statistics of the data used to develop a model to predict backfat thickness of beef cattle

Item	n	Carcass weight (kg)	Average daily gain (kg/d)	Backfat thickness (mm)
Studies	21	-	-	-
Animals	744	248 ± 64.0	1.10 ± 0.413	4.04 ± 2.073
Gender				
Bull	571	265 ± 53.9	1.18 ± 0.367	4.06 ± 1.949
Steer	95	217 ± 64.4	0.80 ± 0.370	4.12 ± 2.442
Heifer	78	162 ± 47.6	0.86 ± 0.532	3.73 ± 2.441
Genotype				
Zebu	589	257 ± 63.8	1.08 ± 0.398	4.27 ± 1.983
Crossbred beef cattle	41	209 ± 43.2	1.42 ± 0.331	5.16 ± 2.409
Crossbred dairy cattle	114	219 ± 57.7	1.15 ± 0.463	2.47 ± 1.583
Slaughter plant				
Commercial	342	288 ± 39.8	1.17 ± 0.361	4.88 ± 1.761
Experimental	402	215 ± 61.6	1.04 ±0.453	3.32 ± 2.049

Thus, a mixed model including the fixed effects of genotype, gender, and slaughter conditions (commercial or experimental), and random effects of the study were tested for developing the BFT equation. The variance component structure was selected to determine the model with the best fit based on the AIC. These analyses were conducted with the MIXED procedure of SAS (version 9.4, Inst. Inc., Cary, NC), and 0.05 was established as the critical level of probability for a type I error. More details regarding this study can be found in Assis (2021).

A linear equation including intercept had the lowest AIC value (AIC = 2840) for predicting BFT from ADG and CW. Moreover, no effects of genotype, gender or slaughter condition were observed (P>0.05) on the intercept or the coefficient associated with the ADG predictive variable. However, interactions between genotype and gender were found for the coefficient associated with the CW predictive variable. Thus, Assis (2021) suggested the following BFT predictive equation:

$$BFT\ (mm) = -2.37 + 0.709 \times ADG + CW \times G \quad (R^2 = 0.49, RMSE = 1.67) \qquad \text{Eq.6.5,}$$

where BFT = backfat thickness (mm), ADG = average daily gain (kg/d), CW = carcass weight (kg), and G = interaction between genotype and gender effect (if Zebu bull = 0.0238, if Zebu steer = 0.03043, If Zebu heifer = 0.03545, if crossbred beef bull = 0.02705, if crossbred beef steer = 0.03368, if crossbred beef heifer = 0.03871, if crossbred dairy bull = 0.01770, if crossbred dairy steer = 0.02433, and if crossbred dairy heifer = 0.02935).

The model proposed adjusts the effect among genotype and gender, as well as the effect of gain rate; therefore, this equation indirectly accessed the effects of intake level and diet type on cattle CY and BFT. The ADG predictive variable explained most of BFT variations.

Validation of backfat thickness predictive equation

Brasileiro (2023) evaluated the goodness of fit of the BFT equation proposed by Assis (2021). Validation database was composed of 43 treatment means from 16 published studies (Table 6.10). The data set used in the validation analysis was not included in the data set used to adjust the BFT equation.

Table 6.10 - Descriptive statistics of the data used to validate the model to predict backfat thickness of beef cattle described on Eq.6.5

Item	n	Carcass weight, kg	Average daily gain, kg/d
Studies	16	-	-
Animals	1142	278 ± 30.2	1.36 ± 0.248
Gender			
Bull	1051	284 ± 24.5	1.38 ± 0.219
Steer	91	237 ± 40.8	1.21 ± 0.407
Genotype			
Zebu	939	276 ± 29.5	1.34 ± 0.249
Crossbred beef cattle	203	287 ± 34.9	1.49 ± 0.212

Validation analysis was performed as described in the previous sections of this Chapter. The Eq.6.5, proposed by Assis (2021), accurately predicted BFT of beef cattle (Table 6.11; Figure 6.2), as the null hypothesis of a respective intercept and slope equal to 0 and 1 (P > 0.05) was not rejected; and presented high CCC (CCC = 0.76). Moreover, the prediction errors for BFT were mostly (more than 71% of MSEP) associated with random error (MoF), rather than central tendency (SB), and due to linear regression or systematic bias (MaF).

Table 6.11 - Validation statistics of the relationship between the observed and predicted backfat thickness of beef cattle

Item*	Backfat thickness	
	Observed	Predicted
Mean, kg	5.18	5.53
Standard deviation, kg	0.98	0.903
Maximum, kg	7.55	7.61
Minimum, kg	3.04	3.49
R^2	-	0.65
CCC	-	0.76
Regression		
Intercept		
Estimate	-	0.29
Standard error	-	0.556
P-value	-	0.610
Slope		
Estimate	-	0.89
Standard error	-	0.099
P-value	-	0.256
MSEP	-	0.45
SB	-	0.12
MaF	-	0.01
MoF	-	0.32

*R^2 = determination coefficient; CCC = correlation and concordance coefficient; MSEP = mean square error of prediction; SB = squared bias; MaF = magnitude of random fluctuation; MoF = model of random fluctuation.

The equation proposed by Assis (2021), Eq.6.5, accurately and precisely estimated and, therefore, is recommended to estimate the BFT of Zebu and crossbred beef bulls and steers. The BFT equation may contribute for decision-making process in the beef cattle industry, allowing a more homogeneous carcass production. Nevertheless, further studies should be performed to evaluate the goodness of fit for predicting the BFT of other cattle categories, such as crossbred dairy cattle and Zebu and crossbred beef heifers.

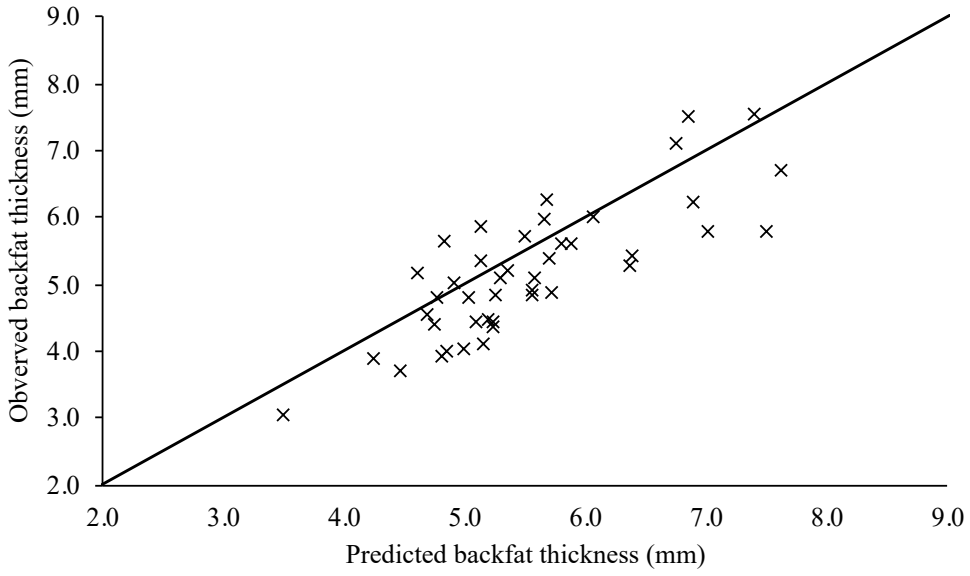


Figure 6.2 - Relationship between the observed and predicted backfat thickness of beef cattle.

WEIGHT LOSS DURING TRANSPORTATION

Andrade (2021) evaluated the effects of transportation on total BW (kg) and rate (kg/h) of BW loss, as well as the fractional rate of BW loss (% BW/h) of beef cattle in Brazilian conditions. Twenty Nellore growing bulls were used. Briefly, all animals were weighed (weight before transportation), transported for 8.45 h in a commercial livestock truck for 320.9 km, and weighed immediately after completing the journey (weight after transportation). Then, total weight loss (kg), weight loss as function of transport duration (kg/h), and the fractional weight loss rate (% BW/h) were calculated (Table 6.12).

Table 6.12 - Weight loss of beef cattle during transportation in Brazil, adapted from Andrade (2020)

Body weight		Weight loss		
Before transportation (kg)	After transportation (kg)	kg	kg/h	% BW/h
274	261	13.0	1.54	0.56
272	265	7.00	0.83	0.31
255	244	11.0	1.3	0.51
250	235	15.0	1.78	0.71
236	229	7.50	0.89	0.38
265	253	12.0	1.42	0.54
273	259	14.0	1.66	0.61
265	250	15.0	1.78	0.67
246	234	12.0	1.42	0.58
241	227	14.0	1.66	0.69
300	283	17.0	2.01	0.67
297	280	17.0	2.01	0.68
252	243	9.00	1.07	0.42
233	221	12.0	1.42	0.61
245	229	16.0	1.89	0.77
302	287	15.0	1.78	0.59
250	239	11.0	1.3	0.52
278	263	15.0	1.78	0.64
230	225	5.00	0.59	0.26
235	223	12.0	1.42	0.60
Average		12.5	1.48	0.57

On average, the weight loss experienced by cattle was: 12.5 kg, 1.48 kg/h, and 0.57 % BW/h. Considering the total duration of transportation (8.45 h), the growing Nellore bulls in Andrade (2021) study lost approximately 4.80 % BW, on average.

Schwartzkopf-Genswein and Grandin (2019) summarized studies conducted in North America evaluating the effects of transportation on productivity and health of cattle. Authors reported that transportation durations between 2 and 48 h resulted in weight loss values between 0 and 8% of BW. Many factors such as cattle category, handling at loading and unloading, drivers experience and training, loading density, environmental and vehicle conditions, and transportation distance and duration were associated with the severity of weight loss.

González et al. (2012), evaluating the factors affecting cattle shrink, reported BW loss from 4.90 to 7.94 % BW in cattle (calves, growing, finishing, and cull cattle) transported in long haul (> 400 km) from 11.6 to 14.9 h in Canada. Also, the authors found that calves, growing, and cull cattle as well as cattle loaded during afternoon and evening appeared to be more affected by transportation than finishing cattle and those loaded during the night and the morning, respectively, because of greater shrink.

Moreover, weight loss of 4.6, 6.5, and 7.0% of BW was observed in steers when transported for 5, 10, and 15 h, respectively (Warriss et al., 1995). Studies performed in Chile corroborate with the previous findings, where weight loss of about 3.5 and 12.5 % of BW were reported in weaned beef calves transported for short (3 h) and long (63 h) journeys, respectively (Werner et al., 2013; Bravo et al., 2018).

Thus, cattle will be subjected to weight loss when they are moved, however, the weight loss rate (% of BW/h) during transportation seems to be variable, and the greatest proportion of BW loss will occur during the early hours of feed and water deprivation (Knowles et al., 1999; Coffey et al., 2001). Weight loss rate calculated from Warriss et al. (1995) study was 0.92, 0.65, and 0.46 % of BW/h for steers transported for 5, 10, and 15 h, respectively, while Andrade (2021) reported an average BW loss rate of 0.57 % of BW/h for Nellore bulls that travelled for 8.45 h.

Studies evaluating the effects of transportation on the productive performance (specially BW loss) of beef cattle under Brazilian conditions are scarce. However, it seems that the results of Andrade (2021) corroborate with the discussion previously performed along this chapter. Nonetheless, caution must be taken when considering the results herein presented, as cattle weight loss due to transportation is dependent on other factors, such as cattle category, management, and environmental conditions.

FINAL CONSIDERATIONS

The equations presented in this chapter correctly estimated and, therefore, are recommended to estimate CW and BFT of beef cattle. We hope that these equations contribute for the production of more homogeneous carcasses and help the decision-making process in the beef cattle production system.

SUMMARY OF EQUATIONS AND PREDICTIONS

We suggest the use of the following equations described below to predict CW and BFT of beef cattle.

Carcass weight:

Eq. 6.1. Linear equation

$$cCW = -11.0 + P + ((0.6094 + G + B) \times SBW),$$

where

cCW = commercial carcass weight (kg); P = slaughter procedure effect (if commercial = -10.98, if experimental = 0), G = gender effect (if steer = 0, if bull = 0.008169, and if heifer = -0.00612), B = genotype effect (if Zebu = 0, if beef crossbred = -0.01595, and if dairy crossbred = -0.03301), and SBW = shrunk body weight (kg).

Eq. 6.4. Non-linear equation

$$cCW\ (kg) = 0.9391 \times (0.41764 \times SBW^{\beta 1})$$

where

cCW = commercial carcass weight (kg);; SBW = shrunk body weight (kg); β1 = genotype and gender effect, if Zebu bull = 1.0583, if crossbred beef bull = 1.0561, if crossbred dairy bull = 1.0479, if Zebu steer = 1.0549, if crossbred beef steer = 1.0527, if crossbred dairy steer = 1.0445, if Zebu heifer = 1.0533, if crossbred beef heifer = 1.0511, and if crossbred dairy heifer = 1.0429;

Eq. 6.5. Backfat thickness:

$$BFT = -2.37 + 0.709 \times ADG + cCW \times G,$$

where BFT = backfat thickness (mm), ADG = average daily gain (kg/d), cCW = commercial carcass weight (kg), and G = interaction between genotype and gender effect (if Zebu bull = 0.0238, if Zebu steer = 0.03043, If Zebu heifer = 0.03545, if crossbred beef bull = 0.02705, if crossbred beef steer = 0.03368, if crossbred beef heifer = 0.03871, if crossbred dairy bull = 0.01770, if crossbred dairy steer = 0.02433, and if crossbred dairy heifer = 0.02935.

In Tables 6.13 (linear CW equation, Eq. 6.1), 6.14 (non-linear CW equation, Eq. 6.4), and 6.15 (BFT equation, Eq. 6.5), predictions of CW and BFT for Zebu, crossbred, beef and dairy cattle are presented for different gender, slaughter in experimental and commercial conditions.

Table 6.13 - Carcass weight estimations[1] of beef cattle with different shrunk body weight (SBW), from Eq. 6.1, Benedeti et al. (2021)

Item	Experimental[2]			Commercial[2]		
	Zebu	Crossbred beef cattle	Crossbred dairy cattle	Zebu	Crossbred beef cattle	Crossbred dairy cattle
350 kg of SBW						
Heifer, kg	200	195	189	189	184	178
Steer, kg	202	197	191	191	186	180
Bull, kg	205	200	194	194	189	183
450 kg of SBW						
Heifer, kg	260	253	246	249	242	235
Steer, kg	263	256	248	252	245	237
Bull, kg	267	260	252	256	249	241
550 kg of SBW						
Heifer, kg	321	312	303	310	301	292
Steer, kg	324	315	306	313	304	295
Bull, kg	329	320	310	318	309	299

[1]Carcass weight (kg) = −11.03 + P + ((0.6094 + G + B) × SBW), where P = slaughter plant effect (if commercial = −10.98, if experimental =0), G = gender effect (if steer = 0, if bull = 0.008169 and if heifer = −0.00612), B = genotype effect (if Zebu = 0, if beef crossbreds = −0.01595, and if dairy crossbred = −0.03301), and SBW = shrunk BW (kg).
[2]Experimental = independent data of animals slaughtered in an experimental plant without carcass dressing/trimming; Commercial = independent data of animals slaughtered in a commercial abattoir.

Table 6.14 - Carcass weight estimations of beef cattle with different shrunk body weights (SBW), from Eq.6.2 and 6.3

Item	Experimental[1]			Commercial[2]		
	Zebu	Crossbred beef cattle	Crossbred dairy cattle	Zebu	Crossbred beef cattle	Crossbred dairy cattle
350 kg of SBW						
Heifer, kg	200	197	188	188	185	176
Steer, kg	202	199	190	189	187	178
Bull, kg	206	203	194	193	191	182
450 kg of SBW						
Heifer, kg	260	257	244	244	241	229
Steer, kg	263	259	247	247	244	232
Bull, kg	268	265	252	252	249	236
550 kg of SBW						
Heifer, kg	322	317	301	302	298	283
Steer, kg	325	320	304	305	301	286
Bull, kg	332	327	311	312	307	292

[1]eCW = 0.41764 × $SBW^{\beta 1}$, where eCW = experimental carcass weight (kg); SBW = shrunk body weight (kg); β1 = genotype and gender effect, if Zebu bull = 1.0583, if crossbred beef bull = 1.0561, if crossbred dairy bull = 1.0479, if Zebu steer = 1.0549, if crossbred beef steer = 1.0527, if crossbred dairy steer = 1.0445, if Zebu heifer = 1.0533, if crossbred beef heifer = 1.0511, and if crossbred dairy heifer = 1.0429;
[2]cCW = 0.9391 × eCW, where cCW = commercial carcass weight (kg).

Table 6.15 - Backfat thickness estimations[1] of beef cattle with different carcass weights (cCW) and average daily gains (ADG), from eq.6.5

Item	Zebu			Crossbred beef cattle			Crossbred dairy cattle		
cCW, kg	200	260	320	200	260	320	200	260	320
0.5 kg of ADG									
Heifer, mm	5.07	7.20	9.33	5.73	8.05	10.37	3.85	5.62	7.38
Steer, mm	4.07	5.90	7.72	4.72	6.74	8.76	2.85	4.31	5.77
Bull, mm	2.74	4.17	5.60	3.39	5.02	6.64	1.52	2.59	3.65
1.0 kg of ADG									
Heifer, mm	5.43	7.56	9.68	6.08	8.40	10.73	4.21	5.97	7.73
Steer, mm	4.43	6.25	8.08	5.08	7.10	9.12	3.21	4.66	6.12
Bull, mm	3.10	4.53	5.96	3.75	5.37	7.00	1.88	2.94	4.00
1.5 kg of ADG									
Heifer, mm	5.78	7.91	10.04	6.44	8.76	11.08	4.56	6.32	8.09
Steer, mm	4.78	6.61	8.43	5.43	7.45	9.47	3.56	5.02	6.48
Bull, mm	3.45	4.88	6.31	4.10	5.73	7.35	2.23	3.30	4.36

[1]BFT = -2.37 + 0.709 × ADG + cCW × G; where BFT = backfat thickness (mm), ADG = average daily gain (kg/d), cCW = commercial carcass weight, and G = interaction between genotype and gender effect (if Zebu bull = 0.0238, if Zebu steer = 0.03043, If Zebu heifer = 0.03545, if crossbred beef bull = 0.02705, if crossbred beef steer = 0.03368, if crossbred beef heifer = 0.03871, if crossbred dairy bull = 0.01770, if crossbred dairy steer = 0.02433, and if crossbred dairy heifer = 0.02935.

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7

Respirometry and nutritional requirements of zebu and crossbred dairy cattle at different levels of feeding and physiological status

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INTRODUCTION

Calorimetry is based on the laws of thermodynamics, in which "energy can neither be created nor destroyed, only transformed" and "the amount of energy released or absorbed in a system does not depend on the paths taken during its transformation, but only on the energy contained in reagents and in the final products" (Lavoisier, 1780). In indirect calorimetry, also known as respirometry, the gaseous exchange between the organism and the environment are measured. Once the oxygen consumption (O_2) and the production of carbon dioxide (CO_2) and methane (CH_4) are known, the energy losses by gas and heat are calculated. The Calorimetry and Metabolism Laboratory of the *Universidade Federal de Minas Gerais* (UFMG), located in Belo Horizonte, Minas Gerais, was the first laboratory to build respirometry chambers in Latin America. Since 2009, experiments have been carried out to evaluate energy metabolism and methane production by ruminants. The results obtained are expressed in net energy (NE), which can be net energy for maintenance (NEm), net energy for lactation (NE_l), net energy for weight gain (NEg) and net energy for pregnancy (NEpreg). Net energy is, in fact, what is used by the animal for maintenance and each productive function. The conversion factors of total digestible nutrients (TDN) into digestible energy (DE) and metabolizable energy (ME), the latter for every physiologic function or NE, are calculated. The values of *k* (conversion efficiency of ME into NE) for maintenance (*km*), milk production (k_l), gain or growth (*kg*), and pregnancy (*kpreg*) are determined.

OPEN-CIRCUIT RESPIROMETRY SYSTEM

In an open-circuit respirometry system, the animal is housed in a sealed chamber system that does not allow any gaseous exchange between the inside and outside air, except through the air circulation system. A mass flow meter adjusts airflow as a function of temperature, pressure and humidity, and the CO_2 concentration inside the chamber never exceeds 1%. During the 24-h measurements, the analyzer instrument (Sable®) takes readings of the concentrations of CO_2, CH_4, and O_2 in atmospheric air and the air coming out of the chamber every 5 min. These concentrations, multiplied by the volume of air that passes through the chamber during the time of measurement, allow for the calculation of how much O_2 was consumed and how much CO_2 and CH_4 were produced (Rodríguez et al., 2007).

A correction factor should be generated to adjust the readings, which should be within appropriate respiratory quotient values. The calibration of gas analyzers is performed whenever the equipment is used, and consists of injecting, at a constant flow rate, gases of known concentrations into the analysis system. Pure nitrogen is used to calibrate the analyzers to the zero value of gases concentration. Atmospheric air is used to calibrate O_2 analyzers, assuming that it presents constant O_2 concentration (20.948%) and gaseous mixtures of known concentrations: CO_2 at 5% diluted in nitrogen, and methane at 1%, also diluted in nitrogen.

RESPIROMETRY FOR DETERMINATION OF HEAT PRODUCTION

An apparent digestibility assay is performed immediately before every measurement in the respirometry chamber. Total feces are collected for 5 days and urine for 24 h. Then, the animal is confined for 24 h in the respirometry chamber. The procedures and system specifications have been described by Rodríguez et al. (2007). Heat production measurements are carried out with animals fed at production levels in accordance with the established treatment (maintenance, intermediate and *ad libitum* level), at the various physiological stages or after 48-h solid feed fasting. The volume (L/d) of O_2 consumed and CO_2 and CH_4 produced in 24 h, and urinary nitrogen excreted (UN, g/d) are used to estimate the heat production (HP) according to Brouwer's equation (1965): HP (kcal) = (3.866 × VO_2) + (1.200 × VCO_2) – (0.518 × VCH_4) – (1.431 × UN). The ME in the diet is determined by subtracting the energy losses in the feces, urine, and methane from the gross energy intake (GEI). The energy loss in the form of methane is quantified by assuming a loss of the 9.45 kcal/L CH_4 produced (Brouwer, 1965). The concentrations of digestible energy (DE) and metabolizable energy (ME) in the diet, expressed in Mcal/kg DM, are obtained during the metabolic assay.

Measurement of gaseous exchange in the chamber is performed at least twice with each animal: once with the animal fed and once with the animal solid fasting of 48 h. Therefore, the heat production of the fed and fasted animal is known, the latter corresponding to the value of net energy required for the maintenance of the animal. The difference between the values obtained for the fed and fasting animal will correspond to the heat increment and, knowing the ME content of the diet, the NE value of the diet can be determined (Kleiber, 1972).

Some authors mention high values for the estimation of the NEm requirement from heat production in fasting. Thus, the regression of heat production in different diets, based on metabolizable energy intake, estimating the net requirement for maintenance by extrapolation, was also conducted in the experiments.

DATABASE

The database for measurements of respiratory exchanges includes a series of experiments performed in the Calorimetry and Metabolism Laboratory of UFMG, using respirometry chambers, since 2009. A total of 202 evaluations were included, and those that did not fit appropriately were discarded. The animals were Zebu (Nellore, Gyr, and Guzerat) and dairy crrossbred (F1 Holstein × Gyr). The forage used was *Tifton-85* hay (*Cynodon spp.*), corn silage (*Zea mays*), sorghum silage (*Sorghum bicolor*), and Tanzania grass silage (*Panicum maximum* Jacq cv. Tanzania) in forage:concentrate proportions ranging from 100:0 to 50:50. The concentrate was composed of ground corn, soybean meal, and mineral supplement. The animals were fed at maintenance, *ad libitum* and intermediate (moderate weight gain, 0.5 to 0.6 kg/d) levels. Table 7.1 describes the database used.

Table 7.1 - Database features used in the development and validation of methane production equations

Source	Degree/Year	n	Sex	Genetic Group	Breed[1]	Intake level
Ochoa, Sandra Lúcia Posada	PhD, 2010	5	Bulls	Zebu	Nellore	Maintenance Restricted[2] *Ad libitum*
Silva, Ricardo Reis	PhD, 2011	18	Non-pregnant females	Zebu, Dairy crossbred	Gyr Hol×Gyr Holstein	Maintenance
Lage, Helena Ferreira	Master, 2011	12	Non-pregnant females	Zebu, Dairy crossbred	Gyr Hol×Gyr Holstein	Maintenance
Fonseca, Marcelina Pereira da	Master, 2012	20	Bulls	Dairy crossbred	Hol×Gyr	*Ad libitum*
Ferreira, Alexandre Lima	PhD, 2014	15	Bulls	Dairy crossbred	Hol×Gyr	Maintenance Restricted[2] *Ad libitum*
Pancoti, Carlos Giovani	PhD, 2015	18	Non-pregnant females	Zebu, Dairy crossbred	Gyr Hol×Gyr Holstein	*Ad libitum*
Lage, Helena Ferreira	PhD, 2015	12	Pregnant females	Zebu, Dairy crossbred	Gyr HolxGyr	Restricted[2]
Carvalho, Pedro Henrique de Araújo	Master, 2016	12	Lactating cows	Zebu, Dairy crossbred	Gyr Hol×Gyr	Maintenance Restricted[2] *Ad libitum*
Souza, André Santos	PhD, 2016[1]	12	Non-pregnant females	Zebu	Nellore Guzerat	Maintenance Restricted[2] *Ad libitum*
Duque, Anna Carolinne Alvim	PhD, 2016	12	Non-pregnant females	Zebu	Guzerat	Maintenance Restricted[2] *Ad libitum*
Vivenza, Paolo Antônio Dutra	PhD, 2016	12	Lactating cows	Zebu, Dairy crossbred	Gyr Hol×Gyr	Maintenance Restricted[2] *Ad libitum*
Silva, Juliana Sávia	PhD, 2016	20	Bulls	Dairy crossbred	Hol×Gyr	Restricted[2] *Ad libitum*

[1]Hol×Gyr = F1 Holstein × Gyr animals
[2]Restricted = intermediate level of feeding between the *ad libitum* and maintenance intake.

The relationship among the dependent and independent variables was estimated used the statistical model below:

$$Y = B_0 + B_1X_{1ij} + b_0 + b_1X_{1ij} + B_2X_{2ij} + \ldots + B_nX_{nij} + e_{ij},$$

where B_0, B_1X_{1ij}, and B_2X_{2ij}, . . . , B_nX_{nij} are fixed effects (intercept and independent variable effects); b_0, is intercept, b_1, ee_{ij} *slope*, random effects of the experiments (i = 1...n studies and j = 1, ..., n_i value). The Minitab 16 program was used for statistical analyses. Multiple regression equations were developed using the unrestricted mixed model. To choose the variables for inclusion in the model, the stepwise regression and best subsets procedures were used. Each variable was tested for its random effects on the intercept, in order to choose the best fit based on the lowest RMSR (root mean square of the residual) and Mallows' CP. The presence of collinearities among the independent variables was evaluated. The equations that presented the best fit were selected.

Descriptive statistics (minimum, maximum, mean, median, standard error of the mean) for all variables, in the development of equations to predict methane production and energy partition, are shown in Table 7.2.

Table 7.2 - Descriptive statistics of the variables: methane production (CH_4), dry matter intake (DMI), dry matter intake per metabolic body weight ($DMI/BW^{0.75}$), body weight (BW), neutral detergent fiber intake (NDFI), neutral detergent fiber intake per metabolic body weight ($NDFI/BW^{0.75}$), digestible neutral detergent fiber intake (dNDF), gross energy intake (GEI), digestible energy intake (DEI), metabolizable energy intake (MEI), and gross energy of methane ($GECH_4$) of Zebu (n = 95) and dairy crossbred (n = 107) cattle

Variables	Minimum	Maximum	Mean	Median	MSE
CH_4, L/d	73.9	313	165	122	4.60
DMI, kg/d	2.92	13.4	6.08	5.70	0.21
DMI, $g/BW^{0.75}$	41.0	214	96.5	94.3	2.30
BW, kg	180	683	366	381	9.70
NDFI, kg/d[1]	1.27	9.21	3.18	3.84	0.11
NDFI, $g/BW^{0.75}$	16.3	72.4	38.6	40.6	1.20
dNDF, kg/d	0.70	4.39	1.94	1.78	0.08
GEI, Mcal/d	12.8	89.1	38.4	32.5	1.47
DEI, Mcal/d	9.10	62.8	27.6	24.5	1.17
MEI, Mcal/d	8.05	53.4	23.4	20.3	0.98
$GECH_4$, Mcal/d	0.70	6.58	2.31	1.83	0.09

[1]NDF = neutral detergent fiber corrected for ash and protein.

RESULTS

Animal, genetic group, sex, and physiological status were evaluated and presented no significant effect on methane production. On the other hand, significance was verified for the effect of study, which was considered in the development of the following equations. The database from specific experiments was deleted when it did not fit well with the models being developed. Equations for estimating the production of methane, shown in Table 7.3, were obtained using the variables selected by the stepwise and best subsets procedures. The same variables also provided the solution of the fixed effects of regression equations for predicting the daily production of methane (CH_4), expressed in L/d, and the respective coefficients of determination (R^2).

Evaluating the parameters obtained from the regressions, the adjusted coefficients of determination (R^2) were high and the RMSR values were relatively low. When analyzed as a fixed effect in the regression model, the dry matter intake (DMI) explained 87.7% of the variation in methane production, there being no improvement in the predictive model with the inclusion of other predictive variables. The same occurred with the GEI. Additionally, the quadratic effect for DMI was tested and, despite its significance ($P < 0.001$), there was no improvement in the fit of the regression model, suggesting the use of a simpler model. In Figure 7.1, methane production is verified as a function of DMI.

Table 7.3 - Fixed effects of regression equations based on variables: dry matter intake (DMI), gross energy intake (GEI), crude protein content in the diet (CP), and proportion of forage in the diet (F)

Equations		1	2	3
Intercept	Estimate	37.52	30.87	-439.0
	SE	4.773	5.238	199.2
	P-value	<0.001	<0.001	0.030
DMI (kg/d)	Estimate	19.33	---	21.71
	SE	0.7629	---	1.528
	P-value	<0.001	---	<0.001
GEI (Mcal/d)	Estimate	---	4.777	---
	SE	---	0.1969	---
	P-value	---	<0.001	---
CP (g/kg)	Estimate	---	---	1.155
	SE	---	---	0.445
	P-value	---	---	0.011
F (%)[1]	Estimate	---	---	417.3
	SE	---	---	189.1
	P-value	---	---	0.030
RQMR (L/d)		17.25	17.89	17.79
R^2		0.877	0.867	0.806

[1]F (%) = proportion of forage in the diet, expressed on a scale from 0 to 1.

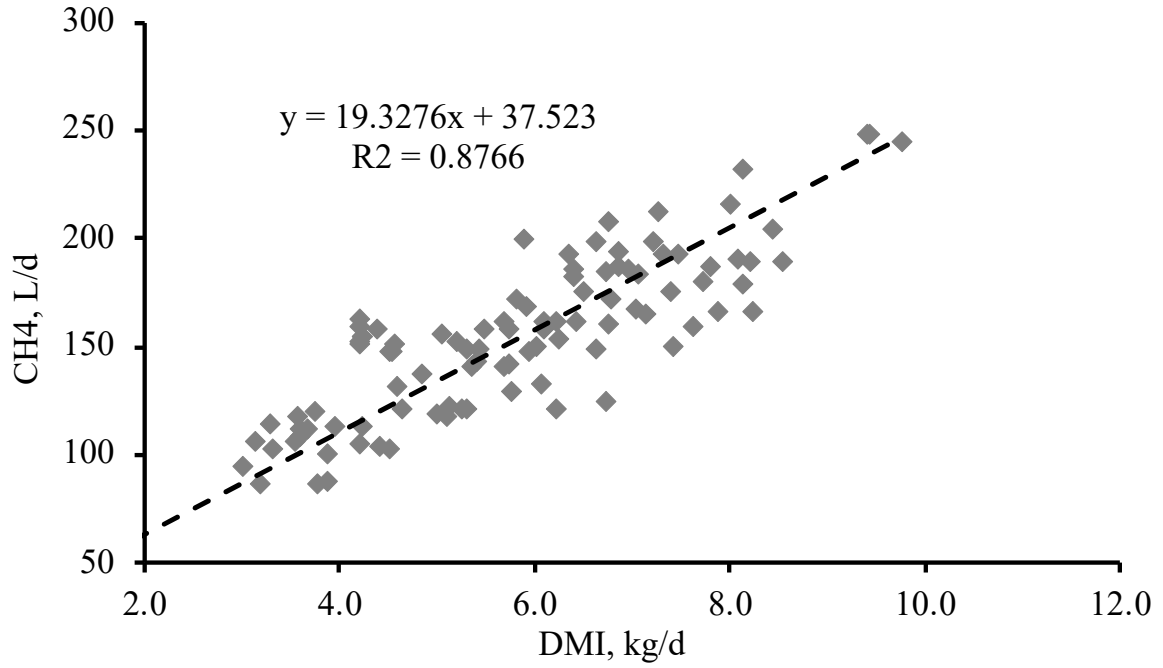


Figure 7.1 - Relationship between daily production methane (CH_4) and dry matter intake (DMI). The points represent the evaluations considered for the development model (n = 125).

Some authors have corroborated this strong positive relationship, considering DMI as a dominant factor in methane production, independent of the diet consumed (Kriss 1930, Axelsson 1949, Shibata et al., 1993). Some equations have been developed relating methane production to dietary composition (Moe and Tyrell, 1979; Bratzler and Forbes,

1940), and to DE intake (DEI), GEI and the level of feeding (Blaxter and Clapperton, 1965). More recently, Ramin and Huhtanen (2013) have developed more complex equations associating variables like DMI, organic matter intake (OMI), ether extract intake (EEI), the ratio of non-fibrous carbohydrates:total carbohydrates (NFC: tCHO) and the organic matter digestibility (OMD). Their equations showed low RMSR values (21.0 – 21.1 L/d), attesting to the accuracy of the estimate. However, considering the greater ease of determination and greater availability of information regarding the DMI variable, Equation 1 (Figure 7.1) is recommended for predicting enteric methane production for cattle growing under tropical conditions.

In order to evaluate the relationships between the amount of energy lost as methane and the energy consumed as GE (Figure 7.2) and DE (Figure 7.3), regression analyses were conducted on these values. They were significant and their prediction errors were 0.546 and 0.532 Mcal, respectively.

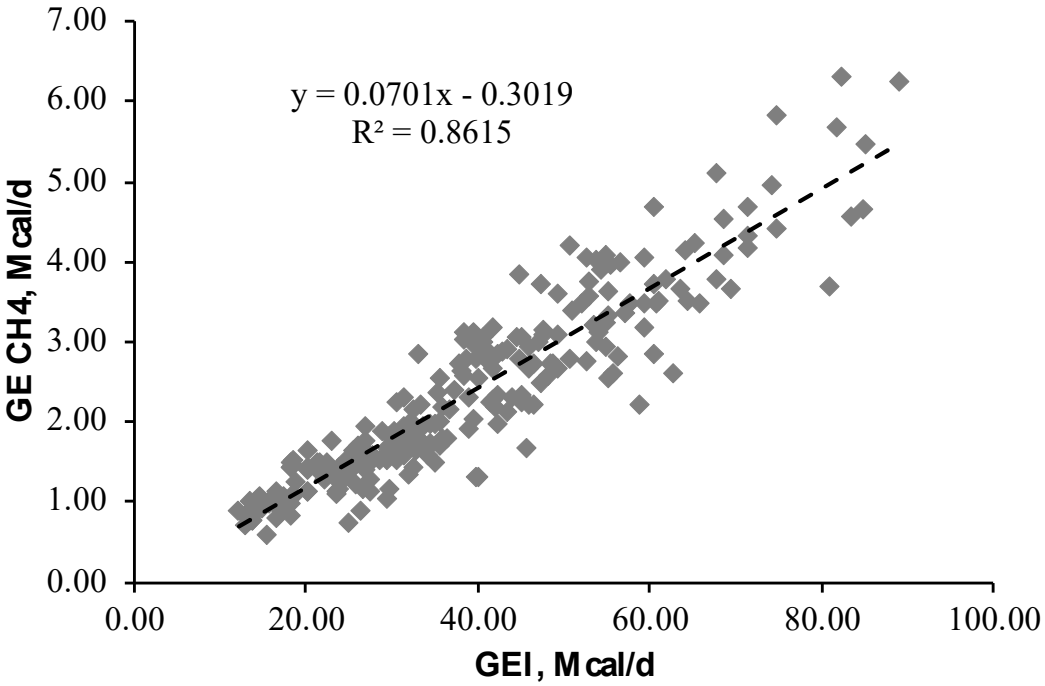


Figure 7.2 - Relationship between loss of gross energy as methane ($GECH_4$) and gross energy intake (GEI). The dots represent all evaluations contained in the database.

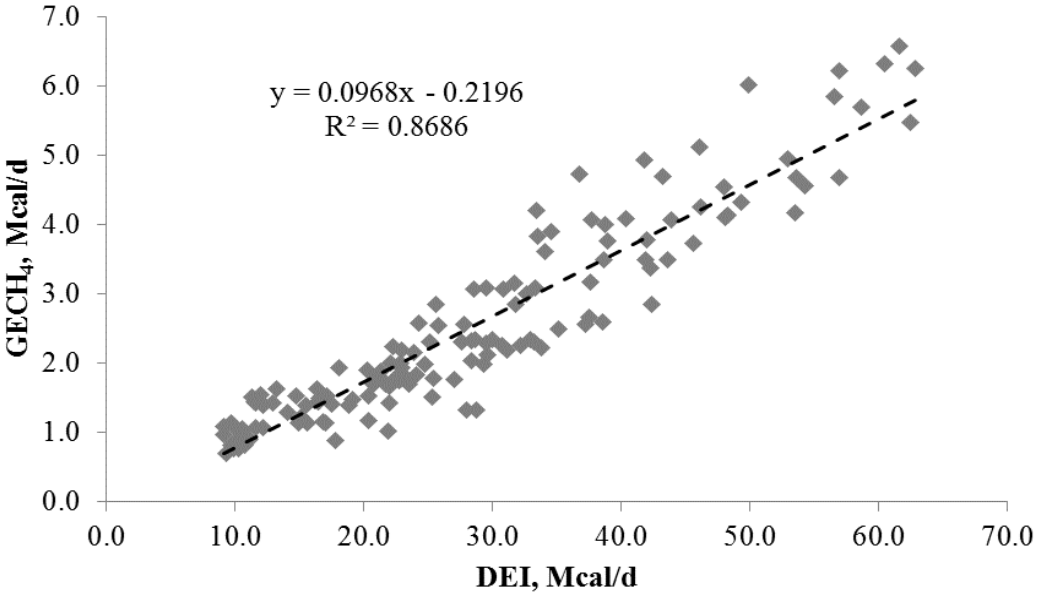


Figure 7.3 - Relationship between loss of gross energy as methane ($GECH_4$) and digestible energy intake (DEI). The dots represent all evaluations contained in the database.

Mcallister et al. (1996) mentioned the importance of nutrient availability for the ruminal microbiota as a main defining factor of the upper limit of production. Thus, when there is a lower efficiency of microbial growth, that is, a lower efficiency of microbial crude protein synthesis, there will be a low protein:energy relationship among the nutrients absorbed and consequently, greater methane production. Therefore, methane emission in relation to the productivity of the ruminant depends on rumen fermentation efficiency and feed conversion efficiency in animal products. Leng et al. (1993) claimed that cattle subjected to low-quality diets lost approximately 15% to 18% of DE in the form of methane, while those provided with balanced diets reduced their methane emission by approximately 7%.

Several studies have shown that when animal productivity is increased, there is a reduction in the proportion of methane produced per unit of product. According to the United States' Environmental Protection Agency (EPA, 2005), increasing livestock productivity to achieve lower methane emissions per unit of product is the most promising and cost-effective way to reduce emissions. Ferreira (2014) found moderate correlations (-0.49; $P = 0.03$) showing that the level of intake relative to maintenance was inversely related to methane production. Increasing the intake by one unit above maintenance resulted in a decrease of 0.73 percentage units of methane production (% GEI).

Moss (1994) claimed that, in low-quality forage, the addition of nutrients for microorganisms increases the efficiency of microbial growth because it increases the efficiency of the fermenting process in the rumen with a decrease in the methanogenic activity per unit of degraded carbohydrates. However, there is an increase in methane production per animal ranging from 8.4% to 12.3% of the GEI because more organic matter is fermented. It was found that the coefficient of the equation shown in Figure 7.2, represents 7% of GEI, and it is lower than the values suggested by the literature. Similarly, it was found that the coefficient of the equation in Figure 7.3 represents 9.68% of the DEI.

The results of NEm, efficiency of ME used for maintenance (*km*), weight gain (*kg*), pregnancy (*kpreg*), and milk (k_l) obtained in the different experiments are shown in Table 7.4.

Table 7.4 - Net energy requirement for maintenance (NEm) and efficiency of utilization of metabolizable energy for maintenance (*km*), weight gain (*kg*), pregnancy (*kpreg*), and lactation (k_l) of Zebu and crossbred cattle in different weight ranges and physiological states (status)

Growing							
Reference	Category	*Status*	BW (kg)	Genetic group	NEm	*km*	*kg*
Ochoa	Zebu, bulls	Growing	200	Nellore	124[2] 116[3]	0.65 0.60	0.23
			300		94.0[2] 92.0[3]	0.60 0.59	0.25
			400		98.0[2] 92.0[3]	0.70 0.65	0.40
			450		83.0[2] 84.0[3]	0.65 0.64	0.40
Fonseca	Dairy crossbred, bulls	Growing	250	F1 HxG	-	-	0.27
Ferreira	Dairy crossbred, bulls	Growing	350	F1 HxG	108[2] 74.6[3]	0.76 0.60	0.23
Silva	Zebu, heifer	Growing	300	Gyr	88.0[2]	0.60	-
	Dairy crossbred, heifers			F1 HxG	95.6[2]	0.67	-
Pancoti	Zebu, heifer	Growing	400	Gyr	83.9[2]	-	-
	Dairy crossbred, heifers			F1 HxG	96.7[2]	-	-
Silva	Dairy crossbred, bulls	Growing, 0-60 days	30-60	F1 HxG	73.7[2]	0.67	0.45
Mature and pregnant							
Reference	Category	*Status*	Body weight	Genetic group	NEm	*km*	*kpreg*
Lage[1]	Zebu, non-pregnant females	Mature	450	Gyr	76.8[2]	0.64	-
	Dairy crossbred, non-pregnant females			F1 HxG	92.0[2]	0.63	-
		Pregnancy (days)	Body weight	Genetic group	NEpreg (Mcal/d)	*km*	*kpreg*
	Zebu, pregnant females	180 d	450	Gyr	2.86	-	0.15
		210 d			2.33	-	
		240 d			1.62	-	
	Dairy crossbred, pregnant females	180 d	550	F1 HxG	2.70	-	
		210 d			2.71	-	
		240 d			2.88	-	
Lactation							
Reference	Category	*Status*	Body weight	Genetic group	NEm	NE_l[4]	k_l[5]
Vivenza	Zebu, lactating cows	1st third of lactation	453	Gyr	79.1[3]	0.778	0.69
	Dairy crossbred, lactating cows	1st third of lactation	526	F1 HxG	88.3[3]	0.778	0.72

[1]Data from master's dissertation and PhD thesis; [2]Net energy requirement for maintenance (NEm^2) obtained by fasting heat production (FHP); [3]Net energy requirement for maintenance (NEm^3) obtained by extrapolation; [4]Net energy requirement for lactation (Mcal/kg milk); [5]Efficiency of utilization of metabolizable energy for lactation.

Ferreira (2014) using dairy crossbred cattle, evaluated heat production in fasting bulls fed different diets corresponding to 1, 1.5, and 2 times (1×, 1.5×, and 2×) the DMI for body weight maintenance. The O_2 consumption ($L/BW^{0.75}$) under fasted and fed conditions did not differ between animals at 1× and 1.5× the maintenance diet, providing mean values of 22.25 and 30.35 $L/BW^{0.75}$, which represented a 36.4% increase in O_2 consumption as a function of feeding. The 2× treatment provided the greatest ($P < 0.001$) O_2 consumption with values of 26.77 and 39.03 $L/BW^{0.75}$ for the animals under fasted and fed conditions, respectively. The CO_2 production, similar to O_2 consumption, was greater for the 2× animals, which presented 21.2% and 37.6% greater production ($P < 0.001$) than the animals in the 1× group, under fasted and fed conditions.

Fasting heat production (FHP) was greater ($P < 0.001$) for the 2× group (133.3 $kcal/BW^{0.75}$), compared with the other groups (112.1 and 107.9 $kcal/BW^{0.75}$, respectively), among those in which the FHP did not differ. The lowest O_2 consumption and CO_2 production that occurred with reduced intake agrees with the results obtained by Ferrell et al. (1986), who indicated that the rates of oxygen consumption by organs as the liver and kidneys, per gram of tissue or as a function of their mass, decreased in response to feeding at the maintenance level. The effect of diet on maintenance metabolism has been associated with variations in the tissue metabolic rate. The causes of these variations are associated with changes in the energy rates and costs of blood flow, of the entrance of oxygen into the liver and in nutrient transference in the intestinal lumen (CSIRO, 2007).

A linear increase ($P < 0.001$) in FHP was seen in the present study with the increased intake of DM. The highest values of FHP found, for the highest levels of feeding, reflect the increase in energy demands as a function of the productive condition of the animal. Calculating how much of this increase is due to the maintenance or weight gain becomes an issue of interpretation, as the ARC (1980) reports, as the curvilinear relationship between retained energy and feed intake may be explained by considering a decrease in the efficiency of use of the feed supplied above the constant maintenance level. It may also be explained by considering a constant efficiency and a progressive increase in the components analogous to the maintenance diet.

Some authors report increased NEm values when using the FHP. Ochoa (2010) and Ferreira (2014) constructed the regression equation obtained by the logarithm for heat production (HP) measured in the respirometry chamber, on different diets, as a function of MEI. The values found by the extrapolation for metabolizable energy intake equal to zero corresponded to the "NEm^3" values described in Table 7.4. It is noted that these "NEm^3" values are lower than those obtained by the FHP (NEm^2), and closer to those obtained in experiments with comparative slaughter. The studies are in an initial phase, and need to be expanded, since they may indicate the change of methodology adopted in the experiments using respirometry. Similar to the NEm, the k_m found using the "NEm^3" is different from the value obtained using the NEm^2.

The efficiency of converting DE to ME is influenced by several factors, such as the rate of microbial growth in the rumen, production of methane, relationship between energy and protein in the diet, and efficiency of the use of metabolizable protein, among others. The ARC (1980) reports that the ME/DE relationship is approximately 0.82. The CSIRO (1990) and the NRC (2000) suggest a value between 0.81 and 0.80, respectively; whereas the AFRC (1993) uses values from 0.81 to 0.86. Higher relationships, from 0.89 to 0.92, were found by Hales et al. (2013). An analysis of the relationship between DE intake (DEI) and ME intake (MEI), determined from the metabolism trials in respirometry chambers, was conducted. The effect of author was significant, and was considered in the development of the plotted models (Figures 7.4 and 7.5).

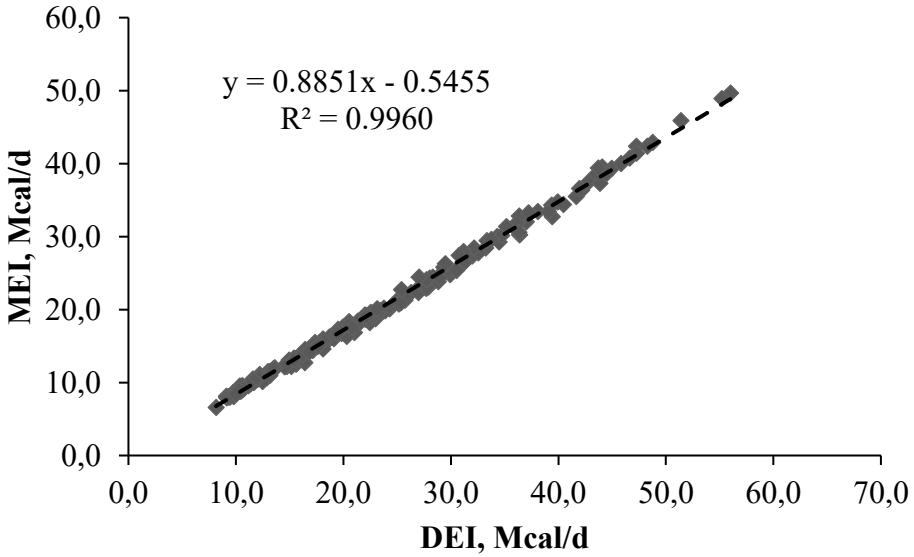


Figure 7.4 - Relationship between digestible energy intake (DEI) and metabolizable energy intake (MEI) expressed as Mcal/d.

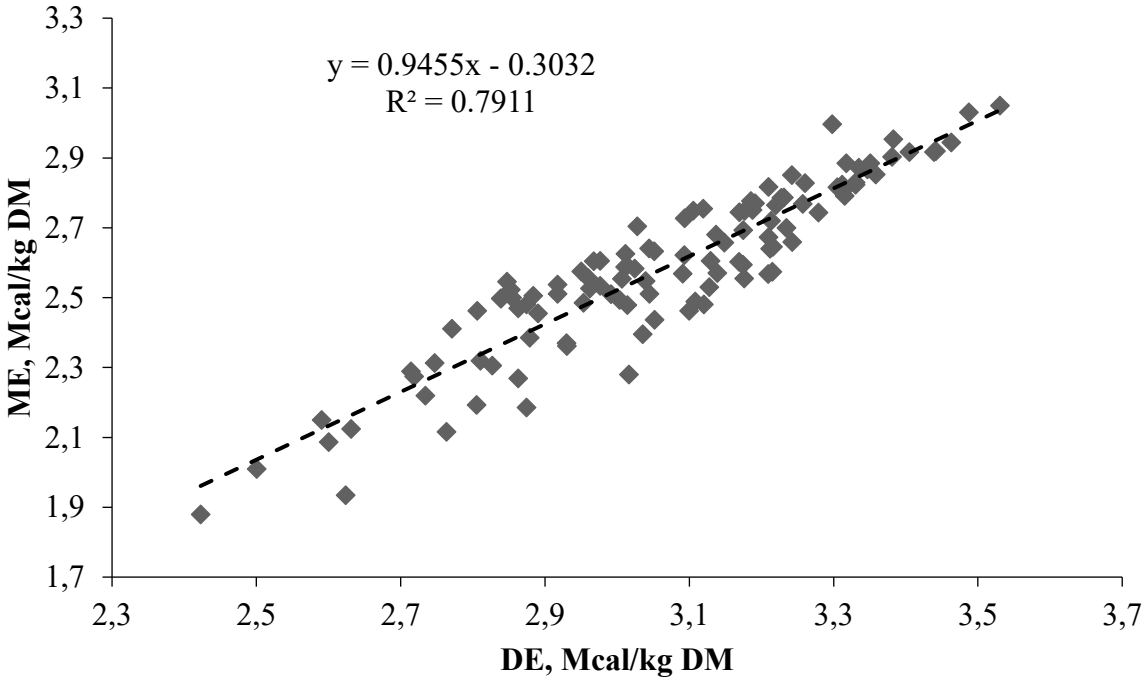


Figure 7.5 - Relationship between digestible energy and metabolizable energy expressed in Mcal per kg of dry matter.

The data presented high dependence of the MEI variable as a function of DEI (Figure 7.4, $R^2 = 0.99$). It is important to emphasize that, considering that in all experiments studied, the methane losses were measured in the respirometry chamber and were not estimated, the ME/DE ratio was always greater than 0.82.

Similarly, Galyean et al. (2016) proposed a model to predict the ME from the DE, in Mcal/kg of DM, based on their analysis of 23 studies published in several journals between 1975 and 2015. The prediction of the ME, using a linear model, showed a strong correlation with dietary components. However, the increase in the precision of the model with the inclusion of the crude protein (% CP), ether extract (% EE), and starch (%) variables was small and the authors recommended the use of a simple linear

regression. The comparison between the proposed model (Figure 7.5) and the one suggested by Galyean et al. (2016) is shown in Figure 7.6.

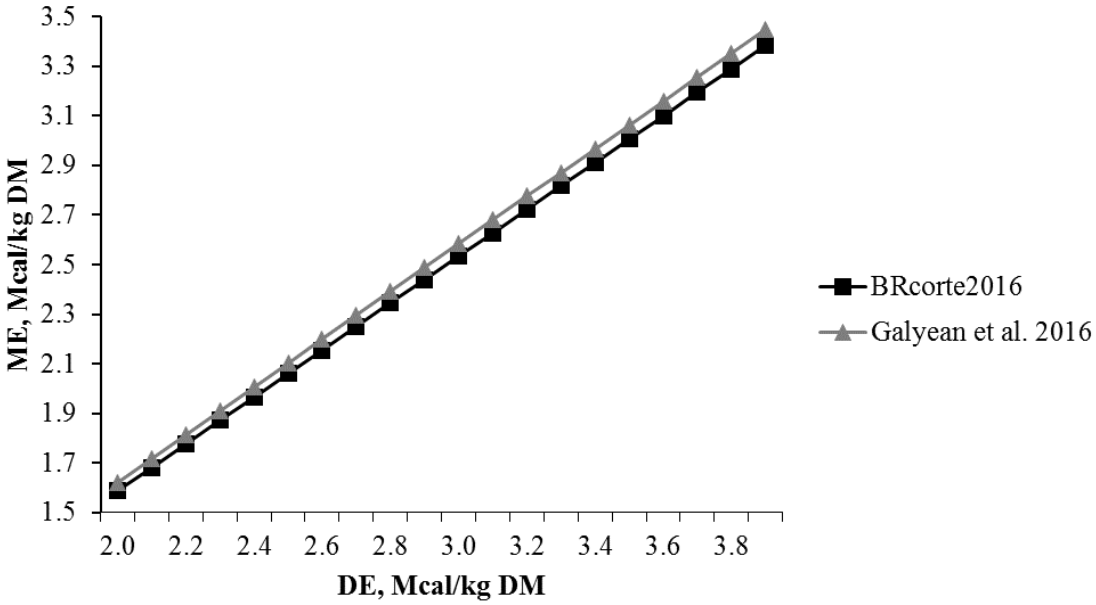


Figure 7.6 - Prediction of metabolizable energy (ME, Mcal/kg) from the digestible energy (DE, Mcal/kg) according to the model proposed by BR-CORTE 2016 and Galyean et al. (2016).

As may be seen in Figure 7.6, there is great similarity among the values predicted by the models. The efficiency of the ME conversion proposed by Galyean et al. (2016) is greater than the efficiency found when the conversion from DE to ME uses the model proposed in the present study (BR-CORTE, 2016, Figure 7.5). It is stressed that the national database contains a greater number of studies that used diets with lower energy density than that of Galyean et al. (2016). Therefore, the use of the simple linear model, proposed in Figure 7.4, is recommended in order to determine the ME from DE.

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8

Energy requirements for beef cattle

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INTRODUCTION

The accurate estimation of energy requirements for growing and finishing cattle is one of the key points of a feeding system. Thus, the energy obtained from nutrients (carbohydrates, proteins, and lipids) is important not only for the basal activities maintenance of the organism, but also for improving animals' performance (Caton and Dhuyvetter, 1997). Thus, energy waste is closely related to higher emission of greenhouse gases, which can lead to environmental problems (Tamminga, 1996). Hence, current models developed around the world have been constantly updated to provide more accurate equations and, thus, to assist nutritionists in diets formulation (BR-CORTE, 2016; NASEM, 2016; INRA, 2018). Therefore, the correct estimation of energy requirements is essential for the adequate supply of metabolizable energy required by an animal, which is desirable from both productive and sustainable points of view.

The energy requirements for growing and finishing cattle are estimated in BR-CORTE by the system presented to the scientific community by Lofgreen and Garrett (1968). This system was later known as the California Net Energy System (CNES) and established the basis for energy requirement recommendations of the subsequent editions of the North American System (NRC, 1984, 1996, 2000 and NASEM, 2016). A summary of what was established by the CNES System can be understood from the equation below:

$$MEt = MEm + MEg = (NEm / km) + (NEg / kg) \quad \text{Eq. 8.1}$$

where MEt = total metabolizable energy required, MEm = metabolizable energy requirements for maintenance, MEg = metabolizable energy requirements for gain, NEm = net energy requirements for maintenance, *km* = efficiency of use of the metabolizable energy for maintenance, NEg = net energy requirements for gain and *kg* = efficiency of use of MEg.

It should be noted that the basis of the definitions proposed by CNES and presented in equation 8.1 was established by previous researchers, who quantitatively studied the most varied aspects of energy use by animals (Atwater and Bryant, 1900; Armsby, 1917; Kleiber, 1961; Blaxter, 1962; Brody, 1945; Blaxter et al., 1966; Blaxter, 1969).

Since energy requirements evaluation is made based on what was established in equation 8.1, it is necessary to know the fractions presented in order to make the estimates. The BR-CORTE System uses a database of comparative slaughter experiments (Garrett et al., 1959). These experiments measure metabolizable energy intake (MEI) and the energy retained in the form of tissues in the animal body (NEg). The net energy spent on maintenance (NEm) and the inefficiency of energy use for maintenance ($1 - km$) and gain ($1 - kg$) represent the energy consumed that was transformed into heat (heat production) and are estimated by difference, based on the principles of energy conservation established in the first thermodynamic law (Clausius, 1850). Representative equations of these relationships are shown below:

$$MEI = RE + HP \quad \text{Eq. 8.2}$$

$$MEI = MEt \quad \text{Eq. 8.3}$$

$$RE = NEg \quad \text{Eq. 8.4}$$

$$HP = NEm + ((1 - km) \times MEm) + ((1 - kg) \times MEg) \quad \text{Eq. 8.5}$$

where MEI = metabolizable energy intake, RE = retained energy, HP = heat production, MEt = total metabolizable energy requirements, NEm = net energy requirements for maintenance, *km* = efficiency of use of metabolizable energy for maintenance, MEm = metabolizable energy requirements for

maintenance, *kg* = efficiency of metabolizable energy use for gain and MEg = metabolizable energy requirement for gain.

Since the value of heat production (HP) is obtained by the difference between metabolizable energy intake and retained energy, and three of the variables presented in equation 8.5 are derived from HP, mathematical models are used to estimate NEm, *km* and *kg* values, and they will be presented in the following text.

Based on the evolution of the database and knowledge on estimating nutritional requirements, the models used to estimate the energy requirements for growing and finishing cattle were discussed, reassessed and validated. Thus, recommendations were generated to estimate the nutritional energy requirements for growing and finishing Zebu beef cattle and their crosses, reared on pasture or feedlot under tropical conditions.

BR-CORTE HISTORY

In the BR-CORTE System, these requirements have been estimated from a database that has grown over its different editions, not only in the number of animals, but also in the variation in weights and genetic groups used. The first edition (BR-CORTE, 2006) used individual data from 180 Zebu (nine studies) reared in feedlot. In the second edition (BR-CORTE, 2010), requirements for Zebu and crossbred cattle were estimated from individual data of 626 animals (25 studies) raised in feedlot or pasture. In the third edition, estimates are presented for nutritional requirements for Zebu, crossbred dairy and beef cattle, and cattle in pasture and feedlot from individual data of 1369 animals and 38 different studies (BR-CORTE, 2016).

In this new edition, we used data from 21 studies (636 individual data) to develop new models for predicting RE from carcass gain (CG) of beef cattle with different gender (Bulls, steers, and heifers) and genotypes (Zebu, crossbred beef and dairy cattle).

DATABASE OF BR-CORTE (2016)

BR-CORTE (2016) was updated based on a database consisting of 38 studies carried out under Brazilian conditions (Table 8.1). The database had a greater predominance of animals raised in feddlot (N = 1369). Furthermore, the Zebu genetic group was the largest group represented in the database, with 744 animals (Table 8.1). The crossbred beef group of animals was formed by 142 Angus × Nellore, 62 Limousin × Nellore, 12 Marchigiana × Nellore, 73 Simmental × Nellore, 11 Brown Swiss × Nellore, 23 Brangus and 16 twice crossbred animals, with a greater European blood fraction coming from the Angus breed (Table 8.2). The crossbred dairy group of animals was formed by 16 Holstein × Gyr, 15 Holstein × Guzerat, 155 Nellore × Holstein, 21 Holstein and 79 crossbred dairy animals (Table 8.3). The database of animals reared in pasture was formed by 127 animals, all Nellore (Table 8.4).

Table 8.1 - Descriptive statistics of the data used to obtain the nutritional energy requirements of Zebu animals in feedlot

Items	N	Mean	Maximum	Minimum	SD
Bulls					
iSBW, kg	454	283	438	110	65.6
fSBW, kg	454	383	592	122	91.2
iEBW, kg	454	249	358	95.2	58.6
fEBW, kg	454	337	549	109	85.0
$EBW^{0.75}$, kg	454	70.9	98.2	32.1	12.5
ADG, kg/d	454	1.00	2.65	-0.14	0.45
EBG, kg/d	454	0.95	2.30	-0.13	0.43
RE, kcal/$EBW^{0.75}$	454	50.9	170	-97.4	36.7
MEI, kcal/$EBW^{0.75}$	454	220	467	0.49	78.2
HP, kcal/$EBW^{0.75}$	454	196	309	87.7	52.3
Steers					
iSBW, kg	166	291	399	164	46.7
fSBW, kg	166	364	520	195	68.4
iEBW, kg	166	255	352	150	41.7
fEBW, kg	166	322	469	148	67.0
$EBW^{0.75}$, kg	166	70.0	91.2	42.7	9.23
ADG, kg/d	166	0.71	1.53	-0.22	0.42
EBG, kg/d	166	0.70	1.63	-0.21	0.38
RE, kcal/$EBW^{0.75}$	166	30.8	103	0.63	23.1
MEI, kcal/$EBW^{0.75}$	166	212	310	114	53.8
HP, kcal/$EBW^{0.75}$	166	181	232	104	40.0
Heifers					
iSBW, kg	124	225	347	127	53.4
fSBW, kg	124	271	437	121	72.4
iEBW, kg	124	197	403	104	48.8
fEBW, kg	124	243	397	108	67.7
$EBW^{0.75}$, kg	124	57.2	89.5	33.0	10.7
ADG, kg/d	124	0.57	1.27	-0.12	0.39
EBG, kg/d	124	0.58	1.25	-0.13	0.37
RE, kcal/$EBW^{0.75}$	124	60.3	272	-6.02	52.3
MEI, kcal/$EBW^{0.75}$	124	217.5	338	110	80.5
HP, kcal/$EBW^{0.75}$	124	157	229	92.3	51.36

N = number of animals; SD = standard deviation; iSBW = initial shrunk body weight; fSBW = final shrunk body weight; iEBW = initial empty body weight; fEBW = final empty body weight; $EBW^{0.75}$ = mean metabolic empty body weight; ADG = average daily gain; EBG = empty body gain; RE = retained energy; MEI = metabolizable energy intake; HP = heat production.

Table 8.2 - Descriptive statistics of the data used to obtain the nutritional energy requirements of crossbred beef animals in feedlot

Items	N	Mean	Maximum	Minimum	SD
Bulls					
iSBW, kg	215	302	435	198	51.8
fSBW, kg	215	445	589	230	86.9
iEBW, kg	215	256	366	173	40.2
fEBW, kg	215	388	541	199	81.1
$EBW^{0.75}$, kg	215	75.9	98.3	50.4	11.3
ADG, kg/d	215	1.15	2.11	-0.07	0.43
EBG, kg/d	215	1.11	2.04	-0.05	0.42
RE, kcal/$EBW^{0.75}$	215	58.7	180	-6.72	34.8
MEI, kcal/$EBW^{0.75}$	215	244	489	97.4	76.0
HP, kcal/$EBW^{0.75}$	215	185	489	22.2	80.2
Steers					
iSBW, kg	75	312	434	189	68.9
fSBW, kg	75	414	581	224	93.2
iEBW, kg	75	274	385	166	65.3
fEBW, kg	75	371	518	201	90.3
$EBW^{0.75}$, kg	75	76.0	97.9	49.9	11.7
ADG, kg/d	75	1.10	2.35	-0.36	0.67
EBG, kg/d	75	1.11	2.11	-0.09	0.61
RE, kcal/$EBW^{0.75}$	75	79.9	114	9.49	32.0
MEI, kcal/$EBW^{0.75}$	75	265	505	90.3	105
HP, kcal/$EBW^{0.75}$	75	185	359	101	69.6
Heifers					
iSBW, kg	49	271	331	194	33.5
fSBW, kg	49	345	494	187	88.5
iEBW, kg	49	241	311	150	36.8
fEBW, kg	49	304	443	176	79.8
$EBW^{0.75}$, kg	49	67.1	85.6	45.5	9.14
ADG, kg/d	49	0.86	1.75	-0.31	0.66
EBG, kg/d	49	0.80	1.73	-0.18	0.58
RE, kcal/$EBW^{0.75}$	49	55.2	104	-7.60	33.4
MEI, kcal/$EBW^{0.75}$	49	238	355	112	82.8
HP, kcal/$EBW^{0.75}$	49	182	268	103	53.3

N = number of animals; SD = standard deviation; iSBW = initial shrunk body weight; fSBW = final shrunk body weight; iEBW = initial empty body weight; fEBW = final empty body weight; $EBW^{0.75}$ = mean metabolic empty body weight; ADG = average daily gain; EBG = empty body gain; RE = retained energy; MEI = metabolizable energy intake; HP = heat production.

Table 8.3 - Descriptive statistics of the data used to obtain the nutritional energy requirements of crossbred dairy animals in feedlot

Items	N	Mean	Maximum	Minimum	SD
Bulls					
iSBW, kg	85	407	495	317	50.5
fSBW, kg	85	451	661	191	110
iEBW, kg	85	341	415	266	40.2
fEBW, kg	85	394	600	167	106
$EBW^{0.75}$, kg	85	83.9	107	56.4	14.4
ADG, kg/d	85	1.68	2.64	0.45	0.60
EBG, kg/d	85	1.52	2.54	0.45	0.65
RE, kcal/$EBW^{0.75}$	85	92.5	167	18.5	36.1
MEI, kcal/$EBW^{0.75}$	85	273	348	154	60.5
HP, kcal/$EBW^{0.75}$	85	181	264	11.9	56.3
Steers					
iSBW, kg	88	279	455	104	90.1
fSBW, kg	88	358	575	159	95.9
iEBW, kg	88	231	363	94.9	66.0
fEBW, kg	88	312	510	146	86.5
$EBW^{0.75}$, kg	88	66.9	95.5	36.4	12.8
ADG, kg/d	88	0.97	2.05	0.15	0.43
EBG, kg/d	88	0.95	2.00	0.14	0.48
RE, kcal/$EBW^{0.75}$	88	47.8	112	-93.0	40.2
MEI, kcal/$EBW^{0.75}$	88	258	372	95.7	83.5
HP, kcal/$EBW^{0.75}$	88	210	343	80.9	67.3
Heifers					
iSBW, kg	113	247	399	150	57.6
fSBW, kg	113	309	399	230	55.7
iEBW, kg	113	161	230	115	31.3
fEBW, kg	113	274	375	192	57.6
$EBW^{0.75}$, kg	113	56.6	72.5	43.6	9.19
ADG, kg/d	113	1.00	1.37	0.29	0.30
EBG, kg/d	113	0.88	1.30	0.30	0.37
RE, kcal/$EBW^{0.75}$	113	72.1	115	36.7	23.5
MEI, kcal/$EBW^{0.75}$	113	416	548	348	59.1
HP, kcal/$EBW^{0.75}$	113	344	475	285	57.9

N = number of animals; SD = standard deviation; iSBW = initial shrunk body weight; fSBW = final shrunk body weight; iEBW = initial empty body weight; fEBW = final empty body weight; $EBW^{0.75}$ = mean metabolic empty body weight; ADG = average daily gain; EBG = empty body gain; RE = retained energy; MEI = metabolizable energy intake; HP = heat production.

Table 8.4 - Descriptive statistics of the data used to obtain the nutritional energy requirements of Zebu animals on pasture

Items	N	Mean	Maximum	Minimum	SD
Bulls					
iSBW, kg	99	278	404	138	50.6
fSBW, kg	99	391	661	138	68.6
iEBW, kg	99	242	363	106	41.4
fEBW, kg	99	343	600	118	58.9
$EBW^{0.75}$, kg	99	70.7	103	34.5	9.28
ADG, kg/d	99	0.42	1.13	-0.54	0.38
EBG, kg/d	99	0.34	0.81	-0.55	0.36
RE, kcal/$EBW^{0.75}$	99	24.3	105	-52.3	29.1
MEI, kcal/$EBW^{0.75}$	99	199	307	83.4	54.5
HP, kcal/$EBW^{0.75}$	99	175	340	12.7	59.7
Steers					
iSBW, kg	28	294	455	104	59.8
fSBW, kg	28	370	581	150	91.7
iEBW, kg	28	253	385	94.9	49.3
fEBW, kg	28	325	518	125	76.9
$EBW^{0.75}$, kg	28	70.2	97.9	33.9	9.66
ADG, kg/d	28	0.57	0.95	-0.15	0.33
EBG, kg/d	28	0.47	0.90	-0.10	0.29
RE, kcal/$EBW^{0.75}$	28	16.3	36.9	-12.4	15.5
MEI, kcal/$EBW^{0.75}$	28	210	306	120	54.7
HP, kcal/$EBW^{0.75}$	28	193	278	129	41.3

N = number of animals; SD = standard deviation; iSBW = initial shrunk body weight; fSBW = final shrunk body weight; iEBW = initial empty body weight; fEBW = final empty body weight; $EBW^{0.75}$ = mean metabolic empty body weight; ADG = average daily gain; EBG = empty body gain; RE = retained energy; MEI = metabolizable energy intake; HP = heat production.

ENERGY REQUIREMENTS FOR MAINTENANCE

Net Energy Requirements for Maintenance

NEm can be understood as the animal's total heat production in a state of absolute fasting. It is correlated with meeting basic functions, such as maintaining homeothermy, circulation, respiration, enzymatic system maintenance and tissue synthesis, and meeting voluntary activities such as rumination and walking (Garrett et al., 1959).

Primarily, the maintenance energy requirements were calculated by long-term feeding experiments, where constant intake levels were maintained until the animals reached a balanced body weight for a period of time (Taylor and Young, 1968). Subsequently, the energy requirement was calculated as a regression between energy intake and animal weight gain, and the point where the weight gain equaled to zero, found by extrapolation, was considered as the animal's maintenance energy requirement (Jenkins and Ferrell, 1983). However, this technique estimated the metabolizable energy requirement for maintenance (MEm), whereas NEm, and the gain requirements should be estimated by other methods.

NEm can be obtained by using respirometric techniques, where an animal in a state of absolute fasting is maintained inside a chamber and its CO_2 and methane gas production and oxygen consumption are measured (Ferrell and Oltjen, 2008). Considering the principle that all heat produced is derived from metabolic oxidation of organic compounds, and that oxygen consumption is necessary to produce CO_2, it is possible to estimate NEm (ARC, 1965).

NEm can also be estimated indirectly using the comparative slaughter method as done in the studies adopted to estimate NEm presented in the BR-CORTE. To use this method, animals

must be fed with different levels of metabolizable energy, which will result in variation in the energy retained in the body and in heat production (Lofgreen and Garrett, 1968). NEm has been calculated (both in respirometric chambers and by comparative slaughter) using an exponential non-linear HP regression as a function of MEI. At this point, NEm is known as the intercept (β_0) of the model (Ferrell and Jenkins, 1998; Figure 8.1).

$$HP = \beta_0 \times e^{\beta 1 \times MEI} \quad \text{Eq. 8.6}$$

where HP = heat production (Mcal/EBW$^{0.75}$/d), MEI = metabolizable energy intake (Mcal/EBW$^{0.75}$/d) and β_0 and β_1 = parameters of the model.

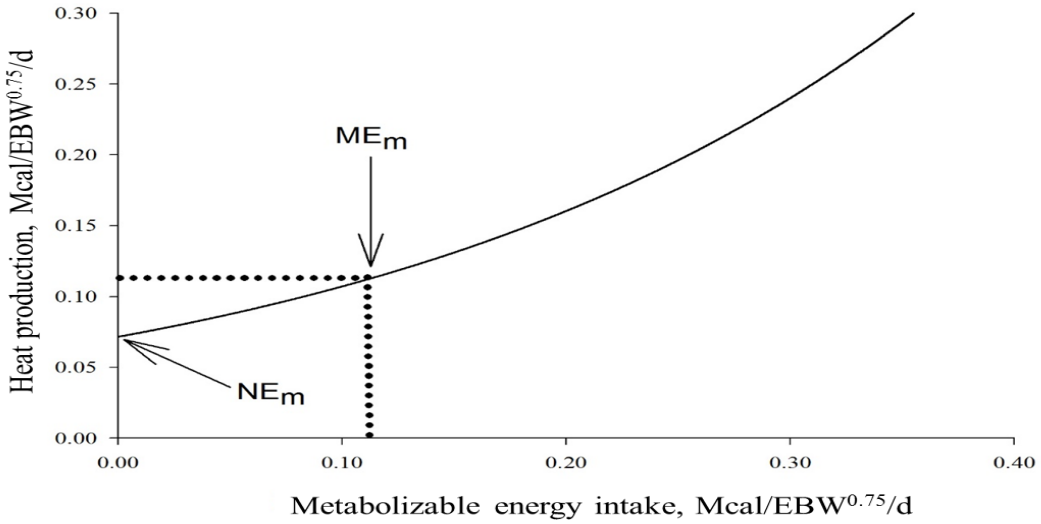


Figure 8.1 - Representation of the relationship between heat production and metabolizable energy intake.

NEm requirements were estimated based on the model above and tested effects of sex, genetic group, and system on the parameters of the model. As the database for pasture-reared animals was not modified in relation to the previous edition, the same recommendations of the previous edition were maintained (Valadares Filho et al., 2010).

a) Animals in feedlot

When the model of equation 8.6 was fitted to the data from feedlot animals, there was no effect of sex on the parameters of the model ($P > 0.05$). Similarly, there was no effect of genetic group on the β_0 parameter of the model ($P = 0.332$), which indicates that there were no differences in the NEm estimate. On the other hand, a genetic group effect was observed on the β_1 parameter of the model described above ($P < 0.001$), which indicates that the genetic group influences the efficiency of use of metabolizable energy for maintenance.

Zebu cattle:

$$HP = 0.0749 \times e^{3.8684 \times MEI} \quad \text{Eq. 8.7}$$

Crossbred beef cattle:

$$HP = 0.0749 \times e^{4.0612 \times MEI} \quad \text{Eq. 8.8}$$

Crossbred dairy cattle:

$$HP = 0.0749 \times e^{4.1487 \times MEI} \quad \text{Eq. 8.9}$$

where HP = heat production (Mcal/EBW$^{0.75}$/d) and MEI = metabolizable energy intake (Mcal/EBW$^{0.75}$/d).

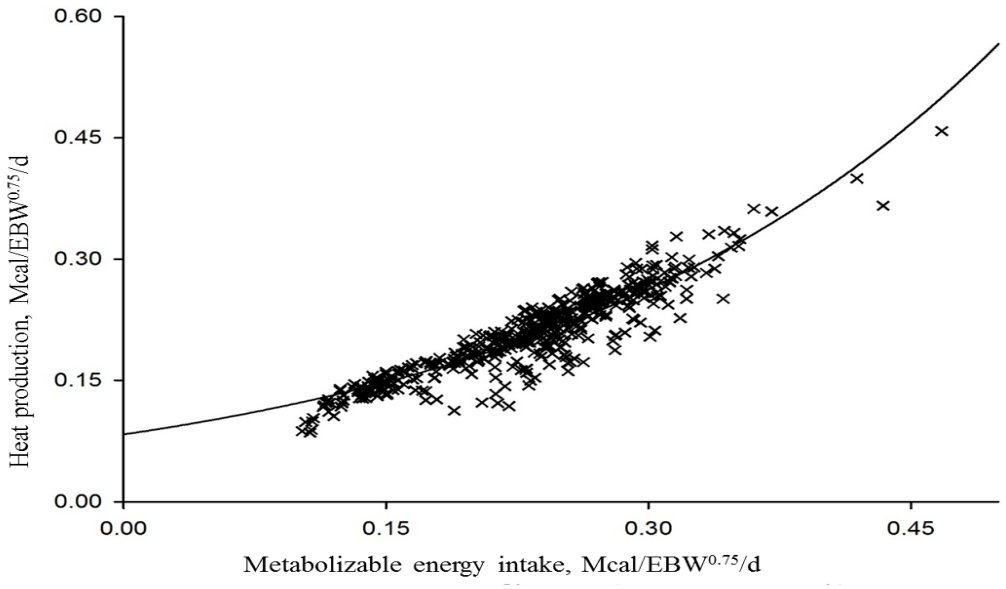


Figure 8.2 - Representation of the relationship between heat production and metabolizable energy intake for Zebu animals reared in feedlot, based on equation 8.7.

Generally, the estimated value of 75 kcal/EBW$^{0.75}$/d for NEm is consistent, because it is similar to the values reported in the literature, as for example, the base metabolic rate of 69 kcal/EBW$^{0.75}$/d, measured in a respirometric chamber (Poczopko, 1971).

The NRC (2000) suggests that there is no difference between steers and heifers for NEm, also described by the ARC (1980) and CSIRO (1990), and recommends a value of 77 kcal/EBW$^{0.75}$/d. The NRC (2000) also suggests that bulls have a NEm requirement 15% greater than the other sexes, but these differences were not observed in our database (Webster et al., 1982; Ferrell and Jenkins, 1985).

The NASEM (2016) changed the recommendation of the previous edition (NRC, 2000) of 77 kcal/EBW$^{0.75}$/d for steers and heifers to 77 kcal/SBW$^{0.75}$/d and also recommended a 15% increase in the NEm for bulls. It was also suggested that Zebu animals, except for Nellore cattle, would have NEm requirements approximately 10% lower than animals with taurine origin, that is, around 69 kcal/SBW$^{0.75}$/d.

However, sex differences were not observed in our database. Chizzotti et al. (2008) also did not observe genetic group effects and estimated a NEm of approximately 75 kcal/EBW$^{0.75}$/d in a study involving data of 389 Nellore or crossbred beef animals (Angus, Red Angus, Simmental, Limousin and Brangus). Generally, the values reported in 2010 and 2016 were similar, which emphasizes the consistency of the BR-CORTE database and the applicability of the estimated values.

b) Animals on pasture

The second edition of the BR-CORTE presented differences in NEm estimate according to the rearing system, and the values were 74.2 and 71.7 kcal/EBW$^{0.75}$/d for animals reared in feedlot and on pasture, respectively. However, with the database of the third edition, there was no effect (P = 0.16) of the rearing system on the β_0 estimate of equation 8.6, and the same NEm value of 75 kcal/EBW$^{0.75}$/d was adopted for both animals reared in feedlot and on pasture. However, a significant difference (P = 0.039) was observed for β_1 estimate suggesting differences regarding MEm.

$$HP = 0.0749 \times e^{4.1986 \times MEI} \qquad \text{Eq. 8.10}$$

where HP = heat production (Mcal/EBW$^{0.75}$/d) and MEI = metabolizable energy intake (Mcal/EBW$^{0.75}$/d).

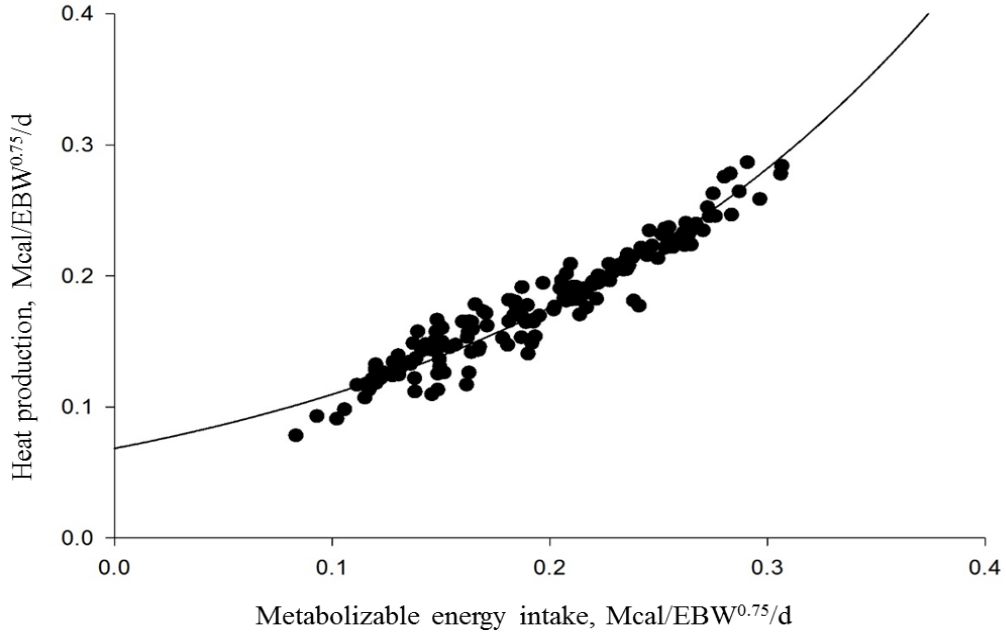


Figure 8.3 - Representation of the relationship between heat production and metabolizable energy intake for Zebu animals reared on pasture, based on the equation 8.10.

Theoretically, NEm is influenced by characteristics that affect the basal metabolism and is independent of diet, which justifies equivalent values for animals reared in different systems (Garrett et al., 1959).

Metabolizable energy requirements for maintenance

The use of the value found for NEm is limited and has no practical application in diet formulation because producing animals are not found in a fasting state. Therefore, the maintenance requirement must be calculated in a more applicable form. In this context, there is the MEm concept, which can be understood as the point at which all of the metabolizable energy intake is used for heat production, that is, no energy is retained in the body (Lofgreen and Garrett, 1968).

To obtain the MEm, the efficiency of use of metabolizable energy for maintenance (*km*) needs to be known. This efficiency can be obtained by applying an iterative process to the exponential model of heat production as a function of the metabolizable energy intake. The point where heat production and metabolizable energy intake are equal, is the value considered to be MEm (Mcal/EBW $^{0.75}$/d). The *km* is estimated from the MEm and NEm ratio (Figure 8.1).

This technique of estimating the *km*, although classic and already used in the first edition of the BR-CORTE (BR-CORTE, 2006), was refuted in the second edition (BR-CORTE, 2010) because it did not take into consideration the action of a series of factors that can affect the *km*. These factors include sex, genetic group, age, environment and the metabolizable energy concentration in the diet (AFRC, 1993; NRC, 2000; CSIRO, 2007). In addition, there is strong evidence that the *km* is also affected by characteristics linked to animal performance, such as weight gain rate and composition (Williams and Jenkins, 2003; Marcondes et al., 2010).

a) Animals on feedlot

Marcondes et al. (2013) used a meta-analysis to study the effect of several variables on the *km*, and found that the efficiency of use of metabolizable energy for gain (*kg*) and empty body gain (EBG) influenced *km* (Eq.8.11), which confirms that the maintenance requirements are affected by animal performance.

$$km = [\beta_0 + (\beta_1 \times kg) + (\beta_2 \times EBG)] \times \theta$$

Eq. 8.11

where: *km* = efficiency of use of metabolizable energy for maintenance, *kg* = efficiency of use of

metabolizable energy for gain, EBG = empty body gain, β_0, β_1 and β_2 = parameters of the equation and θ = fit factor for the rearing system.

In addition, Marcondes et al. (2013) showed a genetic group effect on the estimate of the EBG parameter, which reaffirmed the results found in parameter β_1 of equations 8.7, 8.8, and 8.9.

Reassessing the model proposed by Marcondes et al. (2013), based on the BR-CORTE updated database, a difference was confirmed between genetic groups for the parameter associated with EBG (β_2), but the original values reported by the authors were maintained for Zebu and crossbred beef cattle. The data for Zebu and crossbred beef cattle had high accuracy (85.04%) (Lin and Torbeck, 1998; Tedeschi, 2004) in the model proposed by Marcondes et al. (2013). Thus, it was decided to maintain the *km* equation for Zebu and crossbred beef cattle, and the model was re-parametrized for crossbred dairy cattle, to minimize the mean squared error in the *km* estimates for these animals:

$$km = [0.513 + (0.173 \times kg) + (\beta_2 \times EBG)] \times \theta \quad \text{Eq. 8.12}$$

where: *km* = efficiency of use of metabolizable energy for maintenance, *kg* = efficiency of use of metabolizable energy for gain, EBG = empty body gain (kg/d), β_2 = 0.100 for Zebu, 0.073 for crossbred beef cattle and 0.010 for crossbred dairy cattle and θ = fit factor for the rearing system that takes the value of 1 for animals reared on feedlot.

The model is in agreement with the conclusions by Garrett (1980b), who suggested that the *km* would be affected by body composition and nutritional plan, since the *kg* is affected by the gain composition and the EBG is affected by the nutritional plan. According to Garrett (1980b) variations in protein turnover could be responsible for part of the variation in the *km*, and thus there would be differences in protein turnover in the genetic groups assessed.

Most of the nutritional requirement systems estimate *km* based on the diet characteristics. The AFRC (1993) and CSIRO (2007) consider the metabolizable energy concentration and gross energy ratio in the diet (qm) (equations 8.13 and 8.14, respectively). The *km* established by the NRC (2000) and NASEM (2016) is based on the study by Garrett (1980a) and considers the metabolizable energy concentration in the diet [ME] as the variable that affects the estimate of the net energy concentration for maintenance [NEm] (Eq. 8.15), and the *km* is obtained by dividing [NEm] by [ME]. On the other hand, Fox et al. (2004) recommended a fixed value of 0.64.

$$km = (0.35 \times q_m) + 0.503 \quad \text{Eq. 8.13}$$

$$km = (0.02 \times q_m) + 0.500 \quad \text{Eq. 8.14}$$

$$NEm = -1.12 + 1.37 \times ME - 0.138 \times ME^2 + 0.0105 \times ME^3 \quad \text{Eq. 8.15}$$

where: *km* = efficiency of use of metabolizable energy for maintenance, qm = metabolizable energy and gross energy ratio in the diet (expressed in % in Eq. 8.13, and in MJ/kg DM in Eq. 8.14) and ME = concentration of metabolizable energy in the diet (Mcal/kg DM).

As reported previously, the NRC (2000) and NASEM (2016) suggested that *Bos taurus indicus* cattle, except the Nellore, would have an NEm 10% lower than taurine animals. However, as was presented previously, no difference was shown for NEm in our database, considering crossbred and Zebu cattle of different sexes. However, the *km* calculation model indicates that this difference may not be related to the NEm, but instead to its use efficiency, and *Bos taurus indicus* animals would be more efficient than crossbred beef cattle, which would be more efficient than crossbred dairy cattle.

b) Animals on pasture

Regarding the rearing system, Marcondes et al. (2013) did not compare feedlot and pasture conditions in the development of the *km* models. However, applying the iterative method to the equations generated with the database of Zebu animals reared on feedlot (Eq.8.7) and animals reared on pasture (Eq.8.10) showed that the rearing system influences the MEm estimate. The MEm value obtained for animals on pasture was 128 kcal/$EBW^{0.75}$/d, while for Zebu animals on feedlot it was 118 kcal/$EBW^{0.75}$/d. So presents an 8.5% increase in the final MEm estimate for animals on pasture,

that is, animals on pasture present a *km* 8.5% lower than animals reared on feedlot.

$$km = (0.513 + 0.173 \times kg + 100 \times EBG) \times \theta$$

Eq. 8.16

where: *km* = efficiency of use of metabolizable energy for maintenance, *kg* = efficiency of use of energy for gain, EBG = empty body gain (kg/d) and θ = fit factor for the rearing system that presumes a value of 0.92 for pasture reared animals.

The smaller *km* of animals on pasture may be connected to their bigger energy expenditure for movement and forage gathering that may reduce the efficiency of the diet's energy use. Another aspect is the diet quality, since pastures usually have a lower metabolizable energy concentration than feedlot diets, which may lead to a reduction in the *km* (Garrett, 1980b).

Factors that influence the maintenance requirement

a) Voluntary activities

Nutritional requirements have mainly been established for feedlot animals, because the food supplied and metabolizable energy intake can be measured. However, for animals reared on pasture, locomotion is considered greater compared to animals on feedlot. Therefore, the CSIRO (2007) considered that animals on pasture spend more energy on ingestion activity than animals in feedlot and presumed that the energy spent on walking is 0.62 kcal/km horizontal displacement and 6.69 kcal/km vertical displacement. The additional metabolizable energy of ingestion, expressed in MJ, can be calculated by 0.0025 x DMIp x (0.9 – DMDp), where DMIp is the dry matter intake (kg/d) of pasture and DMDp is the dry matter digestibility of pasture. When these corrections are adopted, animals on pasture would present 10 to 20% greater maintenance requirements compared to animals on feedlot, depending on topography, stocking rate, pasture availability and quality.

In the third edition (BR-CORTE, 2016), only six of the 38 studies included in the database were maintained on pasture. This group of animals was assessed separately for nutritional requirements and, as observed previously, there was an 8.5% increase in the MEm requirements of animals on pasture. However, there is still both wide variability and scarcity of data for animals on pasture, which shows that there is still a lot to be studied in this system. Comparative slaughter experiments to estimate nutritional requirements are difficult to carry out on pasture, because both supplement and pasture intake and fecal excretion are usually estimated using markers.

Many studies have been performed to perfect the intake and excretion estimation methods for animals on pasture (Ferreira et al., 2009). However, more experiments are needed to increase the number of repetitions and provide varied conditions so that the statistical procedures can more precisely identify the effect of pasture on maintenance requirements.

b) Environmental effects

The main factors involved in determining the thermoneutral zone are: the environment (air temperature, air humidity, solar radiation and atmospheric pressure) the animal´s skin structure (thickness, heat insulation, wind penetration, ventilation, emissivity, absorptivity and reflectivity) and body characteristics (body shape, size, surface area, area exposed to solar radiation, epidermis emissivity and absorptivity) (Silva, 2000). The thermoneutral zone range, delimited by critical lower and higher temperatures, is defined as the temperature range where there is no additional energy expenditure to maintain body temperature.

Thus, dry matter intake is lower under heat stress, but while the highest critical temperature is surpassed during short periods of the day, intake recovers in hours of cooler temperature. Thus, the use of this adjust is recommended only in extreme cases.

Heat stress increases respiratory frequency, heart rate, panting and energy expenditure to maintain body temperature, but also decreases metabolic heat production. This makes it hard to adopt adjustments in the nutritional requirements for this factor.

Therefore, the NRC (2000) recommends adjustments to the energy requirements for maintenance in the order of

0.0007 Mcal/$BW^{0.75}$ for each 1ºC of variation in the environmental temperature compared to the 20ºC standard temperature. Thus, when the environmental temperature is greater than 20ºC there will be a reduction in the maintenance requirement, and an increase in the maintenance requirement is expected when temperatures are lower than 20ºC.

There are few studies in Brazil that assess the effect of environmental variables on animal nutritional requirements. Thus, adjustments will not be recommended for these factors in this publication.

ENERGY REQUIREMENTS FOR GAIN

Equivalent empty body weight

Applying performance measurements, such as the average daily gain, is essential in prediction systems for nutritional requirements. However, it is as important as get an idea of the average daily gain, it is understanding the composition that the gain presents (Marcondes et al., 2016). One of the ways to infer an animal's gain composition is from the body weight of the animal at maturity, because when the animal is closest to this weight, there will be a greater tendency to deposit fat compared to protein contents in the empty body weight.

First, the weight at maturity was correlated to the stable weight of an adult cow of a determined breed. However, applying this value to growing animals may not give satisfactory results, because some genetic groups attain an adult weight that is much heavier than the weight normally considered for cattle slaughter, and many animals also stabilize their body composition before maturity (Reid et al., 1955). Following this reasoning, several ways were proposed to estimate the weight at animal maturity, endeavoring to correlate it with growth curves (Brown et al., 1976; Menchaca et al., 1996).

According to Reid et al. (1955) and Marcondes et al. (2016), weight at maturity would be reached when the crude protein concentration in the fat-free dry matter of the animals became constant, that is, all tissue deposition would be in the form of fat. For Tedeschi et al. (2002), body weight at maturity of Nellore animals would be reached when these animals attained 22% body fat in the empty body weight. For the NRC (2000), the body fat content that would define the reference weight would be 25% for animals with only traces of marbling.

From the genetic composition of the animals present in the BR-CORTE database, and based on analysis of the data for body composition of these animals, it was decided to establish the empty body weight at maturity based on the body fat content and the empty body weight exponential ratio in the animals, considering 25% body fat as the point of maturity (Figure 8.4) since the animals in the database mostly have a low degree of marbling (NRC, 2000).

$$BF = \beta_0 \times e^{(\beta_1 \times EBW)} \quad \text{Eq. 8.17}$$

where: BF = body fat content (kg); EBW = empty body weight (kg) and β_0 and β_1 are parameters of the equation.

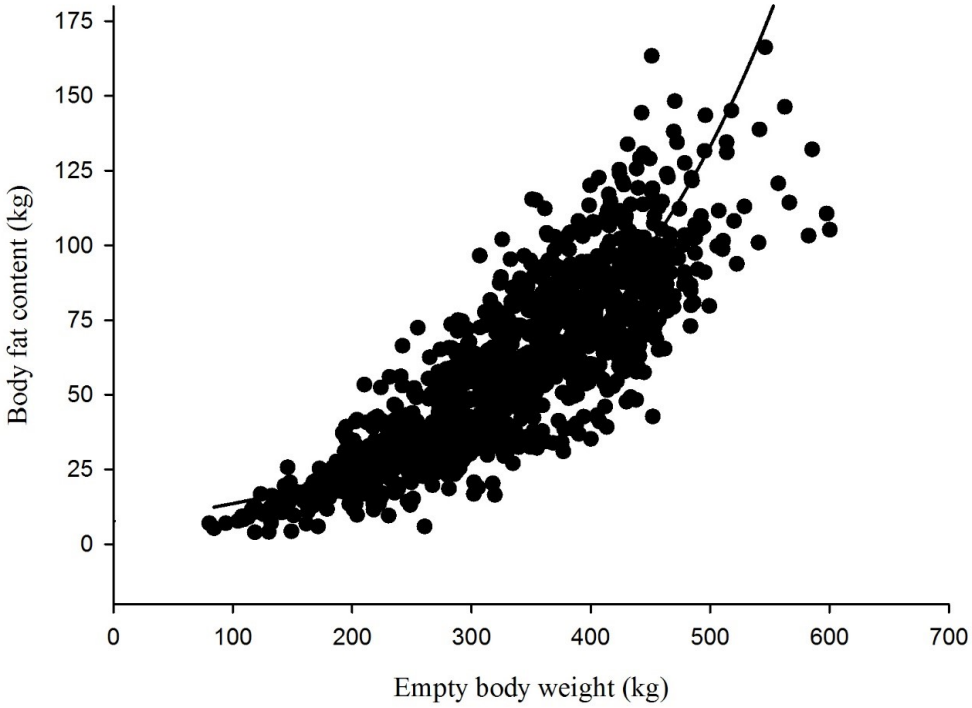


Figure 8.4 - Relationship between empty body weight and body fat, considering all the animals in the BR-CORTE database.

When the model described above was applied to the database, an effect was observed of genetic group and sex on the estimate of the empty body weight at maturity of the animals, and the following values are recommended (Table 8.5).

Table 8.5 - Empty body weight (EBW), fasting body weight (SBW) and body weight (BW) at maturity for different genetic groups/sex classes of beef cattle, estimated from the exponential relationship between body fat content and the animals' empty body weight

Genetic group	Sex	EBW (kg)	SBW (kg)	BW (kg)
Zebu cattle	Bulls	517	585	595
	Steers	433	477	487
	Heifers	402	439	449
Crossbred beef cattle	Bulls	560	631	642
	Steers	482	535	546
	Heifers	417	457	467
Crossbred dairy cattle	Bulls	616	692	708
	Steers	532	588	602
	Heifers	493	535	548

Arnold and Bennett (1991a; b) suggested a 517 kg weight at maturity for bulls and 315 kg for heifers, both for medium body size breeds. Oltjen et al. (1986) estimated a maturity value of 450 kg for steers. As Nellore animals are considered medium-size (NRC, 2000), the data estimated in the present publication is in agreement with the values reported in the literature. Crossbred animals had higher estimated weights at maturity because large size breeds were used in the crosses, which increases progeny weight at maturity.

The NRC (2000) suggests correcting the estimate of the energy requirements for gain by

the weight of the animals of different body sizes or weights at maturity, in order to generate an equivalent value for all animals. This is known as the equivalent empty body weight (EQEBW). Thus, the EQEBW can be calculated from the weight at maturity (MEBW) suggested previously for each type of animal and a reference value for empty body weight (SREBW), adopting the following model:

$$EQEBW = (EBW / MEBW) \times SREBW \quad \text{Eq. 8.18}$$

where EQEBW = equivalent empty body weight (kg), EBW = empty body weight (kg), SREBW = standard reference empty body weight (517 kg) and MEBW = empty body weight at maturity (values presented previously, in kg).

The use of EQEBW allows animals from different genetic groups and/or sexes to be compared at different finishing grades. For this, a reference value needs to be well established to increase the estimate accuracy. In this case, the standard reference empty body weight (SREBW) is the weight where animals would be at the same expected final body fat.

In the BR-CORTE (2010), a value of 440kg was adopted for the SREBW. This value was calculated based on the database of that edition that contained all the animals. For the third edition (BR-CORTE, 2016), the value of the empty body weight at maturity of Zebu bulls (517 kg) was used for the SREBW. This decision was based on the consistency of these animals presented by the database and that they also had most data, and possibly greater reliability in the estimates.

Net energy requirement for gain

Net energy requirement for gain (NEg) can be understood as all the energy that is retained in the empty body weight of the animals in the form of protein or fat (Garrett et al., 1959). Therefore, the composition of the empty body weight gain is the main determinant of the energy requirements for weight gain. In this sense, what determines the composition of the empty body gain is not the absolute body weight, but the weight relative to the weight at maturity of the animal. The closer an animal is to its weight at maturity, the greater the fat deposition compared to protein deposition that tends to increase the requirements for weight gain (Marcondes et al., 2016).

In this context, the model used in the third edition (BR-CORTE, 2016) to estimate NEg is based on the ratio of the energy retained in the body as a function of the EQEBW and the desired empty body weight gain:

$$NEg = \beta_0 \times EQEBW^{0.75} \times EBG^{\beta_1} \quad \text{Eq. 8.19}$$

where NEg = net energy requirement for weight gain (Mcal/d), EQEBW = equivalent empty body weight (kg), EBG = empty body gain (kg/d) and β_0 and β_1 = parameters of the model.

The analysis of the database in the third edition showed the possibility of the EQEBW absorbing not only intrinsic differences in each genetic group (Figure 8.5B), but also differences between sexes (Figure 8.5A).

In this way, a joint equation was generated using the data from all the animals finished in feedlot (Eq. 8.20) while the requirements for animals on pasture were not altered in relation to the last edition (Eq. 8.21).

$$NEg = 0.061 \times EQEBW^{0.75} \times EBG^{1.035} \quad \text{Eq. 8.20}$$

$$NEg = 0.052 \times EQEBW^{0.75} \times EBG^{1.062} \quad \text{Eq. 8.21}$$

where NEg = net energy requirement for weight gain (Mcal/d), EQEBW = equivalent empty body weight (kg) and EBG = empty body gain (kg/d).

For the effect of sex and considering Zebu animals, steers had an NEg 14% greater compared to bulls and 7% lower compared to heifers (Figure 8.5A). For crossbred beef animals, the NEg of steers was 12% higher than bulls and 13% lower than heifers. For crossbred dairy animals, the NEg of steers was 12% higher than for bulls and 6% lower than for heifers.

The BR-CORTE used a similar model to that recommended in the NRC (2000) and NASEM (2016) to estimate NEg, according to the equation: $NEg = 0.0635 \times EQEBW^{0.75} \times EBG^{1.097}$ that is based on the edition of 1984 (NRC, 1984) and was generated for medium-sized animals. Thus, to correct distortions in relation to animal body composition, the NASEM (2016) recommends using the EQSBW. Three different standard reference

weights are used to calculate the EQSBW and are based on the level of marbling presented by different genetic groups: 478 kg for animals with some marbling, 462 kg for animals with moderate marbling and 435 for animals with only traces of marbling.

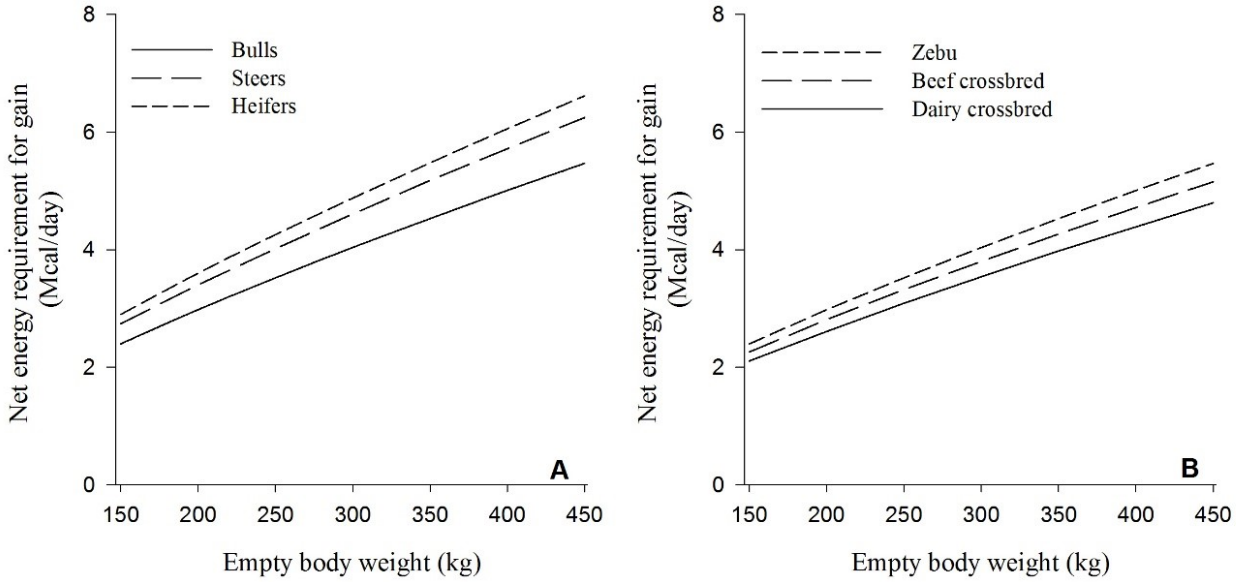


Figure 8.5 - Estimate of net energy requirement for gain for Zebu animals of different sexes (A) and for bulls from different genetic groups (B). For all estimates, the model used was proposed for animals in feedlot, considering the equivalent empty body weight inherent to each category and an empty body weight gain of 1 kg/d.

Differences in weight at maturity of the genetic groups reflect different degrees of fat deposition in animals with the same body weight. Thus, for animals with the same absolute weight and the same weight gain rate, higher energetic concentrations are expected in the gain, and consequently greater NEg, for animals from genetic groups with lower weight at maturity compared to animals from genetic groups with later maturity (Marcondes et al., 2016).

Finally, the EBG can be estimated from the net energy available for gain, which would be computed from the difference between the total energy intake by the animal and its net energy requirement for maintenance, using the following model:

$$EBG = 14.914 \times NEg^{0.9662} \times EQEBW^{-0.7246}$$

Eq. 8.22

In this context, a Nellore bull with 350 kg body weight, equivalent to a 300 kg EQEBW, would have a dry matter intake of approximately 8 kg/d, with a net energy requirement for maintenance of 5.40 Mcal/d. Considering a net energy available for gain of 5.12 Mcal/d, then, an EBG of approximately 1.16 kg/d would be expected.

Use of carcass gain to estimate NEg

A study published by Benedeti et. al. (2021) was used as base to develop this topic. As mentioned before, NEg is the amount of energy that is held within the EBW as protein or fat (Garret et al., 1959). Thus, the NASEM (2016) and BR-CORTE (2016) systems consider the EQEBW and EBG as variables to predict NEg. The EQEBW can be used to correct distortions related to the body composition of animals, in order to generate an equivalent value for animals with different weights at maturity (Valadares Filho et al., 2019). On the other hand, the EBG considers all body constituents, including carcass components, leather, blood, viscera, etc. (Giombelli et al., 2016). However, obtaining this measurement is laborious since the gastrointestinal tract needs to be thoroughly washed and weighed with other carcass and non-carcass components. Furthermore, these procedures are not commonly performed in commercial slaughterhouses, preventing the use

of commercial cattle data to develop models that predict the energy requirements of beef cattle.

Carcass weight (CW) is a commonly measurement collected at the slaughter of beef cattle and represents only the carcass tissue accumulation. Thus, replacing EBG by carcass gain (CG) could simplify the estimation of RE requirements. Therefore, as a first step, Benedeti et al. (2021) proposed a new model (Eq. 8.23) to estimate the CW of beef cattle with different genders (Bulls, steers, and heifers), genotypes (Zebu, crossbred beef and dairy cattle), and slaughter conditions (experimental and commercial). More details can be found in Chapter 6.

$$CW\ (kg) = -11.0 + P + [(0.609 + G + B) \times SBW]. \quad \text{Eq. 8.23}$$

where CW = carcass weight (kg); P = slaughter condition (if commercial = -10.98, if experimental = 0); G = gender effect (if heifer = - 0.00612, if steer = 0, if bull = 0.008169), B = genotype effect (if Zebu = 0, if crossbred beef cattle = - 0.01595, if crossbred dairy cattle = -0.03301), and SBW = shrunk body weight (kg).

Performance measurements (such as ADG, CG and EBG) are important for predicting energy requirements because they can be related to the energy needed for body mass deposition (Costa e Silva et al., 2016). Thus, the current equations of BR-CORTE (2016) use EBG to estimate the NEg (Eq. 8.19). The EBG, in turn, is calculated using a non-linear equation that considers ADG as an independent variable:

$$EBG,\ kg/d = 0.9630 \times ADG^{1.0151} \quad \text{Eq. 8.24}$$

where EBG = empty body weight gain (kg/d); ADG = average daily gain (kg/d).

An issue that must be considered is that the ADG values may vary according to the weighing methodology. Thus, animals can be weighed after different periods of fasting (Krinchev et al., 2018; Martins et al., 2019) or even not be fasted prior to slaughter (some commercial conditions). Furthermore, in commercial plants, animals can be transported long distances before being weighed and slaughtered, which may affect ADG. Hence, the use of CG can be an alternative to replace ADG in EBG calculations. Thus, after validating Eq. 8.23, two models were developed with the objective of: 1) predicting EBG from CG; 2) predicting NEg from CG (Benedeti et al., 2021).

Data from 21 studies were used to perform this meta-analysis (Table 8.6). Thus, the database with 636 individual observations of heifers, steers, and bulls of different genotypes (Zebu, crossbred beef and dairy cattle). All studies used comparative slaughter as a method to determine animals' body composition and energy retention (Garrett et al., 1959).

For the prediction of CG from EBG, a linear model with intercept had the lowest value for the Akaike information criterion. On the other hand, a nonlinear equation had the best fit for NEg prediction when EBG was replaced by CG. Thus, the new models proposed for the prediction of EBG and NEg were:

$$EBG\ (kg) = 0.044 + 1.47 \times CG. \quad \text{Eq. 8.25}$$

$$NEg\ (Mcal/d) = 0.082 \times EQEBW^{0.75} \times CG^{0.777}. \quad \text{Eq. 8.26}$$

where EBG = empty body weight gain (kg/d), CG = carcass gain (kg/d), NEg = net energy for gain (MJ/d) and EQEBW = equivalent empty body weight (kg). The relationship between NEg and CG of the animals used to develop the new equations is shown in Figure 8.6.

The validations of the two new equations (Eq. 8.25 and 8.26) were performed using data from 5 independent studies (Table 8.7), encompassing data from our research group (Inside) and from literature publications (Outside; Goulart et al., 2008; Bonilha et al., 2013; Bonilha et al., 2014). The inside dataset was composed of 49 observations, encompassing only bulls with two genotypes (Zebu and dairy crossbred). The outside dataset consisted of 8 means calculated from 115 animals, encompassing only bulls with two genotypes (Zebu and crossbred beef cattle).

Table 8.6 - Descriptive statistics of the data used to develop models to predict empty body gain and net energy gain in Zebu animals with different genders and genotypes

Item*	Total data	Gender			Genotype		
		Bulls	Steers	Heifers	Zebu	Crossbred beef cattle	Crossbred dairy cattle
Studies (n)	21	14	8	7	13	6	4
Animals (n)	636	362	151	123	349	190	97
Initial (kg)							
SBW	285	287	319	233	260	302	337
EBW	247	250	275	203	229	262	279
CW	154	158	175	117	142	164	173
Final (kg)							
SBW	400	421	422	312	368	437	441
EBW	362	382	379	279	336	395	389
CW	232	248	240	174	216	256	243
EBG (kg/d)	1.05	1.17	1.05	0.716	0.955	1.10	1.31
CG (kg/d)	0.804	0.83	0.887	0.626	0.821	0.759	0.828
NEg ($kJ \times d^{-1}/EBW^{0.75}$)	340	348	378	272	323	336	412

CG = carcass gain; CW = carcass weight; EBG = empty body weight gain; EBW = empty body weight; NEg = net energy for gain; SBW = shrunk body weight.

Table 8.7 - Descriptive statistics of the data used to validate models developed to predict empty body gain and retained energy in Zebu animals with different genders and genotypes

Item	Data set*	
	Inside	Outside
Studies, n	2	3
Animals, n	49	8**
Gender, %		
Bull	100	100
Genotype, %		
Zebu	55.1	80.0
Crossbred beef cattle	-	20.0
Crossbred dairy cattle	44.9	-
Carcass gain kg/d	0.59	0.677
Equivalent empty body weight, kg	302	343

*Inside = independent data from our research group studies; Outside = independent data from literature publications (Goulart et al., 2008; Bonilha et al., 2013; Bonilha et al., 2014).
**8 means from 115 animals.

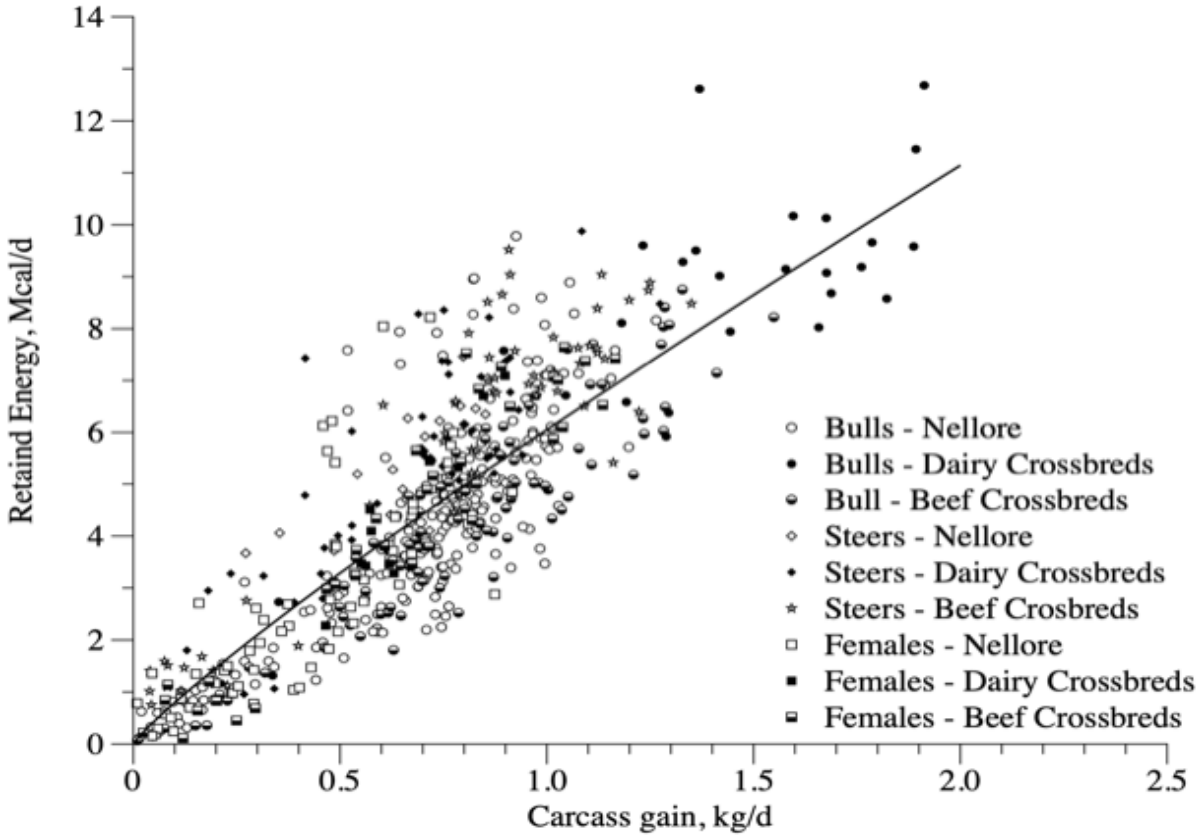


Figure 8.6 - Relationship between retained energy and carcass gain of the animals used to develop the new equations for estimating empty body gain and net energy for gain (adapted from Benedeti et al., 2021).

Analyzing Eq. 8.25, we can observe that when EBG is estimated from the CG, high performance animals are expected to have higher carcass deposition, which seems biologically plausible. As an example of calculation, animals with 0.200 and 1.00 kg of CG would have estimated EBG of 0.338 and 1.51 kg, respectively. Thus, the CG represents 59.4% of the EBG for the former animal, while the same ratio for the animal with the highest performance is 66.2%. According to the literature, the CG/EBG ratio of Zebu cattle varies from 60.0 to 65.0% (Costa et al., 2005; Missio et al., 2009). Therefore, validation analyzes showed that the Eq. 8.25 adequately estimated the EBG using both data from our research group (inside) and from other literature publications (outside; Table 8.8). Furthermore, the high R, CCC and low MSEP observed for the new approach indicate good reproducibility and precision of the proposed equation, making it suitable for estimating EBG from CG.

Regarding the proposed model to calculate NEg from CG (Eq. 8.26), the results indicated a non-linear relationship between these two parameters, evidenced by the increase in energy requirements observed for animals with better performance. Thus, the proposed model presented the highest CCC and the lowest MSEP value in the validation analyses, indicating high reproducibility and accuracy. Furthermore, the MSEP partitioning showed a low participation of SB and MaF, which indicates a lower proportion of prediction error associated with the model. Moreover, validation analysis with outside data showed that the equation was adequate to predict NEg, which is supported by its high R and CCC values and low MSEP. These results indicate that the model presented a good reproducibility index, which may be responsible for accuracy and precision simultaneously. Therefore, the proposed equation accurately and precisely estimated NEg for Zebu cattle and, therefore, are recommended for this purpose.

However, although the new equations proposed to estimate NEg using CG have been validated, CW estimates are still very variable, mainly for animals slaughtered in commercial slaughterhouses. Thus, more results will be

needed for the proposed models to become more robust. Therefore, the committee decided to recommend the Eq. 8.20 and 8.21, which estimate NEg using EQEBW and EBG.

Table 8.8 - Validation analysis of the relationship between the values (observed and estimated) of empty body gain (EBG) and net energy for gain (NEg) of Zebu cattle with different gender and genotypes

Item*	Eq. 8.25 evaluation (EBG, kg/d)		Eq.8.26 (NEg, MJ/d) evaluation			
			Inside**		Outside**	
	Observed	Predicted	Observed	Predicted	Observed	Predicted
Mean	0.922	0.939	14.3	16.5	16.8	19.8
Standard deviation	0.367	0.332	6.84	6.68	6.96	4.40
Maximum	1.69	1.66	28.3	32.7	25.4	26.6
Minimum	0.093	0.089	0.767	0.935	8.33	12.9
R	-	0.961	-	0.92	-	0.922
CCC	-	0.956	-	0.874	-	0.736
Regression						
Intercept						
Estimate	-	-0.074	-	-1.24	-	-12.0
Standard error	-	0.045	-	1.04	-	5.05
P-value (H_0: a=0)	-	0.109	-	0.240	-	0.055
Slope						
Estimate	-	1.06	-	0.942	-	1.457
Standard error	-	0.045	-	0.058	-	0.251
P-value (H_0: b=1)	-	0.184	-	0.327	-	0.117
MSEP	-	0.011	-	12.0	-	18.9
SB	-	0.0003	-	4.82	-	8.96
MaF	-	0.0004	-	0.147	-	3.55
MoF	-	0.01	-	7.02	-	6.38

*R = coefficient of determination; CCC = correlation and concordance coefficient; MSEP = mean square error of the prediction; SB = squared bias; MaF = magnitude of random fluctuation; MoF = model of random fluctuation.
**Inside = independent data from our research group studies; Outside = independent data from literature publications (Goulart et al., 2008; Bonilha et al., 2013; Bonilha et al., 2014).

Metabolizable energy requirement for gain

Similar to NEm, NEg cannot be applied directly to the diet formulation, and needs to be converted to the form of metabolizable energy requirement for gain (MEg). Thus, to convert the NEg to MEg, it is necessary to know the efficiency of the use of the metabolizable energy for weight gain (*kg*). The *kg* is usually estimated from a linear regression of the energy retained as a function of the intake of metabolizable energy for gain, where it is assumed that inclination of this straight line (β_1) would represent *kg* (Figure 8.7).

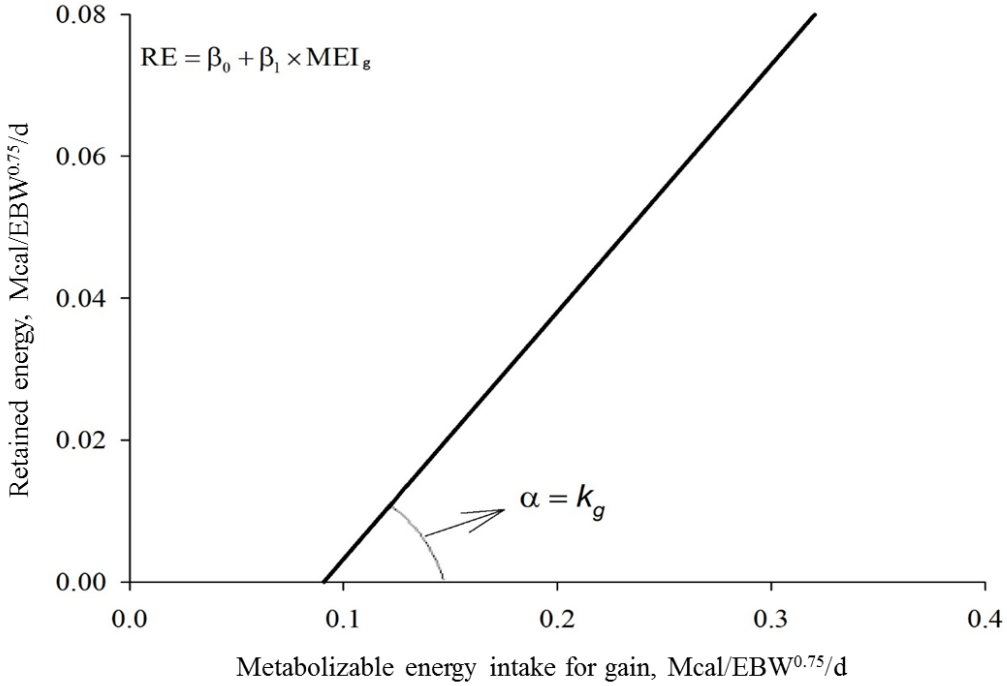


Figure 8.7 - Retained energy and metabolizable energy intake for gain ratio.

However, high variation was observed in the *kg* values between experiments when this value was considered as constant (Figure 8.7), because variations in tissue deposition were ignored. Thus, the efficiency with which energy is retained in the body depends on the proportions of energy retained as protein and fat, emphasizing that energy deposition as fat is more efficient than that of protein (Owens et al., 1995).

As fat is the main form of energy reserve in an animal's body and presents a caloric value of 9.367 kcal/g (Blaxter and Rook, 1953), while protein presents 5.686 kcal/g (Garrett, 1958), the higher the percentage of protein in the gain, the lower will be its energetic concentration. From this principle, Tedeschi et al. (2004) proposed estimating the *kg* based on the percentages of energy retained as protein and on the partial efficiencies of fat and protein deposition:

$$Kg = (kfat \times kp) / [kp + (REp/100) \times (kfat - kp)] \quad \text{Eq. 8.27}$$

where *kg* = efficiency of the use of metabolizable energy for gain (%), *kfat* = efficiency of energy deposition as fat (%), *kp* = efficiency of energy deposition as protein (%) and REp = proportional energy retained as protein (%).

It is well-known that energy deposition as fat is more efficient than as protein; Tedeschi et al. (2004) found values of 20 and 75% for *kfat* and *kp*, respectively. The CSIRO (2007) recommends 45 and 75%, and Chizzotti et al. (2008) obtained 34 and 79% for *kfat* and *kp*, respectively.

Nevertheless, Marcondes et al. (2013) observed overestimation in *kg* values when using the above method and proposed estimating *kg* from the direct ratio with energy retained as protein (REp). For this, the authors obtained *kg* from the RE and metabolizable energy intake for gain (MEIg) for each one of the 25 studies and related the values found to several other variables (Figure 8.8).

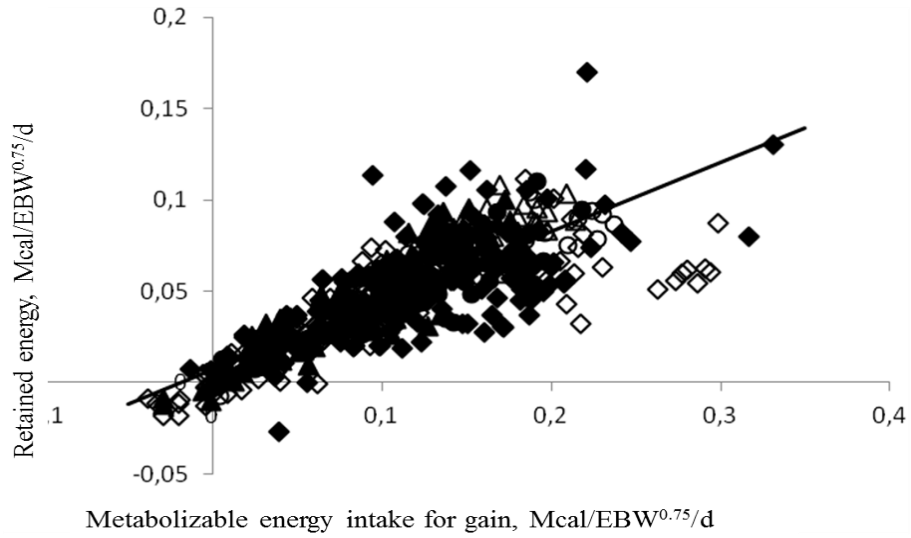


Figure 8.8 - Metabolizable energy intake for gain and retained energy ratio. Symbols represent data from bulls (▲, Δ), steers (◊,♦) and heifers (○, ●). Solid dots represent Zebu animals and empty dots represent crossbred beef cattle (adapted from Marcondes et al., 2010).

The authors observed that the REp was the best variable to explain *kg* and that this variable is important because it correlates the gain efficiency with the gain composition of the animals (Tedeschi et al., 2004; Chizzotti et al., 2008). Thus, the equation obtained by Marcondes et al. (2013) and recommended to estimate *kg* in the current edition is:

$$kg = 0.327 / (0.539 + REp) \quad \text{Eq. 8.28}$$

where *kg* = efficiency of use of the metabolizable energy for gain (%) and REp = proportion of the energy retained as protein.

However, applying this model depends on an accurate REp estimate. Tedeschi et al. (2004) and Chizzotti et al. (2008) proposed exponential models to estimate the REp, and the respective equations were:

$$REp = 0.0554 + 1.6939 \times e^{[-0.5573 \times (RE / EBG)]} \quad \text{Eq. 8.29}$$

$$REp = 10.1 + 166.7 \times e^{[-0.660 \times (RE / EBG)]} \quad \text{Eq. 8.30}$$

However, Marcondes et al. (2013) did not use the same model, because for any of the equations above, there would still be retention as protein even with RE equal to zero. Thus, the authors used a potential model to describe energy retention as protein and obtained the following equation:

$$REp = 1.140 \times (RE / EBG)^{-1.137} \quad \text{Eq. 8.31}$$

where REp = proportion of the energy retained as protein, RE = retained energy or net energy requirement for gain (Mcal/d) and EBG = empty body gain (kg/d).

The NRC (2000) adopted the principle of metabolizable energy concentration in the diet to estimate the net energy concentration for gain and the *kg* estimated by the [NEg] and [ME] ratio. Similarly, the AFRC (1993) considers the metabolizable energy and gross energy ratio to estimate the q_m and later the *kg*.

$$NEg = -1.65 + 1.42 \times ME - 0.174 \times ME^2 + 0.0122 \times ME^3 \quad \text{Eq. 8.32}$$

$$km = (0.78 \times q_m) + 0.006 \quad \text{Eq. 8.33}$$

where [ME] = metabolizable energy concentration in the diet (Mcal/kg DM), *km* = efficiency of the use of the metabolizable energy for maintenance, q_m = metabolizable energy and gross energy ratio in the diet.

Marcondes et al. (2013) did not obtain accurate *kg* predictions when they used only the metabolizable energy concentration in the diet, and they

concluded that using variables that include characteristics related to the weight gain composition of the animals is indicated for *kg* estimate.

SUMMARY OF THE MODELS AND CALCULATION EXAMPLES

The following is a summary of the models described in this chapter.

Table 8.9 - Summary of the models to estimate energy requirements for animals on pasture

Item	Models
SBW (kg)	$0.8915 \times BW^{1.0151}$
EBW (kg)	$0.8507 \times SBW^{1.0002}$
EBG (kg/d)	$0.9630 \times ADG^{1.0151}$
EQEBW (kg)	(EBW / MEBW) × 517
NEm (Mcal/d)	$0.075 \times EBW^{0.75}$
NEg (or RE, Mcal/d)	$0.052 \times EQEBW^{0.75} \times EBG^{1.062}$
REp	$1.140 \times (RE / EBG)^{-1.137}$
kg	$kg = 0.327 / (0.539 + REp)$
km	$[0.513 + (0.173 \times kg) + (0.100 \times EBG)] \times 0.92$
MEm (Mcal/d)	NEm / *km*
MEg (Mcal/d)	NEg / *kg*
MEt (Mcal/d)	MEm + MEg
DE (Mcal/d)	[((MEtotal / DMI) + 0.3032) / 0.9455] × DMI
TDN (kg/d)	DE / 4.4

Table 8.10 - Summary of the models to estimate energy requirements for animals in feedlot

Item		Models
SBW (kg)		Zebu and Crossbred beef cattle: $0.8915 \times BW^{1.0151}$ Crossbred dairy cattle: $0.9247 \times BW^{1.0085}$
EBW (kg)	Bulls	Zebu cattle: $0.8126 \times SBW^{1.0134}$ Crossbred cattle: $0.7248 \times SBW^{1.0314}$
	Steers	Zebu cattle: $0.6241 \times SBW^{1.0608}$ Crossbred cattle: $0.6586 \times SBW^{1.0499}$
	Heifers	Zebu cattle: $0.6110 \times SBW^{1.0667}$ Crossbred cattle: $0.6314 \times SBW^{1.0602}$
EBG (kg/d)		$0.9630 \times ADG^{1.0151}$
EQEBW (kg)		(EBW / MEBW) × 517
NEm (Mcal/d)		$0.075 \times EBW^{0.75}$
NEg (Mcal/d)		$0.061 \times EQEBW^{0.75} \times EBG^{1.035}$
REp		$1.140 \times (RE / EBG)^{-1.137}$
kg		$kg = 0.327 / (0.539 + REp)$
km		Zebu: $[0.513 + (0.173 \times kg) + (0.100 \times EBG)] \times 1$ Crossbred beef cattle: $[0.513 + (0.173 \times kg) + (0.073 \times EBG)] \times 1$ Crossbred dairy cattle: $[0.513 + (0.173 \times kg) + (0.010 \times EBG)] \times 1$
MEm (Mcal/d)		NEm / *km*
MEg (Mcal/d)		NEg / *kg*
MEt (Mcal/d)		MEm + MEg
DE (Mcal/d)		{[(MEtotal / DMI) + 0.3032] / 0.9455} × DMI
TDN (kg/d)		DE / 4.4

To illustrate the application of the models presented in this Chapter, an estimate of the energy requirements will be made for a Nellore bull with 520 kg body weight with ADG of 1.6 kg/d and in feedlot.

- $SBW = 0.8915 \times BW^{1.0151} \rightarrow 0.8915 \times 520^{1.0151} \rightarrow 509.5$ kg
- $EBW = 0.8126 \times SBW^{1.0134} \rightarrow 0.8126 \times 509.5^{1.0134} \rightarrow 450.1$ kg

- EBG = $0.9630 \times ADG^{1.0151} \rightarrow 0.9630 \times 1.6^{1.0151} \rightarrow 1.5518$ kg/d
- EQEBW = (EBW / 517) × 517 → (450.1 / 517) × 517 → 450.1 kg
- NEg = $0.061 \times EQEBW^{0.75} \times EBG^{1.035} \rightarrow 0.061 \times 450.1^{0.75} \times 1.5518^{1.035} \rightarrow 9.40$ Mcal/d
- REp = $1.140 \times (RE / EBG)^{-1.137} \rightarrow 1.140 \times (9.40 / 1.5518)^{-1.137} \rightarrow 0.147$
- *kg* = 0.327 / (0.539 + REp) → 0.327 / [0.539 + 0.147] → 0.48
- MEg = NEg / *kg* → 9.40 / 0.48 →19.6 Mcal/d
- NEm = $0.075 \times EBW^{0.75} \rightarrow 0.075 \times 450.1^{0.75} \rightarrow 7.33$ Mcal/d
- *km* = [(0.513 + 0.173 × *kg* + 0.100 × EBG) × 1] → [(0.513 + 0.173 × 0.48 + 0.100 × 1.5518) × 1] → 0.75
- MEm = NEm / *km* → 7.33 / 0.75 → 9.77 Mcal/d
- MEtotal = MEg + MEm → 19.6 + 9.77 → 29.4 Mcal/d
- DE = [((MEtotal / DMI) + 0.3032) / 0.9455] × DMI → [((29.4 / 10.87) + 0.3032) / 0.9455] × 10.87 → 34.7 Mcal/d
- TDN = DE / 4.4 → 34.7 / 4.4 → 7.88 kg/d

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9

Protein and amino acids requirements for beef cattle

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INTRODUCTION

Proteins are molecules that play several functions in the animal body, contributing to the composition of structural tissues, enzymes, hormones, hormonal receptors, and genetic material (Boye et al., 2012). Dietary protein can be divided into two main portions for ruminant animals: rumen degradable protein (RDP) and rumen undegradable protein (RUP; NRC, 1985). In addition, metabolizable protein (MP) requirements are met by intestinal amino acids (AA) absorption. These AA come from dietary digestible RUP plus the true digestible microbial crude protein (Cervieri et al., 2001; Sinclair et al., 2014). Thereby, protein nutrition is one of the main factors that affect animal performance.

According to Pinto and Millen (2018), commercial feedlots in Brazil use high crude protein (CP) contents in diets of finishing animals (in some cases up to 15 % CP) as strategy to stimulate dry matter intake (DMI) and to reduce feedlot period. However, there is a positive correlation between protein intake and nitrogen excretion in the feces and urine (Sinclair et al., 2014), which contributes to environmental contamination. Menezes et al. (2016) showed that reducing CP levels in the diets of finishing cattle is possible without affecting animal performance besides reducing N excretion to environment. Moreover, unbalanced diets represent economic losses, once protein is considered the most expensive nutrient in beef cattle diets (Appuhamy et al., 2014; Russel et al., 1992). Additionally, toxic effects related to N excess may lead to fertility impairment (Rhoads et al., 2006). Thus, providing more accurate information on protein nutrition may contribute to making beef production systems more environmentally and financially sustainable.

In this context, nutritional models have tried to get as close as possible to the real nutritional requirements of animals. Using AA to formulate diets should allow the feeding of lower protein rations and may also be an alternative to maximize growth performance of ruminants. Therefore, in addition to revised equations for predicting protein requirements, predictive equations to estimate the net and metabolizable AA requirements of beef cattle are also available in the current edition of this publication.

PROTEIN REQUIREMENTS

Ruminant protein requirements are met through absorption in the small intestine of end products resulting from the digestion of nitrogenous compounds, especially the AA available for absorption. The sources of protein that reach the intestine of ruminants are microbial crude protein (MCP), dietary protein that did not suffer action of rumen microorganisms and endogenous protein; thus, ruminants present peculiarities in their protein nutrition (Bach et al., 2005). Amino acids from these sources that are absorbed in the intestine are named MP (ARC 1980).

Formulation based on CP intake can cause several estimation errors once this intake does not consider the biological value of CP as well as the efficiency of MCP synthesis per kg of digestible organic matter. The current systems of nutrient requirements for cattle evolved and recommended MP intake (MPI), accounting for the available protein absorbed as amino acids in the intestine. According to Santos (2006), the use of MP has encouraged and allowed advances in the knowledge of nutritional requirements, allowing animal productivity gains by optimizing the MCP in the rumen, adequacy of the RUP content and of the amount and quality of MP supplied by the animal, reduction of the losses of nitrogenous compounds to reduce the negative

impact of the release of these compounds in the environment.

Protein requirements can be divided into protein required for maintenance (including the endogenous loss of nitrogen compounds through feces, urine, and scurf) and for growth (nitrogen compounds utilized for deposition of body tissues or secreted in milk), as will be explained separately in other sections of this chapter, allowing for a better understanding of the results obtained.

EVALUATION OF CRUDE PROTEIN REQUIREMENTS UTILIZING THE BR-CORTE (2016)

In the third edition of BR-CORTE (BR-CORTE, 2016), there was a considerable effort to improve and to ratify protein requirements for beef cattle. According to Galyean (2014), changes in nutrient requirements associated with sex, genetic groups, physiological status, and environment make establishing requirements more complex and this is a challenge for the committees that try to establish nutrient requirements. This highlights the importance of constantly updating the database and using environmental conditions and handling consistent with the tropics.

Menezes et al. (2016) observed overestimation of CP requirements by the BR-CORTE (2010) of 45.2, 23.5, and 11.2% in relation to the values of CP intake observed for finishing Nellore bulls submitted to diets containing 14, 12, and 10 % CP, respectively. Prados et al. (2015) worked with growing crossbred (Holstein × Zebu) bulls and observed overestimation of 27.5% in CP intake, with a predicted value of 1,200 g/d for CP requirements in relation to the observed intake of 870 g/d. Additionally, Amaral et al. (2014) observed predicted CP intake (1,580 g/d) 17% greater than the observed (1,348 g/d) for finishing crossbred (Holstein × Zebu) bulls while Costa e Silva et al. (2013) found overestimated values of CP intake of 16.75% in relation to the average of observed values for finishing Nellore bulls.

Thus, before generating new equations, the prediction of CP intake by the BR-CORTE (2010) was tested in the last edition (BR-CORTE, 2016). For that, 271 individual data of cattle from 8 studies were collected: Costa e Silva (2011), Souza (2013), Rufino (2014), Silva (2014), Menezes (2016), Prados (2016), Amaral (2016) and Zanetti (2017). The database included dissertations and theses that were concluded after 2010 and were not part of the database of the second edition of BR-CORTE (BR-CORTE, 2010).

The descriptive statistics of data of CP intake referring to the observed values in the studies and the values predicted by the BR-CORTE (2010) are shown in the Table 9.1, and these data were evaluated using the Model Evaluation System (MES; Tedeschi, 2006). The concordance correlation coefficient (CCC) allows us to evaluate the accuracy and precision of the estimates; as this value approaches 1, the estimates are more precise and accurate. The mean square error of prediction (MSEP) considers the magnitude of the errors associated with the estimates and the lower its value, the better the estimates. Furthermore, from the MSEP decomposition, the errors can be associated with mean bias, systematic errors, and random errors; a better estimate is associated with a greater percentage of random errors.

Table 9.1 - Regression analysis and descriptive statistics of observed values and predicted values by the BR-CORTE (2010) for dietary crude protein requirement, adapted from BR-CORTE (2016)

Item	Dietary crude protein	
	Observed value	Predicted value
Mean	1.01	1.13
Standard deviation	0.20	0.16
Maximum	1.74	1.67
Minimum	0.50	0.67
% overestimation	12.24	
P-value (H_0: a = 0 and b = 1)	<0.01	
CCC	0.61	
Cb	0.80	
Mean square error of prediction	0.0324	
Mean bias (%)	0.0153 (47.22%)	
Systematic error (%)	0.0001 (0.31%)	
Random error (%)	0.0170 (52.47%)	

The validation analysis showed that the intercept and slope differ from zero and 1, respectively (P <0.01), which indicates that the estimates of the BR-CORTE (2010) model were inappropriate (Figure 8.1). Moreover, CP requirements were overestimated by 12.24% in relation to the observed CP intake. In the error decomposition, 47.22% of the errors were associated with mean bias, showing a tendency towards CP overestimation. Diets with excess protein will result in high diet costs with increased N excretion. These results demonstrated that new adjustments in the estimates of protein requirements needed to be performed.

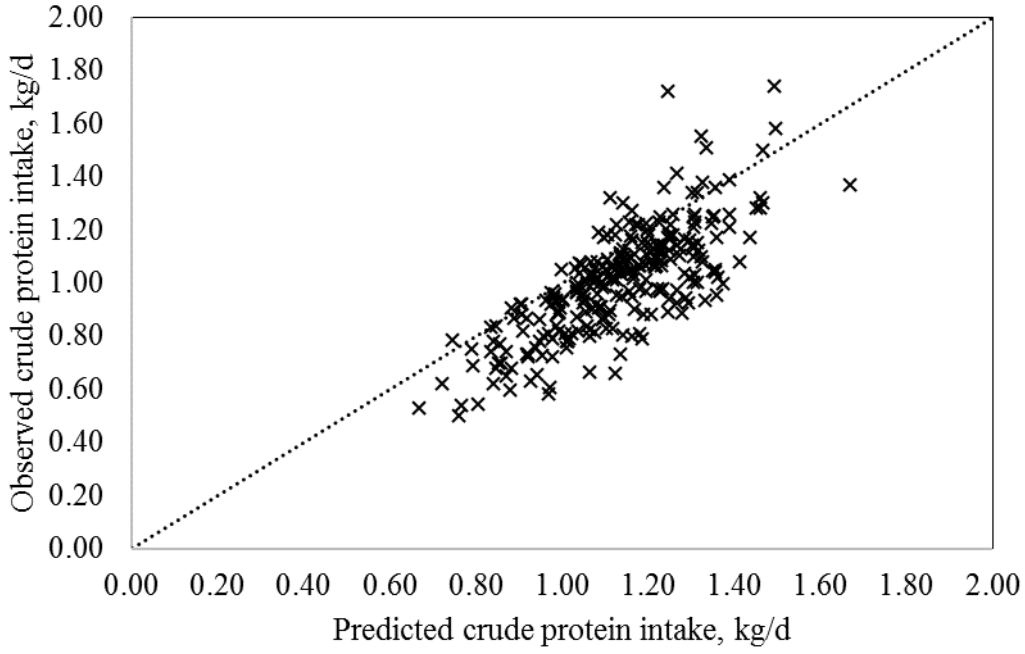


Figure 9.1 - Relationship between observed values and predicted values by the equation proposed by the BR-CORTE (2010) for crude protein intake, adapted from BR-CORTE (2016).

Diets with a protein content below the requirements of animals can affect productivity. However, diets with excess protein result in higher cost with feeding, and higher nitrogen excretion. Thus, knowledge of correct protein requirements is necessary to formulate diets to optimize animals' performance and contribute to the environment.

The results of the predicted CP intake highlight the need to adequate it to genetic, physiological, and environmental factors in Brazil. Then, in the third BR-CORTE edition (BR-CORTE, 2016), protein requirements were adjusted with the inclusion of new variables for MCP and data of animals with different body weights, gender, and genetic groups.

BR-CORTE (2016) DATABASE

In the third edition of BR-CORTE (BR-CORTE, 2016), a database was developed using 32 studies conducted under Brazilian conditions from 1991 to 2016: Galvão (1991), Jorge (1993), Paulino (1996), Ferreira (1997), Véras (2000), Silva (2001), Veloso (2001), Putrino (2002), Tedeschi et al. (2002), Paulino (2002), Backes (2003), Leonel (2003), Martins (2003), Chizzotti (2004), Moraes (2006), Paulino (2006), Marcondes (2007), Paixão (2008), Sales (2008), Porto (2009), Machado (2009), Marcondes (2011), Souza (2011), Costa e Silva (2011), Paula (2012), Rotta (2012), Amaral (2012), Prados (2012), Rodrigues (2014), Costa e Silva (2015), Silva (2015), and Menezes (2016). Among the data presented, 767 animals were raised in feedlot system and 148 in grazing system. In relation to the genetic group, 406 animals were Zebu cattle, 212 animals were crossbred beef cattle, and 149 animals were crossbred dairy cattle (Tables 9.2, 9.3, and 9.4, respectively). For animals raised on pasture, the descriptive statistics can be seen in Table 9.5.

PROTEIN REQUIREMENTS FOR MAINTENANCE

The demand of protein for maintenance of cattle is equal to the endogenous nitrogen losses through feces, urine, and scurf (NRC, 2000). In the first edition of BR-CORTE (BR-CORTE, 2006), the value of 2.69 g/$BW^{0.75}$ was adopted as the net protein required for maintenance (NPm; Véras et al., 2007). Bulls, steers, and heifers were fed four dietary CP levels (7, 10, 13 and 15%). Thus, gender did not affect the relationship between retained nitrogen and nitrogen intake (Figure 9.2). NPm (2.69 g/$BW^{0.75}$) was obtained multiplying the intercept of the regression between retained nitrogen on nitrogen intake (0.4313) by 6.25.

Table 9.2 - Descriptive statistics for Zebu cattle raised in feedlot and used to determine protein requirements, adapted from BR-CORTE (2016)

Item	N[1]	Mean	SD[2]	Maximum	Minimum
Bulls					
Initial shrunk body weight (kg)	214	290	58.3	438	151
Final shrunk body weight (kg)	227	408	73.1	592	215
Initial empty body weight (kg)	215	257	52.5	358	130
Final empty body weight (kg)	227	366	66.7	549	191
Average daily gain (kg/d)	162	0.99	0.40	2.66	-0.04
Empty body gain (kg/d)	214	0.99	0.40	1.87	-0.01
Retained energy (Mcal/d)	207	4.28	2.44	14.2	-0.58
Retained protein (g/d)	207	177	76.9	412	-29.1
Metabolizable protein intake (g/d)	159	700	213	1,263	195
Steers					
Initial shrunk body weight (kg)	123	287	57.1	399	110
Final shrunk body weight (kg)	123	367	80.1	520	125
Initial empty body weight (kg)	123	253	51.9	352	95.2
Final empty body weight (kg)	123	331	74.2	469	113
Average daily gain (kg/d)	110	0.71	0.40	1.41	-0.18
Empty body gain (kg/d)	123	0.67	0.37	1.32	-0.21
Retained energy (Mcal/d)	123	3.62	2.07	7.47	-0.02
Retained protein (g/d)	123	93.1	64.1	242	-122
Metabolizable protein intake (g/d)	48	651	255	1,143	159
Heifers					
Initial shrunk body weight (kg)	82	218	53.1	342	129
Final shrunk body weight (kg)	82	273	73.1	437	131
Initial empty body weight (kg)	82	192	50.1	297	111
Final empty body weight (kg)	82	247	70.2	397	115
Average daily gain (kg/d)	53	0.67	0.42	1.27	-0.12
Empty body gain (kg/d)	82	0.54	0.37	1.25	-0.13
Retained energy (Mcal/d)	82	2.49	2.02	8.22	-0.21
Retained protein (g/d)	81	74.0	62.3	196	-35.6
Metabolizable protein intake (g/d)	69	470	158	741	151

[1]N = number of observations; [2]SD = standard deviation.

Table 9.3 - Descriptive statistics for crossbred beef cattle raised in feedlot and utilized to determine protein requirements, adapted from BR-CORTE (2016)

Item	N[1]	Mean	SD[2]	Maximum	Minimum
Bulls					
Initial shrunk body weight (kg)	133	313	47.4	435	198
Final shrunk body weight (kg)	145	460	73.6	585	248
Initial empty body weight (kg)	133	264	37.9	366	173
Final empty body weight (kg)	145	404	68.4	499	222
Average daily gain (kg/d)	133	1.10	0.37	1.93	-0.08
Empty body gain (kg/d)	131	1.05	0.36	1.98	-0.05
Retained energy (Mcal/d)	133	3.89	1.70	8.76	-0.41
Retained protein (g/d)	133	156	69.7	384	-90.8
Metabolizable protein intake (g/d)	108	738	221	1,409	428
Steers					
Initial shrunk body weight (kg)	41	355	41.4	434	260
Final shrunk body weight (kg)	41	447	73.7	552	265
Initial empty body weight (kg)	41	312	48.8	385	205
Final empty body weight (kg)	41	409	70.2	506	238
Average daily gain (kg/d)	41	0.93	0.62	1.72	-0.36
Empty body gain (kg/d)	41	0.99	0.58	1.64	-0.09
Retained energy (Mcal/d)	41	5.41	2.74	9.53	0.75
Retained protein (g/d)	41	139	96.3	276	-49.3
Metabolizable protein intake (g/d)	35	704	200	918	272
Heifers					
Initial shrunk body weight (kg)	38	271	33.5	331	194
Final shrunk body weight (kg)	38	364	85.2	494	187
Initial empty body weight (kg)	38	241	36.8	311	150
Final empty body weight (kg)	38	327	74.0	443	175
Average daily gain (kg/d)	38	0.86	0.66	1.75	-0.31
Empty body gain (kg/d)	38	0.80	0.58	1.73	-0.18
Retained energy (Mcal/d)	38	4.00	2.61	7.65	-0.48
Retained protein (g/d)	37	125	92.2	297	-69.7
Metabolizable protein intake (g/d)	33	623	233	985	213

[1]N = number of observations; [2]SD = standard deviation.

Table 9.4 - Descriptive statistics for crossbred dairy cattle raised in feedlot and used to determine protein requirements, adapted from BR-CORTE (2016)

Item	N[1]	Mean	SD[2]	Maximum	Minimum
Bulls					
Initial shrunk body weight (kg)	81	297	103	494	150
Final shrunk body weight (kg)	93	412	126	661	169
Initial empty body weight (kg)	123	263	70.7	415	131
Final empty body weight (kg)	135	379	103	600	150
Average daily gain (kg/d)	81	1.34	0.64	2.64	0.02
Empty body gain (kg/d)	120	1.32	0.62	2.74	0.05
Retained energy (Mcal/d)	120	5.33	2.96	12.7	-0.67
Retained protein (g/d)	120	188	118	414	-181
Metabolizable protein intake (g/d)	125	698	271	1,417	118
Steers					
Initial shrunk body weight (kg)	48	325	34.7	453	216
Final shrunk body weight (kg)	48	388	53.1	575	254
Initial empty body weight (kg)	48	268	29.1	363	185
Final empty body weight (kg)	48	342	48.3	510	247
Average daily gain (kg/d)	48	0.77	0.55	1.70	-0.21
Empty body gain (kg/d)	48	0.93	0.38	2.00	0.02
Retained energy (Mcal/d)	48	3.93	1.63	9.00	0.51
Retained protein (g/d)	20	78.3	73.5	210	-110
Metabolizable protein intake (g/d)	28	920	255	1,410	458
Heifers					
Initial shrunk body weight (kg)	20	258	38.6	347	196
Final shrunk body weight (kg)	36	311	56.7	431	215
Initial empty body weight (kg)	36	195	43.3	298	115
Final empty body weight (kg)	36	276	54.2	403	192
Average daily gain (kg/d)	20	0.68	0.36	1.23	-0.04
Empty body gain (kg/d)	36	0.87	0.38	1.67	0.05
Retained energy (Mcal/d)	36	3.98	1.74	7.79	0.73
Retained protein (g/d)	36	100	70.4	240	-52.9
Metabolizable protein intake (g/d)	15	853	186	1,155	570

[1]N = number of observations; [2]SD = standard deviation.

Table 9.5 - Descriptive statistics for Zebu cattle raised on pasture and used to determine protein requirements, adapted from BR-CORTE (2016)

Itens	N[1]	Mean	SD[2]	Maximum	Minimum
Bulls					
Initial shrunk body weight (kg)	128	190	87.4	409	74.0
Final shrunk body weight (kg)	128	335	84.6	519	140
Initial empty body weight (kg)	128	163	72.0	337	63.3
Final empty body weight (kg)	128	292	75.6	463	118
Average daily gain (kg/d)	128	0.56	0.19	0.95	-0.15
Empty body gain (kg/d)	128	0.45	0.19	0.90	-0.10
Retained energy (Mcal/d)	127	1.12	1.01	4.14	-0.83
Retained protein (g/d)	108	87.0	32.4	156	14.5
Metabolizable protein intake (g/d)	84	459	163	893	189
Steers					
Initial shrunk body weight (kg)	20	317	59.8	409	226
Final shrunk body weight (kg)	20	363	66.9	484	243
Initial empty body weight (kg)	20	261	49.3	337	186
Final empty body weight (kg)	20	299	57.5	405	193
Average daily gain (kg/d)	20	0.57	0.33	0.95	-0.15
Empty body gain (kg/d)	20	0.47	0.29	0.90	-0.10
Retained energy (Mcal/d)	20	1.15	1.07	2.35	-0.83
Retained protein (g/d)	18	65.4	37.1	134	14.5
Metabolizable protein intake (g/d)	-	-	-	-	-

[1]N = number of observations; [2]SD = standard deviation.

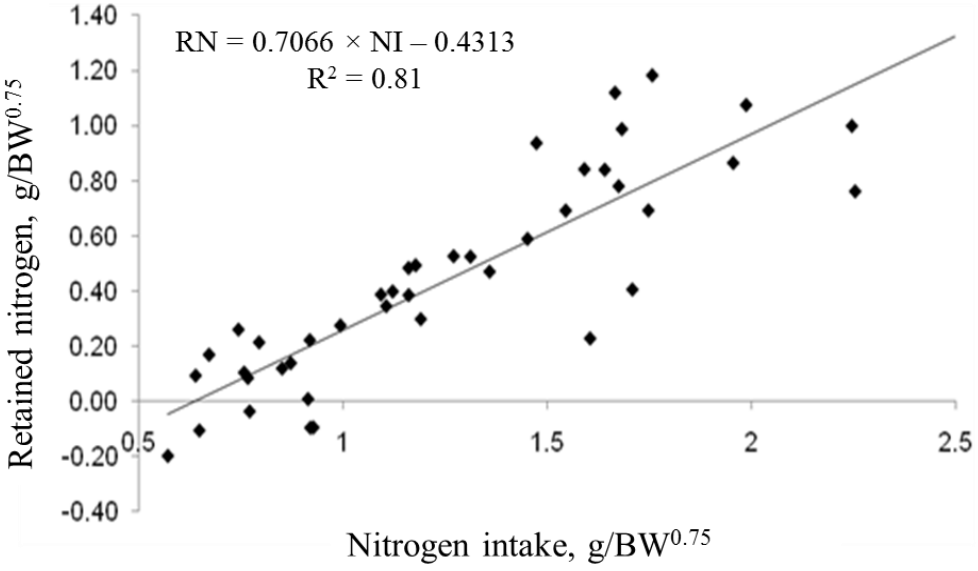


Figure 9.2 - Relationship between retained nitrogen (RN) and nitrogen intake (NI), expressed as g/BW$^{0.75}$. Adapted from Véras et al. (2007).

The AFRC (1993) adopted the value of 2.30 g/BW$^{0.75}$/d for NPm, which was obtained through the sum of the basal requirements of endogenous nitrogen and losses by scurf and hair. The INRA (1988) and Smuts (1935) adopted values of 3.25 g/EBW$^{0.75}$/d and 3.52

g/BW$^{0.75}$/d for NPm, respectively, which were obtained through experiments involving nitrogen balance.

In this context, Ezequiel (1987) obtained the metabolizable protein required for maintenance (MPm) of 1.72 and 4.28 g/BW$^{0.75}$/d for Nellore and Holstein steers, respectively. Costa e Silva et al. (2015) estimated MPm as 1.28 g/BW$^{0.75}$/d of growing Nellore steers and heifers. Furthermore, Valadares et al. (1997), considering the sum of fecal endogenous losses (estimated by regression between absorbed nitrogen and nitrogen intake) and urinary endogenous losses (obtained by regression between urinary nitrogen excretion and nitrogen intake), calculated the MPm of 4.13 g/BW$^{0.75}$/d.

To convert NPm to MPm, BR-CORTE (2006) utilized the factor of 0.667, obtained from the relationship between retained nitrogen and absorbed nitrogen (Figure 9.3), which is close to the recommendation of the NRC (1985) of 0.67. Utilizing this efficiency and considering an NPm of 2.69 g/BW$^{0.75}$, MPm was estimated as 4.03 g/BW$^{0.75}$. Thus, BR-CORTE (2006) recommended the use of 4 g/BW$^{0.75}$/d as the MPm.

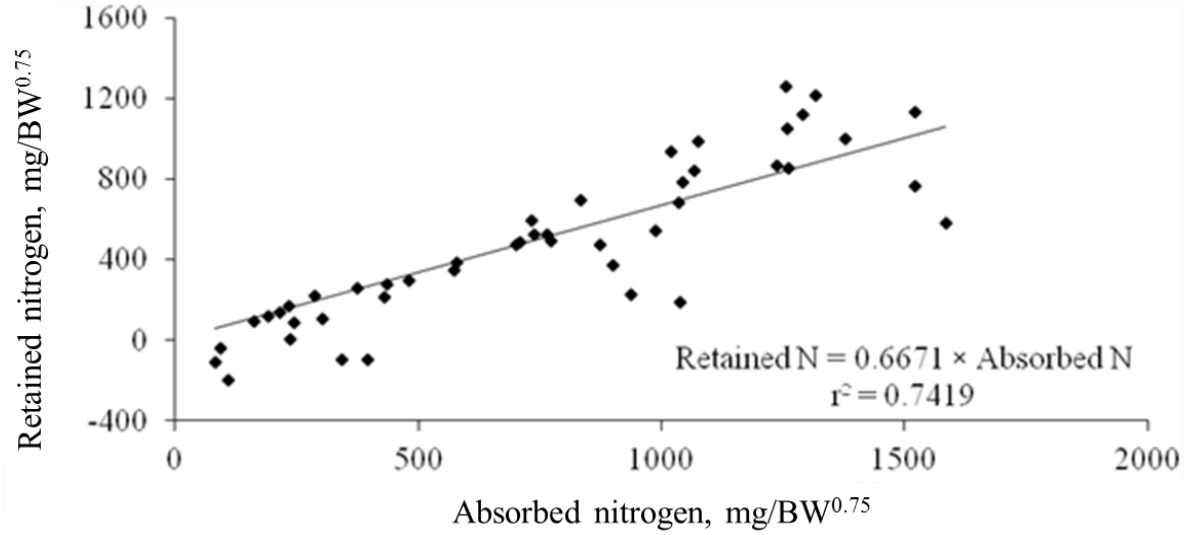


Figure 9.3 - Relationship between retained nitrogen and absorbed nitrogen. Adapted from Véras et al. (2007).

The NRC (2000) adopted the value of 3.8 g/BW$^{0.75}$, obtained by Wilkerson et al. (1993), as the MPm. This value was calculated by the division of the intercept (242) of the regression between MPI (g/d) and average daily gain (ADG; kg/d) of animals, by the average of metabolic body weight of the animals (63.44) in the database, which were fed 45 different protein sources with the number of animals varying from 3 to 30 per protein source. The same value was obtained by Susmel et al. (1993) in experiments involving nitrogen balance. Similarly, the NASEM (2016) recommended for MPm the value of 3.8 g/SBW$^{0.75}$.

In the second edition of BR-CORTE (BR-CORTE, 2010), MPI was correlated with ADG and empty body gain (EBG) to estimate MPm. The two equations estimated MPm values close to that proposed in the first edition of BR-CORTE (BR-CORTE, 2006): 4.0 g/BW$^{0.75}$, which was maintained in the BR-CORTE (2010).

Initially, to convert CP intake for MPI of the database, MCP synthesis should be estimated through the equation proposed in Chapter 3 (MCP = -53.07 + 304.9 × CPI + 90.8 × TDNI – 3.13 × TDNI^2). After MCP synthesis is known, the requirements of RDP can be estimated. Furthermore, the BR-CORTE (2010) considered the efficiency of the use of

degraded N for microbial N as 90%, so 10% of net N losses were considered in the rumen. Then, the requirements of RDP (g/d) were calculated as 1.11 × MCP. However, the inefficiency of this process, represented by the factor 1.11, was removed (for more details, see section "Considerations regarding nitrogen compound recycling"); thereby, the requirements of RDP are considered equal to MCP synthesis. Additionally, RUP intake was estimated by the difference between CP and RDP intakes. Therefore, MPI can be obtained from the following equation: MPI = (MCP × 0.64) + (RUP/0.80).

In the third edition of BR-CORTE (BR-CORTE, 2016), the same methodology of the BR-CORTE (2010) to estimate MPm was utilized, where MPI was correlated with EBG. After evaluations, the effect of production system was observed, suggesting that MPm must be estimated separately for animals raised on pasture and in feedlot. Moreover, effects of the genetic group and sex were tested for animals raised in feedlot and no effect was observed, allowing the development of only one equation for animals raised in feedlot (Figures 9.4 and 9.5; Table 9.5).

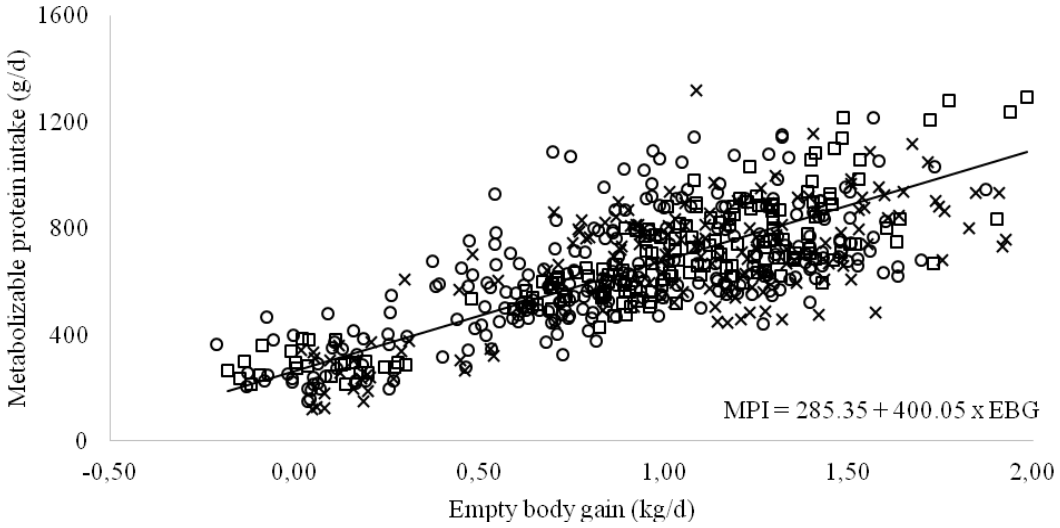


Figure 9.4 - Relationship between metabolizable protein intake and empty body gain of animals raised in feedlot. Symbols represent data from Zebu cattle (○), crossbred beef cattle (□), and crossbred dairy cattle (×).

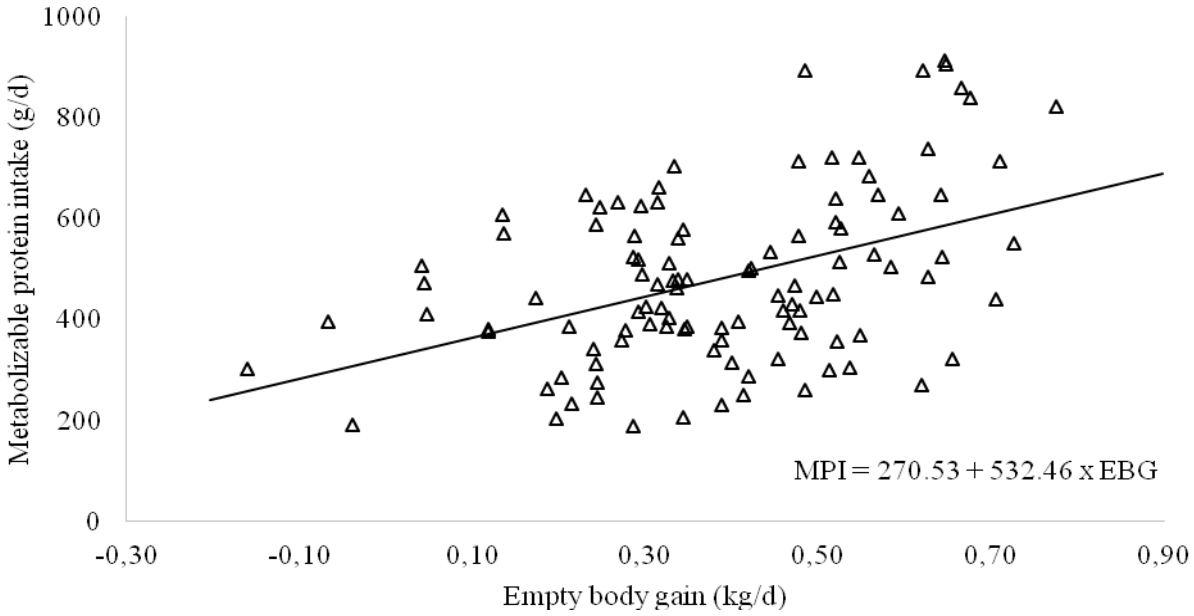


Figure 9.5 - Relationship between metabolizable protein intake and empty body gain of animals raised on pasture.

Table 9.5 - Metabolizable protein required for maintenance of beef cattle raised on pasture and in feedlot adapted from BR-CORTE (2016)

System	Equation	$EBW^{0.75}$	MPm
Feedlot	MPI = 285.35 + 400.05 × EBG	72.0	3.96
Pasture	MPI = 270.53 + 532.46 × EBG	62.7	4.31

MPI = metabolizable protein intake (g/d); EBG = empty body gain (kg/d); $EBW^{0.75}$ = metabolic empty body weight (kg); MPm = metabolizable protein required for maintenance (g/$EBW^{0.75}$).

In the BR-CORTE (2010), the value obtained to estimate MPm for Nellore and crossbred cattle was 3.91 g/$EBW^{0.75}$. This value was close to that obtained in the third edition of BR-CORTE (BR-CORTE, 2016), which was maintained in the current edition (3.96 g/$EBW^{0.75}$) for cattle raised in feedlot. For pasture, the value estimated in the third edition of BR-CORTE (BR-CORTE, 2016) and kept in the current edition for MPm was 4.31 g/$EBW^{0.75}$, which was lower than that observed in the second edition of BR-CORTE (BR-CORTE, 2010; 4.87 g/$EBW^{0.75}$). In both cases, converting these values in terms of shrunk body weight (SBW), the estimates are 3.6 and 3.9 g/$SBW^{0.75}$ for animals raised in feedlot and on pasture, respectively. The value obtained for animals raised in feedlot was lower than those values recommended by the NASEM (2016) and the BR-CORTE (2010) which were 3.8 g/$SBW^{0.75}$ and 4.0 g/$BW^{0.75}$, respectively. Moreover, it is noteworthy that cattle raised on pasture required approximately 8.0% more MPm than those raised in feedlot.

In this context, the committee decided to maintain the values of 3.6 and 3.9 g/$SBW^{0.75}$ for MPm recommended in the last edition of BR-CORTE (BR-CORTE, 2016) for cattle raised in feedlot and on pasture, respectively.

PROTEIN REQUIREMENTS FOR GROWTH

The determination of body composition in animals is important for evaluating the nutritional value of feedstuffs and for studies evaluating animal growth (Boin et al., 1994), because it allows researchers to estimate the protein required for animal growth. The main body chemical components of cattle are water, protein, fat, and minerals. According to Ferreira et al. (1999), animal maturity is characterized by an increase in

body fat content. Young animals have greater proportion of water and protein and lower fat content so that the concentrations of protein, ash, and water decreases with age and finishing. The NRC (2000) reported that body fat and protein contents present quadratic behavior in relation to body weight (BW) with inverse relationships: fat content increases, and protein content decreases as body weight increases.

The proportion and rate of tissues deposition in the body influences growth, body composition, and feed efficiency (Shahin et al., 1993), and, consequently, nutrient requirements. The proportion of tissues and their chemical compositions are influenced by several factors, such as body weight, age, breed, energy intake and gender (Ferreira et al., 1999). According to Garret (1980), breed has greater influence on body composition than the nutritional level at the same body weight.

Differences in the protein required for growth are attributed to variations in the composition of body gain (Garret et al., 1959; Geay, 1984). Protein required for growth is greater for late-maturity bulls than early-maturity steers (Geay, 1984). Boin (1995) observed greater protein content per kilogram of EBG for Nellore bulls in relation to Nellore steers. According to Geay (1984), net protein (NP) requirements tend to be less important compared to the requirements of energy for growing early cattle, such as Angus and Hereford, because there is lower retention of energy as protein (12 to 15%). This type of animal meets their protein requirements using mainly AA from microbial fermentation (Geay, 1984). Most studies indicate reduced net protein required for growth (NPg) as BW increases (Lana et al., 1992; Pires et al.; 1993; Fontes, 1995; Paulino, 1999, Cavalcante et al., 2005, Amaral et al., 2014).

In the first edition of BR-CORTE (BR-CORTE, 2006), NPg was estimated from regression equations of retained protein (RP), retained energy (RE), and ADG, and three equations were obtained as a function of gender for Zebu cattle raised in feedlot. In the second edition of BR-CORTE (BR-CORTE, 2010), a similar model to that proposed by the NRC (2000) was utilized, in which RP was correlated with RE and EBG. In the third edition (BR-CORTE, 2016), 10 different equations to predict NPg (Table 9.6) were recommended, considering the effects of production system (feedlot and pasture), genetic group (Zebu, crossbred beef and dairy cattle), and gender (bulls, steers, and heifers).

Table 9.6 - Equations used to estimate net protein required for the growth of animals raised on pasture and in feedlot of different genetic groups and gender, adapted from BR-CORTE (2016)

System	Genetic group	Gender	Equation
Feedlot	Zebu cattle	Bulls	NPg = 210.09 × EBG – 10.01 × RE
		Steers	NPg = 153.13 × EBG – 2.53 × RE
		Heifers	NPg = 193.90 × EBG – 12.16 × RE
	Crossbred beef cattle	Bulls	NPg = 281.77 × EBG – 27.66 × RE
		Steers	NPg = 219.94 × EBG – 12.04 × RE
		Heifers	NPg = 174.65 × EBG – 3.14 × RE
	Crossbred dairy cattle	Bulls	NPg = 171.43 × EBG – 3.08 × RE
		Steers	NPg = 236.36 × EBG – 19.84 × RE
		Heifers	NPg = 206.58 × EBG – 15.39 × RE
Pasture	Zebu cattle	Bulls	NPg = 181.43 × EBG – 2.88 × RE

NPg = net protein required for growth (g/d); EBG = empty body gain (kg/d); RE = retained energy (Mcal/d).

Development of a new equation to estimate the requirements of net protein for growth (NPg)

Costa e Silva et al. (2020) developed a new model to estimate NPg for cattle raised under Brazilian conditions. Briefly, a meta-analysis was performed using data obtained from 23 studies performed in Brazil from 1997 to 2016 (Costa e Silva et al., 2020). The database comprised 492 animals finished in feedlots and 60 animals raised and finished on pastures, totaling 552 observations that encompassed bulls, steers, and heifers of different genetic groups (Zebu, Crossbred beef cattle, and Crossbred dairy cattle). The general model adjusted was:

$$NPg = 176.01 \times EBG - 6.239 \times RE$$

where NPg = net protein requirements for growth (g/d), EBG = empty body gain (kg/d), and RE = retained energy (Mcal/d).

However, models using EBG and RE as predictive variables, which do not allow adjustments regarding BW when an animal reaches physiological maturity, may lead to overparameterization of NPg prediction, increasing the complexity of calculations. Aiming simplify the calculation of NPg for animals of different genetic groups and gender, authors decided to replace the RE variable of the general NPg equation with the equation used to estimate net energy requirements for growth (NEg). NEg equation, which was previously proposed in the BR-CORTE (2016), utilizes the equivalent empty body weight (EQEBW) as a predictive variable that allows estimating RE for any BW, regardless of gender and genetic group (RE= $0.061 \times EQEBW^{0.75} \times EBG^{1.035}$). Thus, after replacing the RE predictive variable by the NEg equation, the new model obtained was: $NPg = 176.01 \times EBG - 6.239 \times 0.061 \times EQEBW^{0.75} \times EBG^{1.035}$. This new model for predicting NPg can be simplified as:

$$NPg = 176.01 \times EBG - 0.381 \times EQEBW^{0.75} \times EBG^{1.035}$$

where NPg = net protein requirements for growth (g/d), EBG = empty body gain (kg/d), and EQEBW = equivalent empty body weight (kg). In this context, utilizing the EQEBW as a predictive variable allows estimating the RE for any BW, regardless of gender and genetic group (Marcondes et al., 2016). Therefore, the use of EQEBW in models might simplify and can even improve the accuracy and precision of NPg estimates.

Moreover, these authors also evaluated the new equation proposed and compared to current models devised by international nutrient requirements system committees (ARC, 1980; BR-CORTE, 2016; NASEM, 2016) to predict NPg using an independent database. Model evaluation was performed using data from five independent experiments totaling 177 observations encompassing bulls and steers of different genetic groups (Zebu, crossbred beef cattle and crossbred dairy cattle). As a result, the BR-CORTE (2016) and NASEM (2016) equations did not correctly estimate NPg and were not recommended for estimating NPg for cattle in Brazilian production scenarios.

Nevertheless, the new approach (Costa e Silva et al., 2020) and the ARC (1980) presented both precision and accuracy. Furthermore, the inclusion of EQEBW in the new approach (Costa e Silva et al., 2020) improved the estimation of NPg, which presented superior reproducibility and accuracy when compared to the current models evaluated. Therefore, the committee recommends the use of the equation proposed by Costa e Silva et al. (2020) to predict NPg ($NPg = 176.01 \times EBG - 0.381 \times EQEBW^{0.75} \times EBG^{1.035}$) in the current edition of BR-CORTE.

Efficiency of the use of metabolizable protein

To convert NP to MP requirements, the partial efficiency of the use of metabolizable protein for growth (k) must be estimated. MP contains the digestible rumen undegradable protein (dRUP) and the digestible true microbial crude protein (dtMCP) which represent the amount of AAs that reach the small intestine to be absorbed.

Among the international systems for nutrient requirements of beef cattle, the NRC (1984) reported the mean biological value of AA absorbed by cattle as 66%, a value obtained by Zinn and Owens (1983). Then, based on this study and others, the NRC (1985) adopted values of 50 and 65% for k, being these values based on the biological value of protein

and on the value of an ideal mixture AA (Oldham, 1987). Oldham (1987) also suggested an efficiency of 85% for all physiological functions as a value reflecting the efficiency of conversion of an ideal mixture of AA. As this fact does not occur in practice, the real efficiency normally is lower than this value.

According to the British system (AFRC, 1993), the efficiency of the use of an ideal mixture of AA named *kaai*, is a characteristic that is inherent to the animal. However, this system recognized that, in practice, lower values than the real efficiency have been found. These efficiencies are basically dependent on the mixed quality of AA in the dRUP and the proportion between dRUP and dtMCP that reaches the small intestine. Therefore, the AFRC (1993) considers fixed values for the efficiency of the use of MP as follows: 100% for maintenance, 59% for growth, 85% for pregnancy and 68% for lactation.

Due to the high quality of the mixture of AA of MCP, the biological value of MCP is high, and therefore, the proportion of MCP that reaches the small intestine could alter the efficiency of the use of MP (NRC, 2000). However, the French system (INRA, 1988) considers that as body weight increases, *k* decreases. This decreasing efficiency was confirmed by Ainslie et al. (1993) and Wilkerson et al. (1993), with data from animals with body weight varying from 150 to 300 kg. In this context, the NRC (2000) adopted the equation proposed by Ainslie et al. (1993) to estimate *k* for animals from 150 to 300 kg BW, as follows:

$$k = 83.4 - (0.114 \times \text{EQEBW})$$

Thus, an animal with 150 kg EQEBW will have a *k* value equal to 0.663, while a 300kg animal will have efficiency of 0.492. The NRC (2000) recommended the equation above only for animals with EQEBW lower than 300 kg; while for heavier animals, the NRC (2000) suggested the fixed value of 0.492, from the previous version (NRC, 1984). Also, we highlight that the protein required for growth is relatively low when animals achieve body weight of approximately 400 kg.

Data from Brazil reported *k* values of 33.3% (Costa e Silva et al., 2013) and 34.4% (Menezes et al., 2016) for growing and finishing Nellore cattle, respectively. Nevertheless, Zanetti et al. (2016) and Silva et al. (2016) obtained values of *k* equal to 26.72 and 25.2% for Holstein × Zebu steers and heifers, respectively. However, Mariz et al. (2018) have described an average value for *k* of 40% for Nellore and Angus × Nellore bulls. Several factors such as age, body composition, and feeding conditions can affect *k* (Blaxter et al., 1966; Garrett, 1980; Gionbelli et al., 2012, Marcondes et al., 2013).

The first edition of BR-CORTE (BR-CORTE, 2006) utilized the recommendations of the NRC (2000) for *k*, whose k value was considered the slope obtained from the regression between RP and MPI. On the other hand, the BR-CORTE (2010) evaluated RP as a function of MPI (Figure 9.6) and found no effect of genetic group or gender on *k*, and the equation adopted was:

$$\text{RP} = -2.223 + 0.4691 \times \text{MPI}$$

where RP = the retained protein (g/EBW$^{0.75}$) and MPI = the metabolizable protein intake (g/EBW$^{0.75}$).

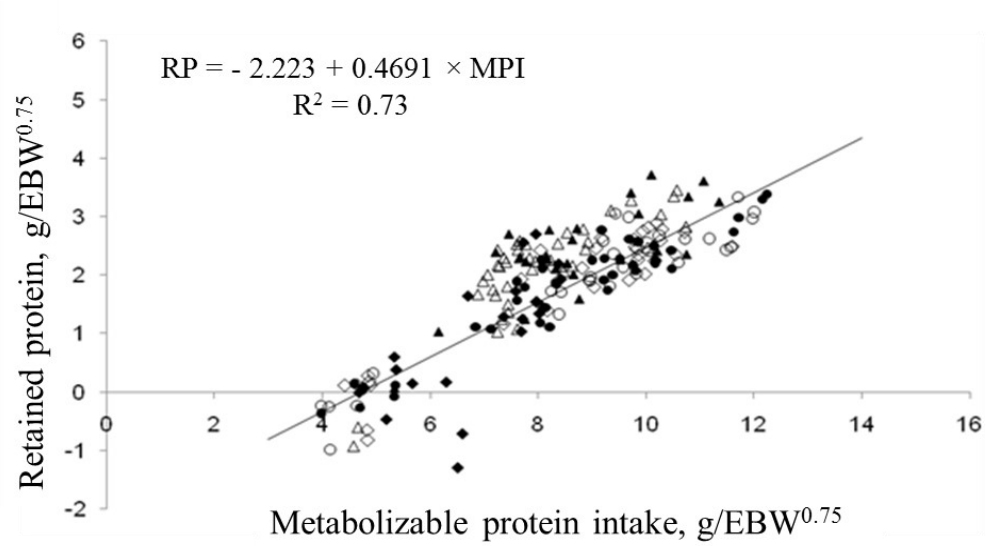


Figure 9.6 - Relationship between retained protein and metabolizable protein intake. Symbols represent data from bulls (▲, Δ), steers (◊, ♦), and heifers (○, ●). Solid points represent Nellore and empty point represent crossbred *Bos taurus indicus* × *Bos taurus taurus* cattle.

From this equation, the value estimated for *k* was 46.9% for Zebu and crossbred cattle. This estimated value was similar to 49.2% recommended by the NRC (2000). In addition, the same value estimated for *k* for animals raised in feedlot was adopted for grazing animals in the second edition of BR-CORTE (BR-CORTE (2010) due to the limited data available in such conditions. In the third edition of BR-CORTE (BR-CORTE, 2016), a similar equation was adjusted; the value obtained was 47.4% (Figure 9.7) for animals raised on pasture and in feedlot. Also, the amount of data from animals raised on pasture was small, preventing us from evaluating the effect of the production system on *k*.

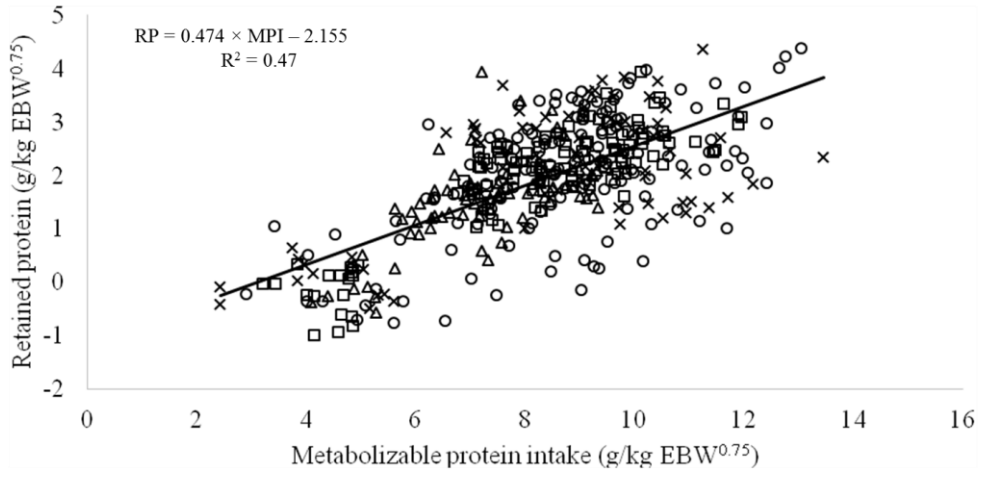


Figure 9.7 - Relationship between retained protein (RP) and metabolizable protein intake (MPI) of animals raised in feedlot. Symbols represent data from Zebu cattle (○),crossbred beef cattle (□), crossbred dairy cattle (×), and animals raised on pasture (Δ).

Most of the nutrient requirement systems (CSIRO, 2007; NRC, 2000; AFRC, 1993; INRA, 1988) report that the use of a constant efficiency (*k*) does not represent the real efficiency of the animals. *k* seems to be more related to the MP composition that reaches the small intestine than EQEBW (Oldham,1987), as suggested by the INRA (1988).

In this way, an average efficiency (*k*) of each experiment was estimated, and these values were correlated with the mean EQEBW of each experiment to generate the equation to estimate *k* in the second edition of BR-CORTE (BR-CORTE, 2010):

$$k\,(\%) = 84.665 - 0.1179 \times \text{EQEBW}$$

where EQEBW = equivalent empty body weight.

This equation recommended in the second edition of BR-CORTE (BR-CORTE, 2010) was kept in the current edition. However, in the second edition of BR-CORTE (BR-CORTE, 2010), the committee recommended this equation to be utilized for animals that present SBW < 350 kg. As the value of *k* increased for adult animals (46.9 vs. 47.4%) from the second (BR-CORTE, 2010) to the third edition (BR-CORTE, 2016) of BR-CORTE, the recommendation would be the use of this equation for animals with SBW < 340 kg. Therefore, considering an animal with 150 kg EQEBW, using the equation, the efficiency might be 67%. This estimated value is similar to 66% which was suggested by the NRC (2000). Additionally, as the animal grows, the estimated *k* value decreases up to SBW equals to 340 kg. After this value of SBW, *k* might be constant and equal to 47.4%. The NRC (2000) and NASEM (2016) considered the value of 49.2% for *k* for animals with BW greater than 300 kg.

MCP can be calculated by considering the recommendation presented in Chapter 3, where MCP synthesis was calculated as a function of CPI and total digestible nutrients intake (TDNI) as follows:

$$\text{MCP (g/d)} = -53.07 + 304.9 \times \text{CPI} + 90.8 \times \text{TDNI} - 3.13 \times \text{TDNI}^2$$

where CPI = crude protein intake (kg/d) and TDNI = total digestible nutrients intake (kg/d). Thus, the requirements of RDP can be calculated from recommendations of the current edition, where MCP synthesis equals to RDP requirements: RDP = MCP. While the requirements of RUP can be obtained by the following equation: RUP = (Total metabolizable protein – (MCP × 0.64))/0.80. To obtain CP requirements, RDP and RUP requirements should be added. It is noteworthy that the values used for MCP true digestibility and RUP digestibility in the small intestine were recently confirmed by Mariz et al. (2018), who estimated MCP true digestibility and RUP digestibility as approximately 80%., evaluating Nellore and Angus × Nellore cannulated bulls in the rumen and ileum,

CONSIDERATIONS REGARDING NITROGEN COMPOUND RECYCLING

Urea recycling from liver to rumen and salivary glands is one of the peculiarities that involves ruminant physiology and nutrition and represents an evolutionary advantage for these animals, allowing their survival in periods of dietary protein restriction (lower than 7%; Lazzarini et al., 2009; Sampaio et al., 2010). According to Batista et al. (2016), providing ammonia for rumen microorganisms, urea recycling affects the amount of N available in the rumen provided directly from the diet. Therefore, the nutrient systems should consider recycled N to estimate protein requirements of the animals. Considering such aspects, the current edition of the North America system (NASEM, 2016) considers urea recycling for the rumen as:

$$\text{N urea} = (-0.1113 + 0.996 \times \exp^{(-0.0616 \times \text{CP})}) \times (0.745 \times \text{NI} - 11.98)$$

where N urea = N recycled for rumen as urea (g/d); CP = dietary crude protein content (% DM); NI = nitrogen intake (g/d). Thereby, the NASEM (2016) aims to bring CP requirements closer to the real with the use of N recycling in the calculations, allowing diet formulation that optimize animal performance, reduce economic losses, and avoid environment contamination. Up to the second edition of BR-CORTE (BR-CORTE, 2010), nitrogen recycling was not considered in the calculations of protein requirements, which may have contributed to the overestimation of the recommendation of CP in cattle diets.

However, Batista et al. (2016), evaluating low quality forage (5.0% CP on DM basis) or diets containing ruminal protein infusion to meet 100% RDP requirements and from 0 to 150% RUP requirements, found that 22% of the total microbial N in the control diet was from urea recycling, while in supplemented diets this

incorporation was 10%. Furthermore, evaluating diets with different CP contents (9, 11, 13, and 15% on DM basis) and considering RDP content, the amount of RDP intake and microbial nitrogen (MN) synthesis obtained for each dietary CP level, Prates (2015) verified that the efficiency of the uptake of rumen degradable N intake as MN varied from 120% to 90.28% for diets with 9% and 15% CP, respectively. Thus, the amount of recycled N incorporated into microbial N was approximately 20% in the diet with 9% CP, decreasing to 10% in the diet containing 11% CP, and approximately zero for the diet with 13% CP. This author observed a net N loss in the rumen close to 10% for the diet containing 15% CP. Thus, considering the data described above, N recycling for rumen might contribute with 10 to 20% of microbial N, in diets varying from 5 to 13% CP. These values are lower than those calculated by the equation suggested by the NASEM (2016).

Although recognizing the importance of N recycling, the BR-CORTE committee does not recommend any value to account for this process, as so far only Batista et al. (2016) effectively measured urea recycling using animals fed low-quality forage and N infusions under tropical conditions. However, despite not recommending any value for N recycling, the committee considers that the amount of N compounds recycled into rumen could compensate the inefficiency of degradable N utilization. Nevertheless, the committee suggests that if the user desires to compute N recycling, values from 5% to 10% would be appropriate for conventional diets.

PRACTICAL EVALUATION OF CRUDE PROTEIN LEVELS IN BEEF CATTLE DIETS

Two studies were developed to evaluate the effect of reducing crude protein levels in the diets of beef cattle. In Study 1 (Menezes et al., 2019), animals were weaned, and the growing/finishing phase was conducted in a feedlot, in which static and oscillating levels of 10.5, 12.5, and 14.5 % CP in the diet DM were tested. In Study 2 (Menezes et al., 2016), animals were weaned, allocated on pasture for one year following a finishing phase in feedlot. In this case, levels of 10, 12, and 14% CP on the diet DM were evaluated.

Study 1

Forty-two young bulls (initial BW of 260 ± 8.1 kg; age of 7 ± 1.0 months) were fed *ad libitum* and were randomly assigned to receive one of the six diets with different CP concentrations for 140 d: 10.5 (LO), 12.5 (MD), or 14.5% CP in the diet DM (HI), and LO to HI (LH), LO to MD (LM), or MD to HI (MH) oscillating CP at a 48-h interval for each feed. Dry matter intake, growth performance, and carcass traits were not affected ($P > 0.05$) by dietary CP content or oscillating dietary CP (Table 9.7), suggesting that oscillating CP diets were not detrimental to bull performance.

On the other hand, results on N balance were more variable. Overall, bulls fed the HI CP diet presented greater N intakes and excretions than those fed the MD or LO CP diets. Moreover, bulls fed the HI and MD CP diets had greater N retained than those fed low (LO CP diet). Differences were also observed among oscillating dietary CP treatments and the MD static treatment, where greater N intake and excretions were observed for bulls fed LH and MH in comparison to those receiving MD treatment; whereas bulls fed LM showed lower N intake and urinary N excretion than those fed MD. Furthermore, bulls receiving the MD diet retained more N than those fed LM and MH CP diets.

Table 9.7 - Growth performance and carcass traits of Nellore bulls fed different crude protein levels [Adapted from Menezes et al. (2019)]

Item[1]	Treatment[2]						SEM[3]	Contrasts[4]				
	LO	MD	HI	LH	LM	MH		Linear	Quadratic	M × LH	M × LM	M × MH
Animal performance												
Dry matter intake (kg/d)	7.71	7.62	7.29	7.54	7.51	7.62	0.21	0.27	0.33	0.51	0.77	0.77
Initial SBW (kg)	276	275	279	275	274	277	9.09	0.75	0.95	0.85	0.92	0.93
Final SBW (kg)	440	447	433	455	445	448	14.1	0.46	0.98	0.8	0.71	0.67
ADG (kg)	1.17	1.25	1.13	1.32	1.23	1.25	0.06	0.15	0.79	0.51	0.34	0.35
Gain to feed ratio (G:F)	0.15	0.16	0.15	0.17	0.16	0.16	0.01	0.11	0.24	0.19	0.10	0.14
Carcass traits												
Cold carcass weight (kg)	261	266	258	271	262.2	268	8.43	0.53	0.92	0.93	0.69	0.56
Cold carcass dressing (%)	59.4	59.4	59.7	59.5	59	59.8	0.43	0.73	0.79	0.53	0.96	0.53
Fat thickness (mm)	4.9	3.9	3.2	4.0	3.8	5.1	0.50	0.41	0.06	0.11	0.16	0.77
N balance												
N intake (g/d)	135.2	149.7	197.6	171.9	143.8	165.9	2.38	<0.01	<0.01	0.02	<0.01	<0.01
Urine N (g/d)	67.7	85.5	116.1	92.8	71.2	90.7	2.39	<0.01	<0.01	0.33	<0.01	<0.01
Fecal N (g/d)	43.9	44.3	52.1	49.9	47.0	50.0	1.21	<0.01	0.01	0.07	0.81	<0.01
N retained (g/d)	23.8	29.0	29.1	29.9	26.4	27.3	1.16	0.96	0.01	0.13	<0.01	0.04

[1]SBW, shrunk body weight; ADG, average daily gain.
[2]LO, low (10.5% CP); MD, medium (12.5 % CP); HI, high (14.5% CP), LH, oscillating low (LO; 10.5% CP) to high (HI; 14.5% CP) every 48 h; LM, oscillating low (10.5%) to medium (MD; 12.5 % CP) every 48 h; MH, oscillating medium (12.5 % CP) to high (14.5% CP) every 48 h.
[3]SEM = standard error of the mean.
[4]Linear and quadratic contrasts compared 10.5, 12.5, and 14.5% CP; M vs. LH compared 12.5 vs. oscillating 10.5 to 14.5% CP every 48 h; M vs. LM compared 12.5 vs. oscillating 10.5 to 12.5% CP every 48 h; M vs. MH compared 12.5 vs. oscillating 12.5 to 14.5% CP every 48 h.

This study showed that reducing CP from 14.5 to 10.5% in diets or oscillating CP supply did not affect growth performance and carcass traits of growing Nellore bulls; but increasing diet CP content increased N intake, excretions, and retention. It is important to highlight that MD and HI diets presented similar N retention and MD diet showed an overall improvement on N intake, excretion, and retention when compared to the LH and MH oscillating dietary CP treatments.

It seems that although there is no adverse effect of feeding oscillating CP diets in relation to a static level of 12.5% CP, nor static low (10.5% CP) and high (14.5 % CP) levels on growth performance of young Nellore bulls; there may be undesirable increases in environmental N excretion when the average dietary CP content is increased. Thus, it appears plausible that diets containing 10.5 and 12.5% CP contents, or within this range should be indicated for finishing Nellore young bulls. This recommendation on dietary CP content may reach the requirements, reduce environmental impact related to N excretion, and avoid economic losses.

Study 2

Nellore bulls with an average age of 20 ± 1.0 months and initial BW of 330 ± 8.1 kg were used in this experiment. Bulls were divided into three groups and were randomly assigned to the treatments consisting of three levels of CP in the diets: 10, 12, and 14% of CP. The experiment lasted 112 days. Similar to Study 1, no effect of dietary CP levels was observed on animal performance or carcass traits of Nellore bulls finished in feedlot (Table 9.8).

Table 9.8 - Performance and carcass traits of finishing Nellore bulls fed three different crude protein content

	Crude protein content				Contrast	
Item	10%	12%	14%	SEM	Linear	Quadratic
Initial body weight (kg)	324	325	329	-	-	-
Final body weight (kg)	470	479	477	9.13	0.57	0.64
Average daily gain (kg/d)	1.30	1.50	1.50	0.06	0.64	0.53
Hot carcass weight (kg)	286	288	285	6.42	0.90	0.72
Subcutaneous fat thickness (mm)	5.00	5.60	4.40	0.72	0.59	0.30
Hot carcass yield (%)	60.9	60.1	59.6	0.58	0.14	0.90

According to Winschester et al. (1957), CP levels influence ADG of growing animals, although the same behavior is not observed for finishing animals. This occurs because protein requirements reduce as the animals reach maturity (NRC, 2000), when they start depositing more fat, increasing fat:muscle ratio in the carcass.

Nevertheless, Brazilian feedlots normally adopt CP levels ranging from 11 to 15%, with mean values of 13.6% CP (Pinto and Millen, 2018), because higher CP levels stimulate intake and are related to high weight gain (Véras et al., 2007). However, Menezes et al. (2016) showed that DMI is not affected by dietary protein levels and the reduction of CP contents during the finishing phase contributes to the reduction of feeding costs. According to these authors, the excessive intake of CP in the diet of 14% CP in relation to 10% was 330 g/d, which is equivalent to 733 grams of soybean meal that could be saved per animal each day. Thus, the reduction of CP contents in diets is possible and viable, mainly during the finishing phase, which reduces feeding costs.

Based on these experiments, the current edition of BR-CORTE suggests that diets containing 10.5 and 12.5% CP contents, or within this range may be indicated if the aim is to produce young bulls in feedlots. In other respects, no difference in animal performance

among Nellore bulls fed diets containing 10, 12 or 14% CP were detected when finishing more mature animals with initial BW of 330 kg (Menezes et al., 2016).

AMINO ACIDS REQUIREMENTS

Nutritional models for feeding protein have evolved from basic CP (NRC, 1976; ARC, 1965) to more complex systems based on RDP and RUP (ARC, 1980; INRA, 1988; NASEM, 2016; BR-CORTE, 2016). However, AA and not protein per se, are the required nutrients. Thus, it would be more appropriate to use AA instead of CP requirements to meet the cattle maintenance and production requirements when formulating diets. Furthermore, formulating diets utilizing the AA requirements may contribute to reducing protein content of beef cattle diets, without adversely affecting animal performance, resulting in reduction of protein intake, feed costs, and excreted N compounds to the environment.

Despite the considerable progress in modeling microbial protein synthesis (NASEM, 2016) and AA digestibility (Tamminga and Oldham, 1980; Mariz et al., 2018), there have been limited advances in intermediate metabolism of AA and especially in net AA requirements of ruminants (Tedeschi et al., 2015; Schwab and Broderick, 2017; Amaral et al., 2021). Thus, robust predictive models need to be developed to estimate net and metabolizable AA requirements of cattle, which allow balancing diets for both rumen microorganisms and the host animal.

Few measures of AA requirements for ruminants are available. In the CNCPS (O'Connor et al., 1993), the AA requirements of ruminants are based on NP requirement and AA profile in whole-body tissue (Titgemeyer and Loest, 2001). However, the efficiency in which absorbed AA are used for protein retention is difficult to access (NASEM, 2016), and there are few and contradictory estimates. According to the AFRC (1993), the efficiency of AA usage for gain was assumed to be 59% for all essential AA (EAA), while BR-CORTE (BR-CORTE, 2016) suggested 47.4% as efficiency of MP, which is near to that of 49% suggested in NASEM (2016). Despite these systems adopted the same values for efficiency for AA usage, recent evaluations showed that differences exist among individual AA (Titgemeyer et al., 1990; Löest et al., 2002; Batista et al., 2016).

In this regard, Amaral et al. (2021) and Mariz et al. (2018) developed complementary studies, which 1) evaluated the AA content in empty body and estimated net requirements of AA and energy for weight gain of purebred (Nellore) and crossbred Angus × Nellore (A × N) bulls; 2) determined the apparent and true intestinal digestibility of total and individual AA and estimated the efficiency of whole-body AA retention from individual and total absorbed AA.

There is a deficiency of AA requirements data in the literature, especially for beef cattle. Moreover, data utilized for Amaral et al. (2021) and Mariz et al. (2018) were obtained in Brazilian production conditions. Therefore, the above-mentioned studies will serve as the basis of the net and metabolizable AA requirements incorporated into the current edition of this publication.

The content of each AA and CP (kg) in the empty body and the AA requirements were described in equations forms by Amaral et al. (2021). This database included data from 48 bulls (24 Nellore and 24 A × N) fed three dietary CP contents (100, 120 and 140 g CP/kg DM) in a comparative slaughter experiment. Considering that no differences were found between the genetic groups evaluated, a single equation was obtained to estimate the individual AA content in empty body and the net individual AA requirements for weight gain (g/kg EBG and g/100 g CP) for both Nellore and crossbred A × N bulls (Table 9.9).

Table 9.9 - Amino acids composition of crude protein in the empty body and the net amino acids requirements for gain of Nellore and crossbred Angus × Nellore bulls[1], adapted from Amaral et al. (2021)

Amino acid	Body composition (kg)	R^2	Net requirements for gain	
			g/kg EBG	g/100 g of CP
CP, g/d	$0.3501 \times EBW^{0.8942}$	0.96	$313.1 \times EBW^{-0.1058}$	100
Essential amino acids, g/100 g CP				
Arginine	$0.0368 \times EBW^{0.8369}$	0.94	$30.8 \times EBW^{-0.1631}$	$9.84 \times EBW^{-0.0573}$
Histidine	$0.0035 \times EBW^{1.0556}$	0.91	$3.69 \times EBW^{0.0556}$	$1.18 \times EBW^{0.1614}$
Isoleucine	$0.0102 \times EBW^{0.9369}$	0.93	$9.56 \times EBW^{-0.0631}$	$3.05 \times EBW^{0.0427}$
Leucine	$0.0239 \times EBW^{0.9003}$	0.95	$21.5 \times EBW^{-0.0997}$	$6.87 \times EBW^{0.0061}$
Lysine	$0.0167 \times EBW^{0.9536}$	0.93	$15.9 \times EBW^{-0.0464}$	$5.09 \times EBW^{0.0594}$
Methionine	$0.0059 \times EBW^{0.9197}$	0.88	$5.43 \times EBW^{-0.0803}$	$1.73 \times EBW^{0.0255}$
Phenylalanine	$0.0096 \times EBW^{0.9370}$	0.94	$8.98 \times EBW^{-0.0630}$	$2.87 \times EBW^{0.0428}$
Threonine	$0.0102 \times EBW^{0.9349}$	0.94	$9.54 \times EBW^{-0.0651}$	$3.05 \times EBW^{0.0407}$
Tryptophan	$0.0016 \times EBW^{0.9698}$	0.84	$1.57 \times EBW^{-0.0302}$	$0.50 \times EBW^{0.0756}$
Valine	$0.0099 \times EBW^{0.9751}$	0.90	$9.61 \times EBW^{-0.0249}$	$3.07 \times EBW^{0.0809}$
Non-essential amino acids, g/100 g CP				
Alanine	$0.0421 \times EBW^{0.8115}$	0.93	$34.2 \times EBW^{-0.1885}$	$10.9 \times EBW^{-0.0827}$
Aspartic	$0.0267 \times EBW^{0.8751}$	0.73	$23.4 \times EBW^{-0.1249}$	$7.46 \times EBW^{-0.0191}$
Cystine	$0.0016 \times EBW^{1.0111}$	0.85	$1.64 \times EBW^{0.0111}$	$0.52 \times EBW^{0.1169}$
Glutamic	$0.0416 \times EBW^{0.9058}$	0.91	$37.7 \times EBW^{-0.0942}$	$12.0 \times EBW^{0.0116}$
Glycine	$0.1134 \times EBW^{0.7291}$	0.84	$82.7 \times EBW^{-0.2709}$	$26.4 \times EBW^{-0.1651}$
Proline	$0.0632 \times EBW^{0.7550}$	0.86	$47.7 \times EBW^{-0.2450}$	$15.2 \times EBW^{-0.1392}$
Serine	$0.0189 \times EBW^{0.8491}$	0.95	$16.0 \times EBW^{-0.1509}$	$5.13 \times EBW^{-0.0451}$
Tyrosine	$0.0069 \times EBW^{0.9474}$	0.91	$6.53 \times EBW^{-0.0526}$	$2.09 \times EBW^{0.0532}$

[1]EBW = Empty body weight; EBG = Empty body gain.

The equations to estimate the net Lysine (Lys) and Methionine (Met) requirements (g/100 g of CP) reported by Amaral et al (2021) were: Lys = 5.09 × $EBW^{0.0594}$ and Met = 1.73 × $EBW^{0.0255}$. Considering a bull with EBW of 350 kg, the net Lys and Met requirements calculated by these equations were 7.20 and 2.01 g/100 g CP, respectively.

The equations to estimate the net Lys and Met requirements (g/kg EBG) reported by Amaral et al (2021) were: Lys = 15.9 × $EBW^{-0.0464}$ and Met = 5.43 × $EBW^{-0.0803}$. Silva et al. (2002) reported values of net requirement of Lys and Met for weight gain of Nellore bulls (EBG = 1 kg/d and BW = 350 kg) of 10.36 and 3.54 g/d, respectively. Similarly, the net requirements of Lys and Met for weight gain predicted for Holstein steers based on the AA body composition observed by Ainslie et al. (1993) were 10.71 and 3.69 g/d. The values obtained by these authors were close to those reported in the study by Amaral et al. (2021) of 12.15 and 3.39 g/d for the net requirement of Lys and Met, respectively.

To convert the individual and total net AA to metabolizable AA requirements, individual and total AA retention efficiencies must be estimated. Such efficiencies were estimated by Mariz et al (2018) through a linear regression between individual and total AA absorbed (g/d) and their respective whole-body retention (g/d). For this, Mariz et al. (2018) utilized data from two studies. In study 1, the intestinal digestibility and total and individual AA daily absorbed were estimated in a digestion trial (for more details, please check Mariz et al., 2018). Study 2 data were composed by the efficiency of individual and total AA utilization for whole-body protein retention previously described in Amaral et al. (2021) complementary study.

True intestinal digestibility of AA was obtained by a linear regression model fitted between the AA absorbed in the small intestine and their respective omasal flow. The intercept of the equation represented the endogenous losses, and the slope represented the true digestibility of the dietary AA (Table 9.10) or microbial AA (Table 9.11). The true intestinal digestibility of total AA was 75%, and the endogenous loss was 17.18 g/d. True digestibility of individual EAA varied from 72% for threonine to 86% to Met, while it varied from 67% for tyrosine to 85% to cystine for non-essential amino acids (NEAA). The true intestinal digestibility of Lys was 77%.

Table 9.10 - True intestinal digestibility of amino acids, adapted from Mariz et al. (2018)

Item	Equations[1]	TID[2]
Total amino acids	$\hat{Y} = -17.18 + 0.75X$	75
Essential amino acids	$\hat{Y} = -8.14 + 0.77X$	77
Non-essential amino acids	$\hat{Y} = -9.29 + 0.74X$	74
Essential amino acids		
Arginine	$\hat{Y} = -0.76 + 0.81X$	81
Histidine	$\hat{Y} = -0.47 + 0.83X$	83
Isoleucine	$\hat{Y} = -0.87 + 0.77X$	77
Leucine	$\hat{Y} = -1.78 + 0.79X$	79
Lysine	$\hat{Y} = -1.70 + 0.77X$	77
Methionine	$\hat{Y} = -0.38 + 0.86X$	86
Phenylalanine	$\hat{Y} = -1.21 + 0.78X$	78
Threonine	$\hat{Y} = -1.65 + 0.72X$	72
Tryptophan	$\hat{Y} = -0.56 + 0.82X$	82
Valine	$\hat{Y} = -1.69 + 0.76X$	76
Non- essential amino acids		
Alanine	$\hat{Y} = -1.97 + 0.74X$	74
Aspartic acid	$\hat{Y} = -1.08 + 0.81X$	81
Cystine	$\hat{Y} = -1.41 + 0.85X$	85
Glutamic acid	$\hat{Y} = -1.91 + 0.75X$	75
Glycine	$\hat{Y} = -2.59 + 0.71X$	71
Proline	$\hat{Y} = -2.23 + 0.73X$	73
Serine	$\hat{Y} = -1.30 + 0.76X$	76
Tyrosine	$\hat{Y} = -0.05 + 0.67X$	67

[1]$\hat{Y}$ = AA absorbed in small intestine (g/d); X = AA omasal flow.
[2]True intestinal digestibility.

The true intestinal digestibility of total microbial AA obtained in this study was 80% (Table 9.11), which is similar to the value of 80% adopted for microbial protein in some feeding systems such as NASEM (2016) and the previous edition of this publication (BR-CORTE, 2016). Nevertheless, when considering true intestinal digestibility of individual AA, these values varied substantially. Microbial arginine and tyrosine showed the highest values for true digestibility (arginine = 85% and tyrosine = 89%) among EAA and NEAA, respectively. The estimated intestinal digestibilities of microbial Lys and Met were 84 and 80%, respectively.

Table 9.11 - True intestinal digestibility of microbial amino acids, adapted from Mariz et al. (2018)

Item	Equations[1]	TID[2]
Total amino acids	$\hat{Y} = -21.27 + 0.80\ X$	80
Essential amino acids	$\hat{Y} = -10.87 + 0.82\ X$	82
Non-essential amino acids	$\hat{Y} = -10.62 + 0.79X$	79
Essential amino acids		
Arginine	$\hat{Y} = -1.34 + 0.85\ X$	85
Histidine	$\hat{Y} = -0.60 + 0.79\ X$	79
Isoleucine	$\hat{Y} = -1.97 + 0.83X$	83
Leucine	$\hat{Y} = -3.19 + 0.84\ X$	84
Lysine	$\hat{Y} = -0.60 + 0.84\ X$	84
Methionine	$\hat{Y} = -0.36 + 0.80\ X$	80
Phenylalanine	$\hat{Y} = -1.60 + 0.81\ X$	81
Threonine	$\hat{Y} = -0.67 + 0.79\ X$	79
Tryptophan	-	-
Valine	$\hat{Y} = -1.03 + 0.79\ X$	79
Non- essential amino acids		
Alanine	$\hat{Y} = -1.62 + 0.75\ X$	75
Aspartic acid	$\hat{Y} = -0.79 + 0.81\ X$	81
Cystine	$\hat{Y} = -0.43 + 0.70\ X$	70
Glutamic acid	$\hat{Y} = -3.20 + 0.76\ X$	76
Glycine	$\hat{Y} = -1.55 + 0.81\ X$	81
Proline	$\hat{Y} = -2.54 + 0.87\ X$	87
Serine	$\hat{Y} = -1.21 + 0.83\ X$	83
Tyrosine	$\hat{Y} = -0.87 + 0.89\ X$	89

[1]$\hat{Y}$ = AA absorbed in small intestine (g/d); X = AA omasal flow.
[2]True intestinal digestibility.

The individual and total AA retention efficiencies estimated by Mariz et al. (2018) are described in Table 9.12. The intercept of the equation represented the endogenous losses, and the slope represented the AA retention efficiency.

The efficiency of utilization of total AA obtained in this study was 40%, whereas the efficiencies of utilization of EAA and NEAA were 38% and 42%, respectively.

Table 9.12 - The efficiency of individual absorbed amino acids to whole-body deposition, adapted from Mariz et al. (2018)

Item	Equations[1]	Efficiency (%)
Total amino acids	$\hat{Y} = -36.67 + 0.40\ X$	40
Essential amino acids	$\hat{Y} = -17.43 + 0.38\ X$	38
Non-essential amino acids	$\hat{Y} = -18.80 + 0.42\ X$	40
Essential amino acids		
Arginine	$\hat{Y} = -2.17 + 0.56\ X$	56
Histidine	$\hat{Y} = -1.42 + 0.62\ X$	62
Isoleucine	$\hat{Y} = -1.41 + 0.30\ X$	30
Leucine	$\hat{Y} = -3.36 + 0.30\ X$	30
Lysine	$\hat{Y} = -2.28 + 0.37\ X$	37
Methionine	$\hat{Y} = -0.37 + 0.58\ X$	58
Phenylalanine	$\hat{Y} = -1.57 + 0.31\ X$	31
Threonine	$\hat{Y} = -1.42 + 0.34\ X$	34
Tryptophan	$\hat{Y} = -0.18 + 0.39\ X$	39
Valine	$\hat{Y} = -2.55 + 0.40\ X$	40
Non-essential amino acids		
Alanine	$\hat{Y} = -1.25 + 0.35\ X$	35
Aspartic	$\hat{Y} = -3.65 + 0.26\ X$	26
Cystine	$\hat{Y} = -0.14 + 0.18\ X$	18
Glutamic	$\hat{Y} = -4.57 + 0.67\ X$	67
Glycine	$\hat{Y} = -0.68 + 0.63\ X$	63
Proline	$\hat{Y} = -0.40 + 0.43\ X$	43
Serine	$\hat{Y} = -1.16 + 0.31\ X$	31
Tyrosine	$\hat{Y} = -0.88 + 0.26\ X$	26

[1]$\hat{Y}$ = absorbed amino acid (g/d); X = whole-body amino acid retention.

Considering a bull with an EBW of 350 kg, the values for the metabolizable requirements of Lys and Met estimated based on the recommendations of Amaral et al. (2021) for net requirements of Lys (7.20 g/100 g CP) and Met (2.01 g/100 g CP) and their respective values of efficiency of use (Lys = 37%; Met = 58%) previously reported by Mariz et al. (2018) were: 19.47 and 3.47 g/100 g of CP, respectively.

It is noteworthy that Mariz et al. (2018) found differences in the retention efficiency of total and individual AA. Furthermore, arginine (56%), histidine (62%), and methionine (58%) showed the greatest estimates for retention efficiency among the EAA. For NEAA, glutamic acid (67%) and glycine (63%) showed the greatest estimates for retention efficiency. This discrepancy among AA suggests that there are differences in how efficiently the different AA are used for meat production. In this way, using a single coefficient for total AA utilization would not suit in the concept of precision feeding.

The above-mentioned studies (Amaral et al., 2021; Mariz et al., 2018) allow BR-CORTE users to estimate the EAA and NEAA requirements of beef cattle raised in tropical conditions. However, the unique features of the intermediate metabolism, in addition to the complex feed transformation during ruminal fermentation and the difficulties in determining the AA available for absorption in the duodenum, still pose a challenge to formulate diets based on AA requirements for cattle. Due to these challenges, the AA requirements estimates have been recommended as a guide and should be used according to the feeding system.

SUMMARY OF PROTEIN AND AMINO ACIDS REQUIREMENTS

The equations used to estimate protein requirements for Zebu, crossbred beef and dairy cattle are presented for different sexes, raised in feedlot or on pasture. in Tables 9.13 and 9.14. The metabolizable AA requirements for gain (g/kg EBG) are presented for different EBW in Table 9.15.

Table 9.13 - Summary of equations utilized to convert body weight and average daily gain for empty body weight and empty body gain of Zebu, crossbred beef cattle, and crossbred dairy cattle of three sexes, raised in feedlot or on pasture

Item	System	Genetic group	Gender	Equations	Unit
SBW		Zebu and Crossbred beef cattle		$0.8915 \times BW^{1.0151}$	kg
		Crossbred dairy cattle		$0.9247 \times BW^{1.0085}$	
EBW	Feedlot	Zebu cattle	Bulls	$0.8126 \times SBW^{1.0134}$	kg
			Steers	$0.6241 \times SBW^{1.0608}$	
			Heifers	$0.6110 \times SBW^{1.0667}$	
		Crossbred cattle	Bulls	$0.7248 \times SBW^{1.0314}$	
			Steers	$0.6586 \times SBW^{1.0499}$	
			Heifers	$0.6314 \times SBW^{1.0602}$	
	Pasture			$0.8507 \times SBW^{1.0002}$	
EBG				$0.9630 \times ADG^{1.0151}$	kg/d
EQEBW		Zebu cattle	Bulls	(EBW/517) × 517	kg
			Steers	(EBW/433) × 517	
			Heifers	(EBW/402) × 517	
		Crossbred beef cattle	Bulls	(EBW/560) × 517	
			Steers	(EBW/482) × 517	
			Heifers	(EBW/417) × 517	
		Crossbred dairy cattle	Bulls	(EBW/616) × 517	
			Steers	(EBW/532) × 517	
			Heifers	(EBW/493) × 517	

Table 9.14 - Summary of equations utilized to estimate protein requirements for beef cattle raised in feedlot or on pasture

Item	System	Equations	Unit
MPm	Feedlot	$3.6 \times SBW^{0.75}$	g/d
	Pasture	$3.9 \times SBW^{0.75}$	
NPg		$NPg = 176.01 \times EBG - 0.381 \times EQEBW^{0.75} \times EBG^{1.035}$	g/d
k		SBW < 340 kg: 84.665 – 0.1179 × EQEBW SBW > 340 kg: 47.4	%
MPg		NPg/k	g/d
MPtotal		MPm + MPg	g/d
MCP		$- 53.07 + 304.9 \times CPI + 90.8 \times TDNI - 3.13 \times TDNI^2$	g/d
RDP		MCP	g/d
RUP		(MPt - (MCP × 0.64))/0.80	g/d
CP		RDP + RUP	g/d

Thus, considering a 520-kg Nellore bull gaining 1.6 kg/d raised in feedlot:

- $SBW = 0.8915 \times BW^{1.0151} = 0.8915 \times 520^{1.0151} = 509.5$ kg
- $EBW = 0.8126 \times SBW^{1.0134} = 0.8126 \times 509.5^{1.0134} = 450.1$ kg
- $EBG = 0.963 \times ADG^{1.0151} = 0.963 \times 1.6^{1.0151} = 1.55$ kg/d
- EQEBW = (EBW/517) × 517 = (450.1/517) × 517 = 450.1 kg
- $MPm = 3.6 \times SBW^{0.75} = 3.6 \times 509.5^{0.75} = 386.1$ g/d
- $NPg = 176.01 \times EBG - 0.381 \times EQEBW^{0.75} \times EBG^{1.035} = 176.01 \times 1.55 - 0.381 \times 450.1^{0.75} \times 1.55^{1.035} = 214.2$ g/d
- $k = 47.4\%$
- MPg = NPg/k = 214.2/0.474 = 451.9 g/d
- MP total = MPm + MPg = 386.1 + 451.9 = 838 g/d

• MCP = - 53.07 + 304.9 × CPI + 90.8 × TDNI – 3.13 × $TDNI^2$ = - 53.07 + 304.9 × 1.215 + 90.8 × 7.88 – 3.13 × 7.88^2 = 838.5 g/d
• RDP = MCP = 838.5 g/d
• RUP = [MPt – (MCP × 0.64)]/0.80 = [838 – (838.5× 0.64)]/0.80 = 376.7 g/d
• CP = RDP + RUP = 838.5 + 376.7 = 1215 g/d

Table 9.15 - Metabolizable amino acids requirements for gain of Nellore and crossbred Angus × Nellore bulls

Requirements	Utilization efficiency (%)[1]	Empty body weight (kg)			
		250	350	450	550
Essential amino acids (g/kg empty body weight gain)					
Arginine	56	22.35	21.16	20.31	19.65
Histidine	62	4.39	4.31	4.25	4.20
Isoleucine	30	22.59	22.11	21.76	21.49
Leucine	30	41.33	39.96	38.98	38.20
Lysine	37	33.26	32.75	32.37	32.07
Methionine	58	5.98	5.82	5.70	5.61
Phenylalanine	31	20.50	20.07	19.76	19.51
Threonine	34	19.50	19.08	18.77	18.53
Tryptophan	39	3.47	3.44	3.41	3.39
Valine	40	20.92	20.74	20.61	20.51
Non-essential amino acids (g/kg empty body weight gain)					
Alanine	35	34.51	32.39	30.89	29.74
Aspartic	26	45.16	43.30	41.96	40.92
Cystine	18	9.45	9.49	9.51	9.53
Glutamic	67	33.45	32.41	31.65	31.05
Glycine	63	29.41	26.85	25.08	23.76
Proline	43	28.72	26.45	24.87	23.68
Serine	31	22.43	21.32	20.53	19.92
Tyrosine	26	18.70	18.37	18.13	17.94

[1]Adapted from Mariz *et al.* (2018).

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10

Mineral requirements for beef cattle

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INTRODUCTION

Minerals are present in different amounts and proportions in all foods and animal tissues (Underwood, 1981). Many of them, despite being present in the body, do not play a specific role in animal metabolism. Essential minerals are elements that perform a specific function in the body (McDonald et al., 2002). Twenty-two minerals were identified as essential for animal life: calcium (Ca), phosphorus (P), potassium (K), sodium (Na), chlorine (Cl), magnesium (Mg) and sulfur (S), considered macronutrients minerals; iron (Fe), iodine (I), zinc (Zn), copper (Cu), manganese (Mn), cobalt (Co), molybdenum (Mo), selenium (Se), chromium (Cr), tin (Sn), vanadium (V), fluorine (F), silicon (Si), nickel (Ni) and argon (Ar), considered mineral micronutrients (Spears and Kegley, 2002). According to their concentration, macrominerals are expressed in g/kg of animal tissue, while trace minerals are expressed in mg/kg of animal tissue.

Although minerals are present in animals in lower proportions than other nutrients such as protein and fat, they perform vital functions in the body. Mineral deficiencies and excesses can cause severe nutritional changes that impair animal performance. Fundamentally, minerals perform five broad functions in animals (Suttle, 2010; Wilson et al., 2016):

1. **Structural:** composition of organs and body tissues, such as Ca, P, Mg, F, and Si in bones and teeth; and P and S in muscle proteins. Approximately 99% Ca, 80% P, and 70% Mg are present in the skeleton (AFRC, 1991; Coelho da Silva, 1995; NRC, 2000);
2. **Physiological:** constituents of body tissues and fluids responsible for maintaining osmotic pressure, acid-base balance, membrane permeability, and tissue irritability, such as Na, K, Cl, Ca, and Mg in the blood, brain-spinal fluid, and gastric juice (Suttle, 2010);
3. **Catalytic:** catalysts of enzymatic and hormonal systems, performed primarily by trace minerals. The regulation of lipid metabolism and synthesis by Cu and spermatogenesis by Zn are among numerous examples (Suttle, 2010);
4. **Regulatory**: replication, regulation and cell differentiation, such as the influences of Ca on signal transduction, and selenocysteine on gene transcription (Suttle, 2010); and
5. **Immune response:** in calves, Cu supplementation increases its hepatic concentration during respiratory challenges, positively impacting the immune response under stress (Wilson et al., 2016).

These functions can only be performed if adequate amounts of dietary minerals are absorbed and retained to maintain growth, development, and reproduction, as well as to replace minerals lost to milk yield, for example (Suttle, 2010). Common beef feeds typically provide cattle with their adequate nutrients (Genther and Hansen, 2014); however, the mineral concentrations are variable and/or inadequate (Smart et al., 1981), contributing to low animal performance and meat quality (Spears and Kegley, 2002). According to Arthington et al. (2014), mineral supplementation can be achieved in several ways: salt blocks fortified with minerals, injectable trace minerals, and protein-energy supplements fortified with trace minerals. Thus, the adequacy of the amount of each mineral supplied to the animals is recommended to ensure adequate animal performance and to avoid soil and watercourse contamination by minerals excreted via feces and urine.

Factorial models are the most common methods used to predict the mineral dietary requirements for cattle (ARC, 1980). The dietary requirements of each mineral correspond to the sum of the net requirements for maintenance and production and the result

is divided by the absorption coefficient of the mineral in the animal's digestive tract. However, not every mineral absorbed by the animal has a function in the body, then it is excreted via urine. Thus, the use of the absorption coefficient does not seem to be the most appropriate, but the true retention coefficient, which considers mineral losses via urine.

Mineral requirements for cattle are expressed as amounts per day, per unit of product, or as a proportion of the dry matter intake (DMI). Mineral requirements can be affected by breed or genetic group, sex, age, health status, feeding, production level, and environment (Suttle, 2010). Factors inherent to feeds or diets, such as organic or inorganic fractions of the mineral, bioavailability, and chemical form of the element, along with aspects related to inter-associations (antagonism and agonism) among minerals can also influence dietary requirements.

To calculate dietary mineral requirements, it is required to know about the bioavailability, or proportion of the mineral released during digestion of the feed, enabling its absorption and use. Additionally, there are differences regarding mineral release in animals between feeds produced in tropical and temperate regions.

This chapter discusses the dietary requirements of macrominerals (Ca, P, Mg, Na, K, and S) and trace minerals (Co, Cr, Cu, Fe, Mn, Mo, Se, and Zn) for maintenance, as well as the retention coefficient of each mineral, using a database developed by research conducted in Brazil. Also, equations to estimate the net requirements for growth (NRGs) will be presented from a database of animals raised in tropical conditions. Finally, tables of dietary macromineral and trace mineral requirements will be presented for beef cattle.

MINERALS SOURCES

Currently, two categories of minerals are available for animal diets: 1) inorganic, which comprises sources such as oxides, chlorides, and sulfates; and 2) organic, comprising minerals complexed or associated with organic molecules (complexes and chelates), such as polysaccharides, amino acids or proteins (AAFCO, 1998).

Inorganic sources of minerals

There is a large number of inorganic mineral sources on the market for mineral mixtures and balanced feeds for beef cattle diets. To choose one or more sources of minerals to be used, some points must be considered, such as the cost per unit of required elements, the chemical forms in which the elements are combined, the physical forms closely related to the particle size and, above all, the guarantee of the absence of toxic substances for the animals. According to Campos (1980), the main sources of inorganic minerals used in Brazil for beef cattle diets are described in Table 10.1.

Table 10.1 - Sources of inorganic minerals for cattle

Mineral	Commercial Product	Chemical formula	% of element		Physical form
Calcium and Phosphorus	Dicalcium phosphate	$CaHPO_4.2H_2O$	23.3% Ca	18% P	White crystals
	Defluorinated rock phosphate	$Ca_3(PO_4)_2.CaX$	29.2% Ca	13.3% P	Slightly soluble powder
	Calcium carbonate	$CaCO_3$	40% Ca	-	White powder
	Calcitic limestone	$CaCO_3$	38.5% Ca	-	Insoluble powder
	Dolomitic limestone	$CaCO_3.MgCO_3$	22.3% Ca	-	Insoluble powder
	Oyster meal	$CaCO_3CaX$	38% Ca	-	Granulated
	Dibasic ammonium phosphate	$(NH_4)_2HPO_4$	-	23.5% P	White crystals
Chlorine and Sodium	Sodium chloride	NaCl	60% Cl	37% Na	White crystals
Magnesium	Magnesium oxide	MgO	60.3% Mg		White powder
	Magnesium sulfate	$MgSO_4.7H_2O$	9.9% Mg		White crystals
Sulfur	Sublimated sulfur	S	96 (99)% S		Yellow powder
Iodine	Calcium iodate	$Ca(IO_3)_2$	62% I		White crystals
	Potassium iodate	KIO_3	59% I		White crystals
Cobalt	Cobalt carbonate	$CoCO_3$	49.5% Co		White crystals
	Cobalt chloride	$CoCl_2.6H_2O$	24.7% Co		Dark red crystals
	Cobalt sulfate	$CoSO_4.7H_2O$	20.9% Co		Red crystals
Manganese	Manganese carbonate	$MnCO_3$	47.8% Mn		Red powder
	Manganese sulfate	$MnSO_4.H_2O$	32.5% Mn		Red powder
Copper	Cupric chloride	$CuCl_2.2H_2O$	37.2% Cu		Green crystals
	Cupric oxide	CuO	80% Cu		Black powder
	Cupric sulfate	$CuSO_4.5H_2O$	25.5% Cu		Blue crystals
Iron	Anhydrous ferrous sulfate	$FeSO_4$	36.7% Fe		Soluble powder
	Ferrous carbonate	$FeCO_3.H_2O$	41.7% Fe		Slightly soluble, amorphous powder
Zinc	Zinc sulfate	$ZnSO_4.7H_2O$	22.7% Zn		White crystals
	Zinc oxide	ZnO	80.3% Zn		White powder
Selenium	Sodium selenite	Na_2SeO_3	45% Se		White crystals

Adapted from Campos (1980)

Inorganic minerals, of geological or industrial origin, are still the most used sources in animal nutrition (Mottin et al., 2013). This is mainly due to the low market cost when compared to chelated minerals, which is the main advantage of using inorganic minerals (Araújo et al., 2008). On the other hand, some disadvantages are described in the literature regarding the use of inorganic minerals, such as (Araújo et al., 2008):

1) they have a greater polluting potential for the environment, mainly due to their low instability and the presence of contaminants such as arsenic, lead, and cadmium;
2) they can undergo interactions with other minerals in the gastrointestinal tract, becoming complexed and making absorption difficult or making them unavailable to animals; and
3) need to be included in diets in larger amounts than necessary due to lower bioavailability.

Organic sources of minerals

In recent years, new sources of minerals have appeared on the market and are known as organic minerals. However, due to the variety of sources available, the term "organic minerals" referring to all these products is not the most appropriate. These elements are formed by biosynthetic processes or can be combined with amino acids, proteinates, polysaccharides, and hydroxy amino acid analogues (in the form of complexes, chelates, or proteinates, depending on their nature), are characterized by having greater bioavailability and, therefore, being better utilized in the animal organism. Finally, they have a lower excretion by animals compared to inorganic minerals (Rutz and Murphy, 2009).

Currently, there is a variety of sources for organic minerals available in the market for animal nutrition. According to the Association of American Feed Control Officials (AFFCO, 2000), there are several definitions for organic minerals depending on the type and structure of the ligand, where the main compounds can be classified as follows (Table 10.2):

A complex between metal and amino acid: product resulting from the complexation between a soluble metal salt with one or more amino acids (Ex: Fe-amino acid complex);

Specific metal-amino acid complex: product resulting from the complexation of a soluble metal salt with a specific amino acid, forming coordinated covalent bonds (Ex: zinc-methionine (Zn-Met), zinc-lysine (Zn-Lis), copper-lysine (Cu -Lis));

Chelate between metal and amino acid: product resulting from the reaction between a metal ion obtained from a soluble metal salt with amino acids in the molar ratio of one mole of metal to one to three moles of amino acids (preferably two) to form coordinated covalent bonds (e.g. calcium, cobalt, copper, iron, and zinc);

A complex between metal and polysaccharides: product resulting from a complex between a soluble salt and a polysaccharide solution (Ex: zinc-polysaccharide complex);

Proteinates: product resulting from chelation between a soluble salt with amino acids and/or partially hydrolyzed proteins (e.g., manganese proteinate, zinc proteinate).

The use of organic minerals in their different forms can offer some advantages over inorganic minerals, such as (Zanetti,2014):

1) greater bioavailability;
2) the use of a lower dosage in comparison to the inorganic minerals;
3) greater retention in tissues (since they directly reach specific tissues and enzymatic systems, using the pathways of absorption and transport of molecules that are linked);
4) lower interpellation with other mineral elements or other substances in the absorption process; and
5) lower excretion into the environment.

Furthermore, Mottin et al. (2013) reported that there are some more attributions regarding the comparison between organic and inorganic minerals, mainly the type of charge of these compounds, negative or neutral, that is, they are metabolized more efficiently. In addition, the chelation process enhances passive absorption by increasing water and lipid solubility.

However, not all organic trace minerals are the same. Therefore, it is worth mentioning that the choice of the mineral source to be used must be duly based on scientific works that demonstrate the real effects of the source in improving the parameters that are being proposed in the works. Then, Table 10.2 presents the main organic minerals and their respective bioavailability.

In the current edition of BR-CORTE, all dietary requirements for minerals were estimated from studies in which only inorganic sources of minerals were used. Thus, there is a lack of information about the impact of organic minerals on dietary requirements for beef cattle.

Table 10.2 - Organic minerals and bioavailability

Classification	Type of mineral [1]	Bioavailability of the organic mineral (%) [2]
Amino acid metal chelate	Calcium	92-96
	Cobalt	85-89
	Copper	91-98
	Iron	85-94
	Zinc	87-94
Amino acid metal complex	Copper	91-98
	Iron	85-94
	Manganese	83-87
	Zinc	87-94
Specific amino acid metal complex	lysine copper	91-98
	lysine zinc	87-94
	methionine iron	85-94
	zinc methionine	87-94
Proteinates	Calcium	92-96
	Cobalt	85-89
	Copper	91-98
	Zinc	87-94
Metal polysaccharide complex	Copper	91-98
	Iron	85-94
	Zinc	87-94
	Magnesium	85-94

Adapted from AAFCO (2000)[1] and Baruselli (2000)[2] .

DIETARY MINERAL REQUIREMENTS

Mineral requirements for maintenance include those needed to maintain normal bodily functions when an animal is not growing, performing work, reproducing, or generating any product (Underwood, 1981). The body requires nutrients to maintain normal body temperature, internal metabolism for circulation, respiration, and other vital processes, and to compensate external losses and normal animal movements. These requirements are related to the needs of the animal while meeting the unavoidable losses, also called endogenous losses or secretions from the body (Fontes, 1995).

In Brazil, mineral studies evaluating endogenous losses and absorption coefficients in cattle are scarce. Moreover, the studies available present variable results, hence, it has not been possible to establish precise recommendations for cattle raised under Brazilian conditions.

The main global councils for nutrient requirements (ARC, 1980; NRC, 2000; NRC, 2001; CSIRO, 2007) consider that mineral losses via urine are negligible due to the recycling of minerals in the kidneys. However, Costa e Silva et al. (2015a) verified that mineral losses via urine can reach 35% of the mineral intake and should not be disregarded.

These values enable the true retention coefficients for all minerals to be considered rather than their apparent absorption coefficients.

Thus, in this chapter, dietary mineral requirements will be calculated from the sum of their net mineral requirements for maintenance and NRG divided by their retention coefficient.

DATABASE

Net mineral requirements for maintenance and retention coefficient of each mineral

The net mineral requirements for maintenance (intercept) and the retention coefficient (slope) of each mineral can be calculated by linear regression of the association between mineral retention and intake:

$$RM = MI - MEf - MEu$$

where RM is retained mineral, MI is the mineral intake, MEf is mineral excreted via feces, and MEu is mineral excreted via urine.

Then, to estimate the net requirement for maintenance and retention coefficient of each mineral, a database was developed from 10 experiments conducted under tropical conditions: Souza (2010), Gionbelli (2010), Marcondes (2010), Prados (2012), Zanetti (2014), Sathler (2015), Costa e Silva et al. (2015a – **2**), Prados (2016), and Zanetti et al. (2017). The minerals in the animal feed, feces, and urine are presented in Tables 10.3 (macrominerals) and 10.4 (trace minerals). This database comprised 325 animals (181 bulls, 73 steers, and 71 heifers). The animals were from the following genetic groups: Nellore (n = 243), Zebu × Holstein (n = 46), Angus × Nellore (n = 18), and Simmental × Nellore (n = 18). A meta-analysis was used in which sex (fixed effect), genetic group (fixed group), and study (random effect) were considered classificatory effects to evaluate differences for each mineral.

However, only two studies (Costa e Silva et al., 2015a; Zanetti et al., 2017) evaluated the net mineral requirement for maintenance and the retention coefficient for S and trace minerals. Therefore, only the recommendations suggested by these authors will be used in this BR-CORTE edition (Table 10.4).

Table 10.3 - Descriptive statistics of data used to estimate the net macromineral (Ca, P, Mg, Na, K, and S; g/d) requirements

Item	*n*	Mean	SD	Maximum	Minimum
Body weight (kg)	325	302	82.3	557	125
		Calcium (Ca)			
Intake	325	27.1	18.9	138	2.93
Feces	324	11.4	6.27	61.95	1.37
Urine	322	1.14	1.13	7.63	0.04
		Phosphorus (P)			
Intake	325	22.5	20.6	88.0	3.34
Feces	325	9.08	5.94	40.5	1.46
Urine	322	0.99	1.16	8.28	0.01
		Magnesium (Mg)			
Intake	325	16.6	9.42	51.2	2.49
Feces	307	8.22	5.58	41.5	0.89
Urine	304	3.98	3.43	24.4	0.03
		Sodium (Na)			
Intake	325	19.4	13.4	49.7	0.61
Feces	306	7.27	4.81	22.5	0.19
Urine	297	7.49	5.49	26.3	0.02
		Potassium (K)			
Intake	325	47.2	26.3	140	5.14
Feces	307	16.3	9.63	56.4	1.82
Urine	297	16.1	13.2	66.8	0.02
		Sulfur (S)			
Intake	149	5.75	2.08	9.29	1.20
Feces	149	2.43	1.10	4.94	0.44
Urine	143	1.65	1.24	3.96	0.04

SD = standard deviation.

Table 10.4 - Descriptive statistics of data used to estimate the net trace mineral (Cu, Fe, Mn, Se, Zn, Co, Cr, and Mo; mg/d) requirements

Item	*n*	Mean	SD	Maximum	Minimum
Body weight (kg)	149	307	92.6	557	125
		Copper (Cu)			
Intake	149	87.8	58.8	213	1.87
Feces	149	50.6	21.9	104	8.02
Urine	95	8.58	6.42	37.3	1.08
		Iron (Fe)			
Intake	149	2,103	1,173	4,780	333
Feces	149	1,608	872	3,982	316
Urine	92	98.8	73.4	410	5.40
		Manganese (Mn)			
Intake	149	212	133	493	1.87
Feces	136	193	106	425	4.71
Urine	88	2.01	1.66	6.80	0.06
		Selenium (Se)			
Intake	50	2.05	0.88	3.93	0.69
Feces	50	1.43	0.64	2.69	0.31
Urine	50	0.70	0.57	1.22	0.01
		Zinc (Zn)			
Intake	149	293	169	611	28.0
Feces	149	195	110	469	15.9
Urine	92	13.1	7.00	37.9	0.86
		Cobalt (Co)			
Intake	149	7.12	4.64	21.3	0.92
Feces	148	3.68	3.12	12.6	0.04
Urine	80	1.33	1.85	7.67	0.02
		Chromium (Cr)			
Intake	102	16.1	8.00	38.2	0.35
Feces	102	11.3	5.60	28.1	3.30
Urine	46	3.84	1.94	9.26	0.61
		Molybdenum (Mo)			
Intake	47	3.92	1.10	6.19	0.89
Feces	47	2.69	0.80	5.04	0.72
Urine	45	0.41	0.22	1.15	0.11

SD = standard deviation.

Net requirement of each mineral for growth (NRG)

The power model is commonly used to estimate the NRG (ARC, 1980), according to:

$$Mi = \beta_0 \times EBW^{\beta_1},$$

where Mi is the mineral (i) content in the body (Ca and P (kg); Mg, Na, and K (g)), β_0 and β_1 are regression parameters and EBW is the empty body weight (kg). Using the first derivation of this equation and based on the empty body gain (EBG), the NRG is estimated as follows:

$$NRGi = EBG \times (\beta 0 \times \beta 1 \times EBW^{\beta_1 - 1})$$

where NRGi is the net mineral requirements for mineral "i", EBG is the empty body gain (kg/d), and β_0 and β_1 are regression parameters.

Cattle reach a body weight (BW) at which there is no longer minerals deposition in the body, hence, dietary requirements refer only to animal maintenance. Thus, the point at which there is no more significant mineral addition in the EBW is determined by the plateau power method, as suggested by Chizzotti et al. (2009), for Ca and P.

For each mineral, their NRG is considered equal to zero in the EBW when the plateau is achieved.

Thus, a database was developed from 21 studies conducted under tropical conditions: Paulino (1996), Silva (2001), Veloso (2001), Paulino (2002), Backes (2003), Leonel (2003), Martins (2003), Chizzotti (2007), Véras (2006), Moraes (2006), Marcondes (2007), Paixão (2008), Sales (2008), Gionbelli (2010), Souza (2010), Marcondes (2010), Valente (2012), Rodrigues (2014), Amaral (2012), Costa e Silva et al. (2015a), and Zanetti et al. (2017). The NRG values for Ca, P, Mg, Na, and K of the animals are presented in Table 10.5.

In the BR-CORTE (2010), two methods were suggested to estimate NRGCa and NRGP: plateau quadratic and plateau power. We tested these methods and the plateau power method presented the best estimates (lower values of the mean square of error of prediction, MSEP), and was consequently chosen as the standard method to estimate NRGCa and NRGP. For NRGMg, NRGNa, and NRGK, the power method was used to estimate the plateau of deposition of these minerals, once they are more related to body fluid than deposition in bones and body tissues.

Due to the lack of literature data on NRGS and NRG for trace minerals (Co, Cr, Cu, Fe, Mn, Mo, Se, and Zn), the recommendations have been based on the studies of Costa e Silva et al. (2015a) and Zanetti et al. (2017) (Table 10.6).

Table 10.5 - Descriptive statistics of data used to estimate net macromineral (Ca, P, Mg, Na, and K) requirements for the growth of beef cattle

Genetic group/system	Sex	*n*	Item	EBW	EBG	Ca (kg)	P (kg)	Mg (g)	Na (g)	K (g)
Nellore (feedlot)	Bulls	142	Mean	342	1.04	4.64	2.95	140	492	538
			SD	83.7	0.45	1.12	0.74	50.9	134	238
			Maximum	549	1.87	7.15	4.45	311	760	990
			Minimum	172	-0.01	2.09	1.06	49.8	203	170
	Steers	148	Mean	311	0.84	5.66	2.59	103	410	605
			SD	88.6	0.49	1.13	0.76	30.7	141	219
			Maximum	460	2.30	7.97	4.20	168	640	1060
			Minimum	104	-0.21	2.66	0.60	29.7	106	154
	Heifers	84	Mean	226	0.55	4.41	1.56	81.6	323	311
			SD	64.1	0.37	1.00	0.57	28.5	153	71.0
			Maximum	368	1.25	7.15	2.76	150	708	495
			Minimum	108	-0.13	2.78	0.64	34.0	110	177
Crossbred (feedlot)	Bulls	149	Mean	394	1.39	4.20	3.00	220	511	668
			SD	94.6	0.65	1.40	1.02	106	135	261
			Maximum	600	2.74	6.95	4.43	390	764	990
			Minimum	167	0.17	1.53	0.78	45.7	284	156
	Steers	107	Mean	332	0.94	5.21	2.80	105	432	629
			SD	92.2	0.54	1.12	0.60	32.8	168	272
			Maximum	506	1.64	7.83	4.34	169	705	1046
			Minimum	161	-0.09	3.13	1.60	48.0	125	131
	Heifers	73	Mean	292	0.79	4.52	2.10	106	503	323
			SD	73.2	0.50	0.96	0.39	23.1	150	74.6
			Maximum	443	1.73	6.91	2.77	164	776	466
			Minimum	175	-0.18	2.82	1.29	62.3	237	195
Nellore (pasture)	Bulls	141	Mean	308	0.33	5.34	2.20	139	591	751
			SD	106	0.27	1.28	0.84	58.0	236	455
			Maximum	604	0.90	8.30	3.72	265	1109	1662
			Minimum	80.2	-0.41	2.70	0.39	70.0	180	170

SD = standard deviation; EBW = empty body weight (kg); EBG = empty body gain (kg); Ca = calcium; P = phosphorus; Mg = magnesium; Na = sodium; K = potassium.

This database comprised 844 animals: 432 bulls, 255 steers, and 157 heifers, from Zebu (n = 515) and crossbred cattle (n = 329). Meta-analysis was adopted and the production system (feedlot and pasture), sex (bulls, steers, and heifers), genetic group (Zebu, beef crossbred, and crossbred dairy cattle), and study were considered random effects. For the macrominerals (Ca, P, Mg, Na, and K), equations were generated separately when differences were observed for sex (bulls, steers, and heifers) or genetic group (Zebu, beef crossbred, and dairy crossbred cattle). In the crossbred cattle, there were no significant differences (P > 0.05) between crossbred beef and dairy cattle for any of the minerals, so their data were combined. Thereby, the equations were generated separately for Zebu and crossbred cattle when differences were observed in macromineral (Ca, P, Mg, Na, and K) data, enabling the direct effect of the genetic group to be observed.

Table 10.6 - Descriptive statistics of total contents of each mineral used to estimate net S and trace mineral (Co, Cr, Cu, Fe, Mn, Mo, Se, and Zn) requirements for the growth of beef cattle

Item	*n*	Mean	SD	Maximum	Minimum
EBW (kg)	133	288	110	549	104
EBG (kg/d)	133	0.74	0.55	1.87	-0.02
S (g)	87	610	506	2,197	86
Co (mg)	87	1,480	1,683	5,193	12
Cr (mg)	87	1,113	938	3,736	154
Cu (mg)	87	1,519	1,161	4,678	153
Mn (mg)	87	913	874	2,801	112
Mo (mg)	46	9.05	3.96	19.3	2.81
Se (mg)	50	136	92	328	21
Zn (g)	87	20.4	20.2	65.0	2.17
Fe (g)	87	31.2	22.2	78.5	7.02

EBW = empty body weight (kg); EBG = empty body gain (kg); SD = standard deviation; Co = cobalt; Cr = chromium; Cu = copper; Fe = iron; Mn = manganese; Mo = molybdenum; Se = selenium; Zn = zinc.

MACROMINERALS

In the BR-CORTE (2010), a collection of macrominerals (Ca, P, Mg, Na, and K) absorption coefficient data was based on literature studies (Table 10.7). However, due to the variability of data found, mainly in Brazil, the recommendations remained unchanged or followed the suggestions proposed by the NRC (2000) for Ca and P, and the ARC (1980) for Mg, Na, and K.

Table 10.7 - Absorption and retention coefficients of macrominerals (Ca, P, Mg, Na, and K) found in the literature

Source	Absorption coefficient (%)[1]				
	Ca	P	Mg	Na	K
Marshal and Long (1971)	80	-	-	-	-
ARC (1980)	68	60	17	**91**	**100**
Blaney et al. (1982)	50	-	-	-	-
Field (1983b)	-	58	-	-	-
Ezequiel (1987)[2]	62	72	52	66	100
AFRC (1991)	-	58 a 70	-	-	-
Coelho da Silva et al. (1991)[2]	-	-	16	76	-
Rosado (1991)[2]	-	-	44	57	44
Valadares Filho et al. (1991)[2]	-	-	57	-	-
Boin (1993) – calves[2]	-	78	-	-	-
Boin (1993) – steers[2]	-	58	-	-	-
Coelho da Silva et al. (1995)[2]	72	63	38	54	-
NRC (2000)	50	**68**	-	-	-
NRC (2001) – forages	30	80	-	81	-
NRC (2001) – concentrate	60	-	-	100	-
Araújo et al. (2001)[2]	59	56	45	94	78
Gionbelli (2010)[2,3]	**55**	56	**16**	19	4
Costa e Silva et al. (2015a)[2,3]	72	82	98	58	70
BR-CORTE (2016)[2,3]	57	68	36	37	43

[1]Values adopted from the BR-CORTE (2010) are in bold; [2]Experiments conducted in Brazil; [3]Retention coefficient. Ca = calcium; P = phosphorus; Mg = magnesium; Na = sodium; K = potassium.

However, from the database generated in this edition, some of the urinary mineral excretions were lower in relation to their intakes, for example, Ca (4.29%), P (4.33%), Cu (3.82%), Fe (3.59%), Mn (1.72%), Se (6.47%), and Zn (4.03%; Table 10.3). Nevertheless, the urinary excretion of other minerals was considered high, for example, Na (39.3%), S (34.8%), Mg (24.9%), K (30.3%), Co (14.6%), and Cr (14.6%). Therefore, we don't recommend to use the true absorption coefficient to get the dietary requirements, for all minerals. So, in this BR-CORTE edition, all the coefficients reported are the true retention coefficients, directly representing the association between mineral retention and intake.

Calcium

Ca is the most abundant mineral found in animals; approximately 99% is present in bones and teeth and 1% in soft tissues and body fluids. Ca is involved in blood coagulation, muscle contraction, nerve impulse transmission, cardiac movement regulation, hormonal secretion, and enzyme activation and stabilization (Lalman, 2005). Ruminants have a low capacity to excrete Ca absorbed in excess, represented by low urinary Ca excretions, while fecal endogenous losses are constant, which indicates that the absorption is regulated at the intestinal level (Field, 1983a). Costa e Silva et al. (2015a) verified that only 3.85% of Ca intake was excreted via urine while 47.9% was excreted via feces.

Based on Hansard et al. (1954; 1957), in which Ca radioisotopes were used to estimate its true bioavailability, requirements for maintenance, and use for cattle, the NRC (1984) recommended 15.4 mg/kg BW as the net Ca requirement for maintenance and, in the absence of further studies to verify this estimate, the same recommendation was reported in further editions (NRC, 2000; NRC, 2001; BCNR, 2016). Moreover, the ARC (1965) considered the net Ca requirement for maintenance as 16 mg/kg BW; 0.8 mg/kg BW was related to urinary losses. The

AFRC (1991) suggested an equation whereby fecal metabolic losses (FML) are estimated as a function of DMI (kg/d) and BW of the animals, which has been adopted by the CSIRO (2007):

$$FMLCa\ (g/d) = 0.66 \times DMI + 0.74 \times BW - 0.74.$$

In Brazil, few studies have estimated the net Ca requirements for maintenance. Ezequiel (1987) suggested values of 33.2, 43.5, and 26.1 mg/kg BW, using Nellore, Holstein (H), and ½ H × ½ Zebu cattle, respectively. These values are above those recommended by the main global councils (ARC, 1980; NRC, 2000). In the BR-CORTE (2010), only data from a single study (Gionbelli, 2010) were used and was the estimated net Ca requirement for maintenance was 26.5 mg/kg BW. Costa e Silva et al. (2015a), estimated the net Ca requirement for maintenance as 20 mg/kg BW for Nellore cattle. However, from the meta-analysis of seven studies in the BR-CORTE database, the net Ca requirement for maintenance and its retention coefficient were estimated as 11.7 mg/kg BW and 56.8%, respectively (Figure 10.1).

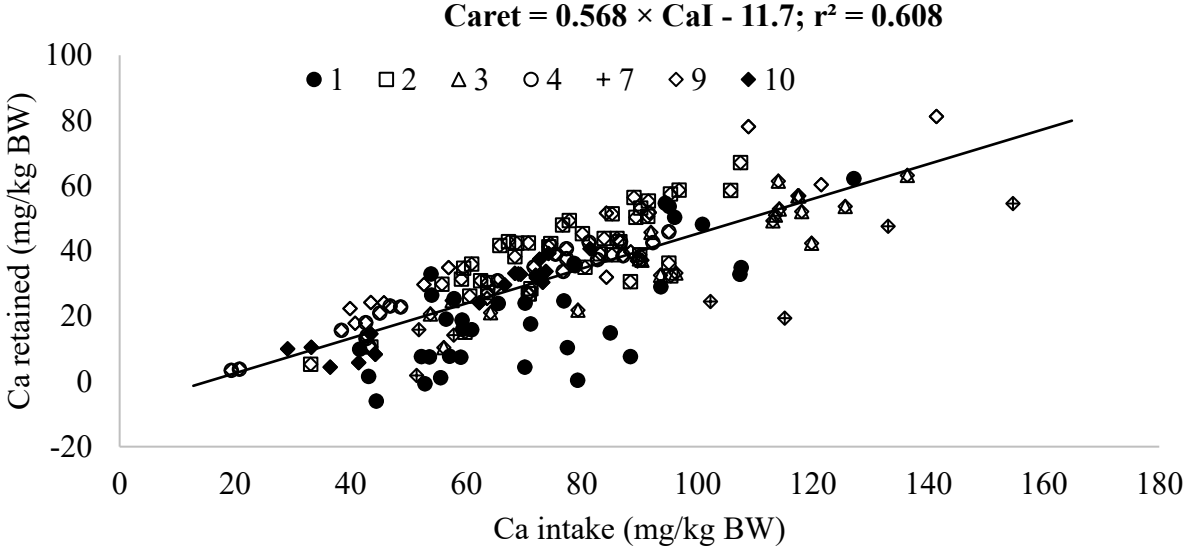


Figure 10.1 - Correlation between Ca retained (Caret) and Ca intake (CaI) in beef cattle. Costa e Silva et al. (2015a - **1** and **2**), Zanetti (2014 - **3**), Prados (2016 - **4**), Gionbelli (2010 - **7**), Prados (2012 - **9**), Zanetti et al. (2017 - **10**).

Based on the estimates in this BR-CORTE edition and the NRC (2000) recommendation, a 300-kg animal would require 3.51 and 4.62 g/d net Ca requirement for maintenance. Thus, the Ca required to compensate for the endogenous losses can be overestimated. Hence, a decreased supply of this mineral to the animals should decrease fecal Ca excretions to the environment.

The nutrient councils (ARC, 1980; AFRC, 1991; NRC, 2000; NRC, 2001) consider that mineral losses via urine are negligible, suggesting the absorption coefficient to be used to estimate mineral requirements. The AFRC (1991), NRC (2000), and NRC (2001) reported that the absorption coefficient might be 68, 70, and 50%, respectively, providing an average of 62.7%, which is close to the retention coefficient found in this BR-CORTE edition. Therefore, we recommend 56.8% to be used as the true retention coefficient of Ca for beef cattle.

Sathler (2015) evaluated Ca absorption at different sites along the gastrointestinal tract. Ca absorption in the rumen depended on the supply of a supplementary Ca source in the diet, which was approximately 25% with supplementation and 5.86% without. In contrast, when Ca absorption was evaluated in the small and large intestines, the absorption of Ca in the small intestine was 3.02 and 10.5% for diets with and without supplementation, respectively. In the large intestine, these values were 15.2 and 27.7%, respectively. Thereby, dietary inorganic Ca supplementation leads to a greater Ca absorption in the rumen, while the

absorption of Ca occurs mostly in the small and large intestines in the absence of an inorganic source.

Fontes (1995) evaluated NRGCa data published in the Brazilian literature and found no effect of the genetic group when animals were divided into Zebu, dairy crossbred, and beef crossbred but verified differences between bulls and steers, with steers presenting lower NRGCa values. In contrast, Marcondes et al. (2009) did not find sex effect on NRGCa. Similarly, several nutrient requirements councils (AFRC, 1991; NRC, 2000; CSIRO, 2007) did not find the effects of sex or genetic group on Ca dietary requirements. In this BR-CORTE edition, differences among genetic groups were observed for NRGCa with Zebu cattle presenting lower NRGCa compared with crossbred cattle ($P < 0.0001$), resulting in distinct estimates of NRGCa (Table 10.8). Moreover, for all equations, a plateau was calculated at which the mineral deposited in the body becomes constant and the NRGCa value is equal to zero (Table 10.8).

Table 10.8 - Net requirements of Ca for growth and plateau of Ca deposition as a function of genetic group (Zebu and crossbred cattle)

GG[1]	Plateau	Body content (kg)	NRGCa[2]
Zebu cattle	EBW < 462 kg	$0.294 \times EBW^{0.50}$	$EBG \times (147 \times EBW^{-0.50})$
	EBW ≥ 462 kg	6.32	0
Crossbred cattle	EBW < 453 kg	$0.096 \times EBW^{0.68}$	$EBG \times (66.0 \times EBW^{-0.32)}$
	EBW ≥ 453 kg	6.17	0

[1]GG = genetic group; [2]NRGCa = net Ca requirement for growth; EBW = empty body weight (kg); EBG = empty body gain (kg).

The NRC (2000) estimated Ca growth requirements as 7.1 g per 100 g/d of protein gain in animals. However, Chizzotti et al. (2009) reported that Ca deposition was poorly associated with protein deposition. Moreover, these authors estimated that the plateau for protein, Ca and P deposition occurred at 450, 416, and 416 kg EBW for Nellore × Angus cattle. When the mineral requirements were calculated as a function of protein deposition, they were overestimated for EBWs between 416 and 450 kg. In the BR-CORTE (2010), a common plateau was suggested for Ca and P of 412 kg equivalent EBW (469 kg BW for Nellore, and 496 kg BW for crossbred beef cattle). In this BR-CORTE edition, the inclusion of data for heavier animals resulted in better adjustment, and differences among genetic groups were verified, and a plateau for Ca deposition could be estimated for each genetic group (Table 10.8). Therefore, we suggest that the EBW at which there is no more Ca deposition to be 462 and 453 kg EBW for Zebu and crossbred cattle, respectively.

In the last few years, dietary mineral requirements have received considerable attention, mainly due to the association between mineral excretion and environment pollution. Costa e Silva et al. (2015b) decreased the dietary Ca requirements recommended in the BR-CORTE (2010) by 43% in Nellore steers and heifers and verified that this decrease did not influence animal performance, intake, or nutrient digestibility. Similarly, Prados et al. (2015) found that decreasing the recommended dietary Ca requirements in the BR-CORTE (2010) by 38% in Holstein × Zebu bulls did not affect animal performance or mineral concentrations in the bones. These authors concluded that lowering Ca supply could decrease costs in feedlot operations and Ca excretion to the environment. Therefore, more studies that evaluate reduced amounts of Ca in cattle diets to reduce the excretion of this mineral should be conducted.

Phosphorus

Phosphorus (P) is the second most abundant mineral in animals, with 80% found in bones and teeth. The remaining 20% is distributed in fluids and tissues (Suttle, 2010). Phosphorus is required for bone formation and mineralization, and is important for the growth and differentiation of ribonucleic acids. Additionally, P is fundamental for osmotic

regulation and acid-base balance, energy use, electron transfer, phospholipid production, fatty acid transport, and amino acid and protein production (Suttle, 2010). Phosphorus is also required by rumen microorganisms for growth and cell metabolism (NRC, 2000).

Dietary P that exceeds animal requirements is not absorbed or, if so, is excreted in the urine. Urinary P excretion is low in normal conditions as large amounts of P are recycled by the saliva (ARC, 1965). Thereby, the net requirements of P for maintenance were calculated by the sum of fecal and urinary metabolic P excretions. The ARC (1980) suggests that this value is 12 mg/kg BW. The AFRC (1991) calculated the net requirements of P for maintenance from an equation based on studies in sheep, whereby metabolic losses of P were calculated as a function of DMI. Furthermore, the NRC (2000) considers the net requirement of P for maintenance to be 16 mg/kg BW. From the BR-CORTE database, the net mineral requirement for maintenance and the true retention coefficient of P were 13.5 mg/kg BW and 67.8%, respectively (Figure 10.2).

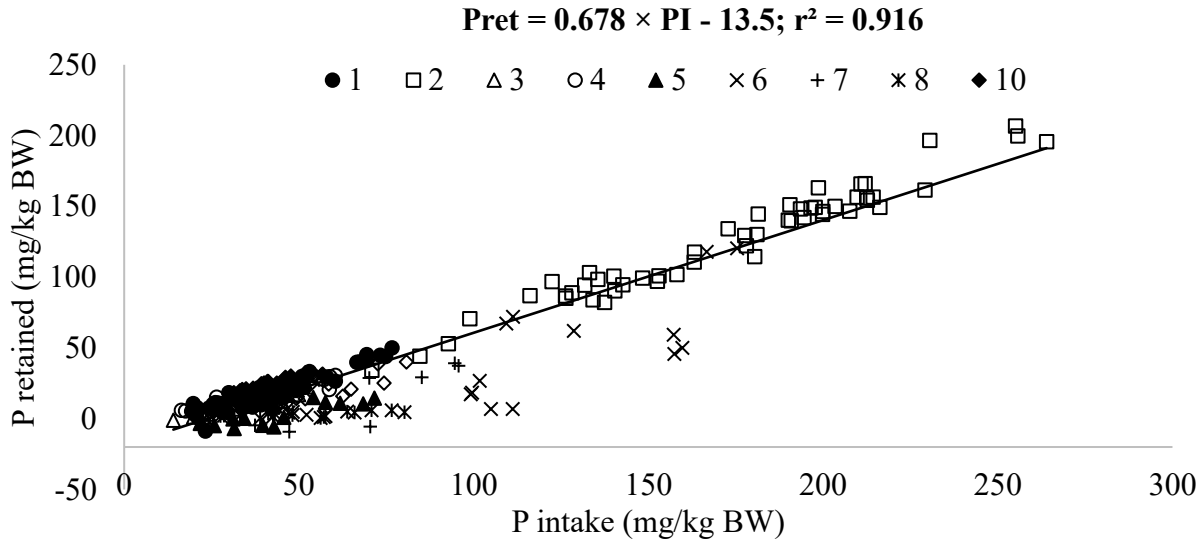


Figure 10.2 - Correlation between P retained (Pret) and P intake (PI) in beef cattle. Costa e Silva et al. (2015a - **1** and **2**), Zanetti (2014 - **3**), Prados (2016 - **4**), Souza (2010 - **5**), Marcondes (2010 - **6**), Gionbelli (2010 - **7**), Sathler (2015 - **8**), Zanetti et al. (2017 - **10**).

Sathler (2015) evaluated P absorption in diets with and without a supplementary inorganic source of P (dicalcium phosphate) and observed that regardless of the P supply, ruminal absorption of P is negative due to P recycling via saliva that arrives in the rumen and is not considered as input to the system. Thus, it is necessary to evaluate the amount of P that is recycled by the saliva as a function of the dietary P content. Furthermore, this author verified that 67.3 and 25.5% of P intake is absorbed in the small and large intestines, respectively, being the main sites of P absorption. According to the NRC (2000), supplementary sources of P can be ranked according to thr bioavailability as dicalcium phosphate > fluorinated phosphate > bone meal (Peeler, 1972). The global councils (AFRC, 1991; NRC, 2000; NRC, 2001; CSIRO, 2007) report absorption coefficients of P between 58 to 75%. Considering that the studies providing data for the estimates used in this BR-CORTE edition were based on dicalcium phosphate as the supplementary source of P, 67.8% is recommended as the true retention coefficient of P. Also, in contrast to the global councils, this BR-CORTE edition considers the retention coefficient instead of the absorption one.

The NRGP is presented in Table 10.9. The EBW at which there is no significant increase of P was also estimated. As observed with Ca, studies of nutrient requirements did not consider the effects of sex or genetic group on the dietary P requirements and this was documented in the previous BR-CORTE

editions. However, with the inclusion of new studies developed with animals having a BW greater than 500 kg, NRGP differences were detected among genetic groups (Zebu and crossbred cattle; Table 10.9). The NRC (2000) estimated NRGP as 3.9 g per 100 g/d of protein gain. In this BR-CORTE edition, Zebu cattle presented a higher NRGP than crossbred cattle. Regarding the EBW for stabilization of P deposition, Zebu, and crossbred cattle reached values of 445 and 479 kg, respectively.

Table 10.9 - Net requirements of P for growth and plateau of P deposition as a function of genetic group (Zebu and crossbred cattle)

GG	Plateau	Body content (kg)	NRGP[2]
Zebu cattle	EBW < 445 kg	$0.05995 \times EBW^{0.6446}$	$EBG \times (38.6 \times EBW^{-0.36})$
	EBW ≥ 445 kg	3.05	0
Crossbred cattle	EBW < 479 kg	$0.0339 \times EBW^{0.7496}$	$EBG \times (25.4 \times EBW^{-0.25})$
	EBW ≥ 479 kg	3.46	0

[1]GG = genetic group; [2]NRGP = net requirement of P for growth; EBW = empty body weight (kg); EBG = empty body gain (kg).

Current publications have addressed the need to decrease environment impacts caused by P excretions by cattle (Vasconcelos et al., 2007; Costa e Silva et al., 2015b; Prados et al., 2015). Costa e Silva et al. (2015b) verified that a decrease of 20% of P in the diet of Nellore steers and heifers did not impact intake, nutrient digestibility, or animal performance. Similarly, Prados et al. (2015) found that decreasing the BR-CORTE (2010) recommended dietary requirements of P of crossbred cattle by 14% did not affect animal performance or P bone concentrations. Also, Erickson et al. (1999; 2002) did not observe differences in either steers or calves performance when fed diets with 71 or 162% (steer) and 76 or 190% (calves) of P requirements recommended by the NRC (2000). Call et al. (1978) fed beef heifers for two years with 66 and 174% of the P requirements recommended by the NRC (2000) and did not observe differences in weight gain. This shows that dietary P requirements can be decreased without affecting animal performance and that the excess of dietary P is excreted in the feces. Furthermore, the mineral nutrition of cattle is not fully understood, and we recommend further studies in this area to have a better understanding of the mineral metabolism in cattle.

The ARC (1980) reports that the association between dietary Ca and P in ruminants is important because both minerals participate in bone production, and recommends a Ca:P ratio between 1:1 and 2:1. An inadequate Ca:P ratio can alter these maintenance requirements if either mineral is deficient in the diet. Hansard and Plumlee (1954) observed an increase in metabolic excretion of P when Ca intake was low and suggested that a portion of the excess P that would typically be used for bone deposition is excreted when there is insufficient Ca in the blood for bone calcification. Costa e Silva et al. (2015a) found an average Ca:P ratio of 2.15:1 for Nellore cattle with three different sexes raised in a feedlot. Zanetti et al. (2017) found the feeding behavior, nutrient intake, and performance of Nellore bulls during the growing and finishing phases were not affected by a Ca:P ratio between 0.63 to 1.82. Furthermore, this author observed that this low Ca:P ratio decreased their fecal excretion, resulting in less environment impact.

In this BR-CORTE edition, the ratio between Ca and P was 1.46:1, which is close to the inferior limit recommended by the NRC (2000). However, the NRC (2000) emphasized that a Ca:P ratio between 1:1 to 7:1 resulted in similar ruminant performance (Dowe et al., 1957; Wise et al., 1963).

Magnesium

Approximately 70% of the Mg in the body is located in the bones, while the

remaining 30% acts in the muscle and other soft tissues. Only 1% of Mg is found in extracellular fluids. In the soft tissues, Mg is involved in the energy metabolism, mainly through Mg-ATP complex, maintenance of electric potential that affects intra- and extracellular ionic gradients, and enzyme activation. The maintenance of the ideal concentrations of is essential for its functions. According to the ARC (1980), endogenous Mg losses via urine are disregarded. However, from datasets used in this BR-CORTE edition, 49.5% of the Mg intake (Table 10.3) is excreted in feces, while 24% is excreted via urine. Therefore, urinary excretion of Mg should be considered to accurately estimate its retention coefficient, which is 35.5 % (Figure 10.3). In comparison, the ARC (1980) and NRC (2000, 2001) considered absorption coefficients with mean values of 29.4% and 17%. The ARC (1980) and NRC (2001) suggested 3 mg/kg BW as the net requirement of Mg for maintenance. However, this BR-CORTE edition shows that the estimated net requirement of Mg for maintenance is 5.9 mg/kg BW (Figure 10.3).

In the BR-CORTE (2010), the NRGMg values were estimated from the EBG. This BR-CORTE edition adopted the power model intending to standardize mineral requirements. Thus, the NRGMg was estimated and the effect of the genetic group was observed (Table 10.10).

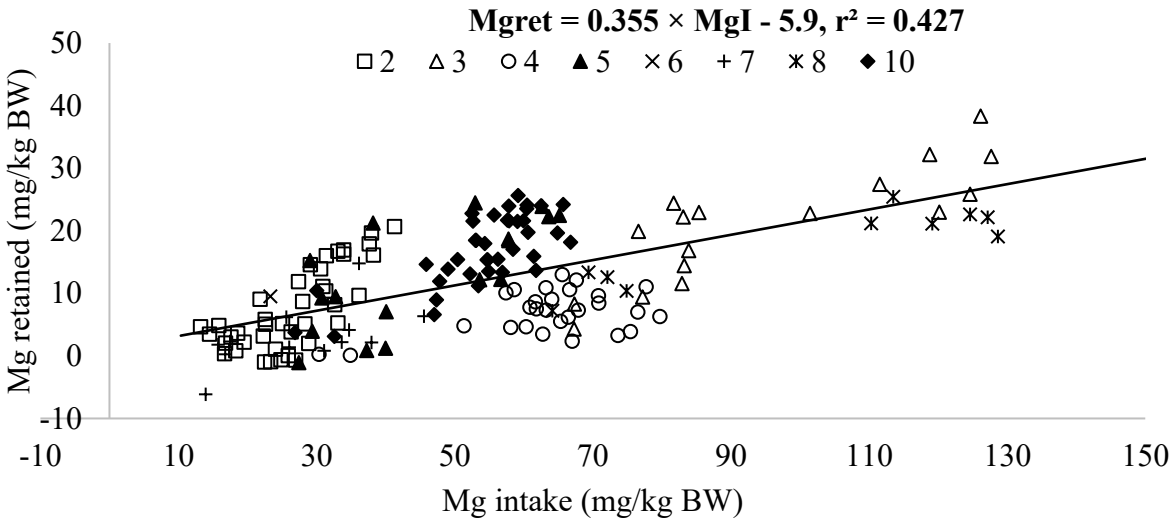


Figure 10.3 - Correlation between Mg retained (Mgret) and Mg intake (MgI) in beef cattle. Costa e Silva et al. (2015a - **2**), Zanetti (2014 - **3**), Prados (2016 - **4**), Souza (2010 - **5**), Marcondes (2010 - **6**), Gionbelli (2010 - **7**), Sathler (2015 - **8**), Zanetti et al. (2017 - **10**).

Table 10.10 - Net requirements of Mg for growth as a function of the genetic group (Zebu and crossbred cattle)

GG	Body content (g)	NRGMg[2]
Zebu cattle	$0.3427 \times EBW^{1,0113}$	$EBG \times (0.3466 \times EBW^{0,0113})$
Crossbred cattle	$1.3918 \times EBW^{0,7614}$	$EBG \times (1.0597 \times EBW^{-0,2386})$

[1]GG = genetic group; [2]NRGMg = net requirement of Mg for growth; EBW = empty body weight (kg); EBG = empty body gain (kg).

Sodium

Na presents the greatest concentration among the ions that contribute to the osmotic balance. Moreover, Na contributes to muscle contraction, nerve impulse transmission, and nutrient (e.g. glucose) transport. The ARC (1980) suggests that dietary Na is not complexed and, therefore, is completely absorbed. This infers that fecal endogenous losses do not apply to Na. However, the amount of Na in feces and urine is 37.5 and 38.6% of Na intake, respectively (Table 10.3). Based on this data, the net requirements of Na for maintenance and the true retention coefficient of Na were estimated as 6.3 mg/kg BW and 37.1%, respectively (Figure 10.4). This net requirement of Na for maintenance is lower than that suggested by the ARC (1980) and the NRC (2001) of 6.8 and 15 mg/kg BW, respectively. According to Aitken (1976), Na losses via saliva are negligible, except for non-acclimated cattle in tropical conditions, where the Na loss through saliva is 1.4 g/d for each 100 kg BW. However, there is no data from animals raised in tropical conditions that evaluate endogenous losses through the skin and the saliva.

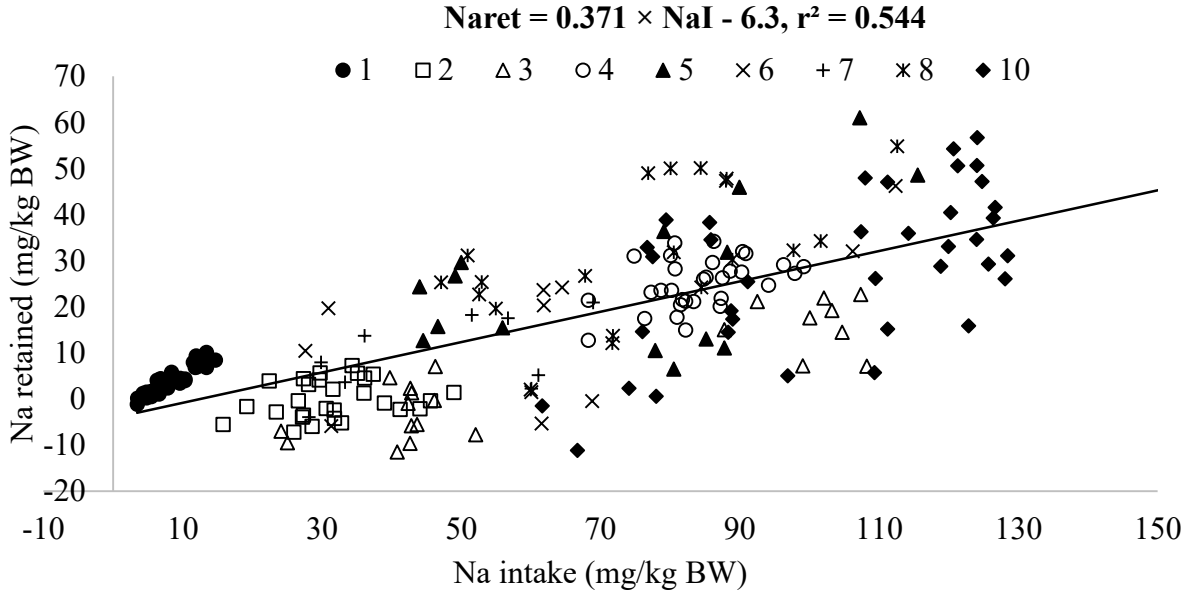


Figure 10.4 - Correlation between Na retained (Naret) and Na intake (NaI) in beef cattle. Costa e Silva et al. (2015a - **1** and **2**), Zanetti (2014 - **3**), Prados (2016 - **4**), Souza (2010 **- 5**), Marcondes (2010 **- 6**), Gionbelli (2010 - **7**), Sathler (2015 - **8**), Zanetti et al. (2017 - **10**).

The NRC (2000 , 2001) recommended 91 and 90% as the absorption coefficient of Na, respectively. However, from the BR-CORTE database, the retention coefficient was estimated as 37.1% (Figure 10.4). This difference may be due to the excretion of Na in the urine, which is not accounted for by global councils (NRC, 2000; NRC, 2001), even with the urinary Na reaching approximately 38.6% (Table 10.3). However, we highlight that some estimated dietary requirements in this BR-CORTE edition used data from diets formulated with sodium bicarbonate and magnesium oxide, as buffering and alkalizing agents, respectively, which could have contributed to the increased urinary excretion of these minerals.

In the BR-CORTE (2010), the effects of sex and the genetic group were identified based on the NRGNa, acquired using the same model as the one used for Mg. Thus, in this BR-CORTE edition, the effect of the genetic group was observed for the NRGNa using the power model (Table 10.11).

Table 10.11 - Net requirements of Na for growth as a function of genetic group (Zebu and crossbred cattle)

GG[1]	Body content (g)	NRGNa[2]
Zebu cattle	$7.9897 \times EBW^{0.7002}$	$EBG \times (5.594 \times EBW^{-0.2998})$
Crossbred cattle	$2.0985 \times EBW^{0.942}$	$EBG \times (1.977 \times EBW^{-0.058})$

[1]GG = genetic group; [2]NRGNa = net Na requirement for growth; EBW = empty body weight (kg); EBG = empty body gain (kg).

Common salt (NaCl) is routinely used in ruminant feeding as Na source. One of the main reasons for the innate desire of ruminants to consume salt was justified as a reflex response to dietary requirements and physiological status (Cheeke, 2005). However, ruminants have a considerable appetite for salt, consuming amounts greater than required (Morris, 1980). Thereby, the best indicator of Na nutrient status is its ratio with K, which should be approximately 20:1. Generally, diets of herbivores present a high K content due to its high concentrations in forages, which can cause low Na:K ratios (reaching a minimum limit of 10:1), contributing to an enhanced appetite for Na in herbivores.

Ruminants have a high capacity to retain Na in the rumen because Na can be absorbed into the blood in cases of Na deficiency, and under these conditions, K replaces Na in saliva (Cheeke, 2005). Na deficiency can decrease osmotic pressure, causing body dehydration. Decreased growth and protein efficiency and energy use are among the symptoms of Na deficiency (McDonald et al., 2002). More severe deficiency causes depraved appetite (Underwood and Suttle, 1999).

Potassium

Potassium (K) is the third most abundant ion in the body and the major cation in intracellular fluid. Along with Na, K has important functions in osmotic balance, muscle contraction, nerve impulse transmission, and several enzymatic systems. According to the ARC (1980), endogenous losses of K can be divided into estimated fecal (2.6 g/kg DM), urinary (37.5 mg/kg BW), salivary (0.7g/100 kg BW), and skin (1.1 g/d) losses, with the net requirements of K for maintenance calculated as the sum of these losses. These estimates were adopted by the BR-CORTE (2010). Notwithstanding, the data used by the ARC (1980) were only based on one study (St. Omer and Roberts, 1967), in which nine heifers were studied using a 3 × 3 Latin square experimental design to evaluate mineral balance. To standardize the net mineral requirements for maintenance, the BR-CORTE dataset estimates the net requirements of K for maintenance as 23.5 mg/kg BW (Figure 10.5). This value is lower than 38 mg/kg BW, which is recommended by the NRC (2001).

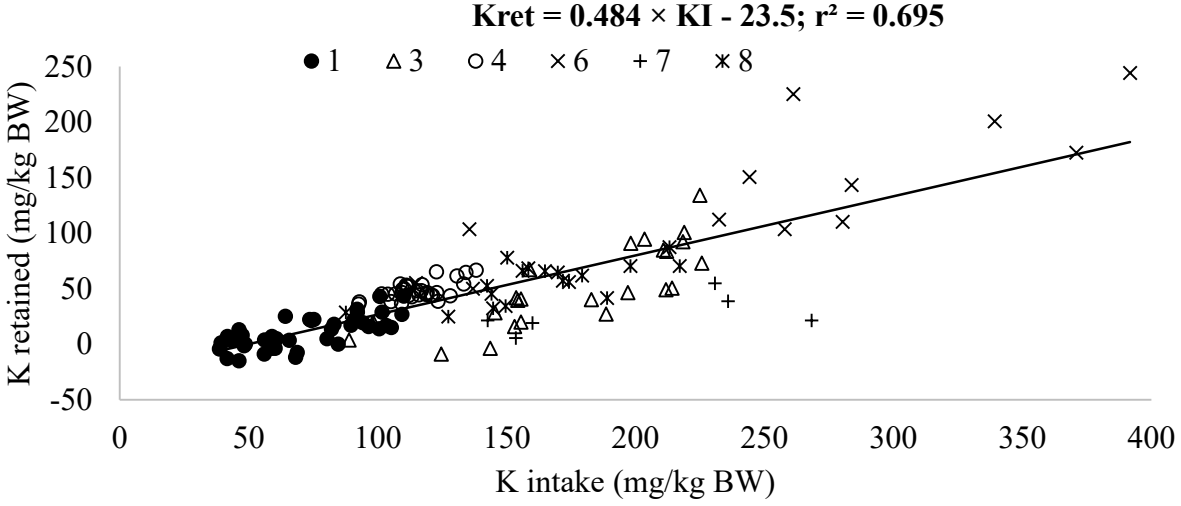


Figure 10.5 - Correlation between K retained (Kret) and K intake (KI) in beef cattle. Costa e Silva et al. (2015a - **1**), Zanetti (2014 - **3**), Prados (2016 - **4**), Marcondes (2010 - **6**), Gionbelli (2010 - **7**), Sathler (2015 - **8**).

Ward (1966) reported that K is absorbed in the rumen, abomasum, and small and large intestines. Sathler (2015) evaluated the absorption of K from several sites within the gastrointestinal tract and observed a negative absorption of K in the rumen and colon, suggesting that the secretion of K into the gastrointestinal tract is greater than its absorption. The substantial amount of ruminal K was due to salivary K secretions that were not quantified as part of K intake. The substantial colonic K secretion that occurs when Na absorption is high may be due to the contribution of K, Na, and Cl ion channels to transepithelial flow by coupling electrochemical gradients (Sathler, 2015).

The ARC (1980) and the NRC (2001) considered the absorption coefficient of K as 100 and 90%, respectively. These high values can be justified by Ward (1966), who indicated that urine is the main route of K excretion, which minimizes K reserves. Based on the dataset developed for this BR-CORTE edition, the fecal excretion of K cannot be neglected and the urinary excretion of K does not represent the total daily K excretion. Indeed, fecal and urinary excretions of K were 35.3 and 30.3% of the K intake, respectively, which provided a true retention coefficient of 48.4% (Figure 10.5), that is the value recommended in this BR-CORTE edition. This shows that there is no main route for K excretion. Therefore, the relatively lower nutrient requirement values currently recommended by several global councils should be re-assessed.

Regarding the effect of genetic group, the NRGK resulted in distinct equations for Zebu and crossbred cattle (Table 10.12). This NRGK is approximately 17% lower than the one previously reported in the BR-CORTE (2010).

Table 10.12 - Net requirements of K for growth as a function of genetic group (Zebu and crossbred cattle)

GG[1]	Body content (g)	NRGK[2]
Zebu cattle	$0.8437 \times EBW^{1.1216}$	$EBG \times (0.9463 \times EBW^{0.1216})$
Crossbred cattle	$0.2589 \times EBW^{1.3200}$	$EBG \times (0.3418 \times EBW^{0.3200})$

[1]GG = genetic group; [2]NRGK = net requirements of K for growth; EBW = empty body weight (kg); EBG = empty body gain (kg).

Sulfur

Several biomolecules are composed of S, such as amino acids (methionine, cystine, and cysteine), hormones (insulin and oxytocin), and metalloproteins, which are important to safeguard animals against Cu, Cd, and Zn excesses (Suttle, 2010).

Despite affirming that the dietary S requirements for beef and dairy cattle are not well-defined (NRC, 2000; NRC, 2001), the NRC recommended values between 1.5 and 2.0 g/kg DM. However, no net requirement of S for maintenance or retention coefficient were provided. From the database of this BR-CORTE edition, the net requirements of S for maintenance and the retention coefficient for Nellore cattle were 10.4 mg/kg BW and 77.3%, respectively (Figure 10.6).

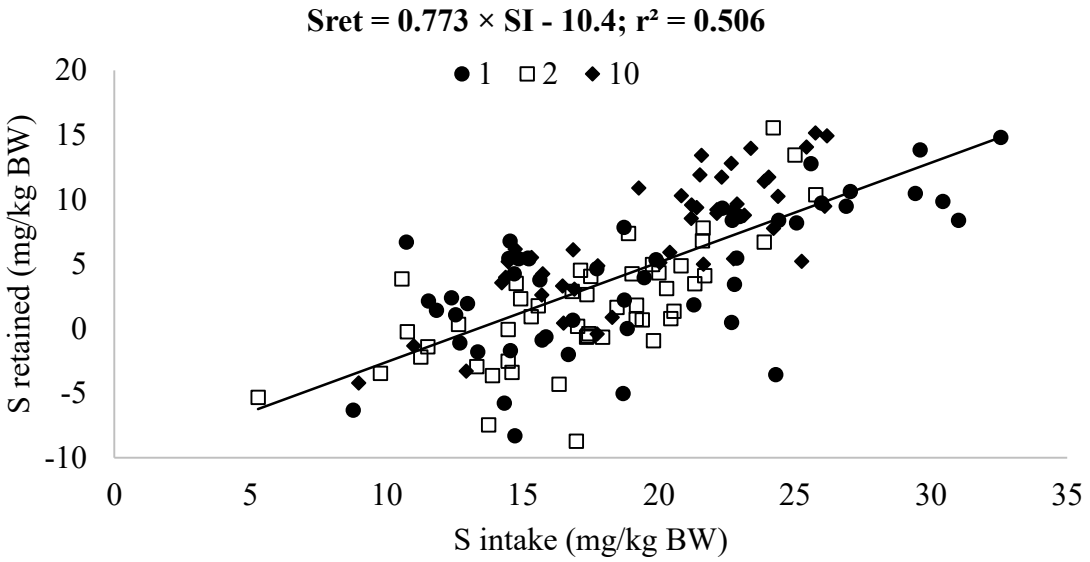


Figure 10.6 - Correlation between S retained (Sret) and S intake (SI) in beef cattle. Data from Costa e Silva et al. (2015a - **1 and 2**) and Zanetti et al. (2017 – **10**).

The NRGS is based on the data available, which is a single study developed by Costa e Silva et al. (2015a) and estimated based on the following equation:

$$NRGS = EBG \times (0.03 \times EBW^{0.89})$$

where EBG is the empty body gain (kg/d) and EBW is the empty body weight (kg).

In contrast to the other macrominerals, the exponent of the equation was positive, which infers that as the animal grows (increases its EBW), the NRGS increases. When expressed as DMI (g/kg), the estimated average dietary requirement of S is 1.36 g/kg DM, which approximates to that recommended by the NRC (2000), but is lower than that recommended by the NRC (2001). Costa e Silva et al. (2015a) reported that these differences could be due to the NRC (2001) data that was based on a single study (Bouchard and Conrad, 1973) of mid-term lactation Holstein cows producing 30 to 37 kg milk/d. However, we highlight the need for more studies to evaluate dietary requirements of S to improve the accuracy of these estimates.

Chlorine

In nature and in the body, Cl exists primarily as the chloride anion, Cl^-, which is the major anion present in extracellular fluid. This mineral is needed for the production of HCl in the gastric juice and amylase activation. Both Na and Cl^- are involved in the osmotic pressure maintenance, hydric balance control, and acid-base balance regulation (Underwood, 1981). To date, studies on dietary Cl^- are primarily concerned about microorganism control, such as *Escherichia coli* in the gastrointestinal tract (Callaway et al., 2002; Anderson et al., 2005), rather than evaluating the dietary requirements of this mineral.

Thus, the net requirements of Cl for maintenance and its retention coefficient in beef cattle are not well defined (Underwood and Suttle, 1999). Chloride deficiency does not seem probable in practical conditions (NRC, 2000). Information about endogenous Cl^- losses are not found in the literature; nevertheless, the ARC (1980) considers that there is an inevitable urinary loss, as occurs for Na. According to Aitken (1976), cattle raised under tropical conditions have a high maintenance requirement of Cl^- due to losses via skin and saliva, suggesting 1.6 g/d for a 500-kg animal raised under tropical conditions, *i.e.* exposed to approximately 40ºC for 7 h/d and air humidity of 90%. Such conditions are particularly probable in grazing animals raised under these conditions. For salivary losses, the recommendation of Cl^- is 0.9 g/d for each 100 kg BW. Smith et al. (2012) reported an average absorption of Cl^- (as $NaClO_3$) in cattle of 12.6% based on a compilation of studies that evaluated several chlorides using $^{36}Cl^-$ as isotopic marker.

The ARC (1980) estimated dietary requirements of 0.7 g/kg DM in beef cattle gaining 1.0 kg/d and due to the absence of studies

on this subject in Brazil, we suggest that this value is adopted.

TRACE MINERALS

Due to the lack of studies on the dietary requirements of trace minerals in the literature, the recommendations in this BR-CORTE edition are only based on two studies (Costa e Silva et al, 2015a; Zanetti et al., 2017) and their descriptive statistics are shown in Table 10.4.

Copper

The functions of Cu in the body are related to lipid metabolism and the activation of several enzymes, such as cytochrome oxidase, ceruloplasmin, and superoxide dismutase. The main reserve organ of Cu is the liver, where Cu concentrations are influenced by dietary concentrations. Costa e Silva et al (2015a) reported an average intake of Cu of 83.5 mg/d, and Cu retention of 25.4 mg/d, which suggests that only 30.4% of the Cu intake is retained in animals. Nevertheless, 65.7 and 3.8% of the Cu intake was excreted via feces and urine, respectively. Sathler (2015) reported that fecal excretion of Cu in Nellore bulls varied from 38.6 to 62.0% of Cu intake, depending on whether macrominerals and/or trace elements were included in the diet. However, the urinary excretion of Cu was not measured.

In this BR-CORTE edition, the net requirements of Cu for maintenance was 95.6 µg/kg BW (Figure 10.7). This is higher than the value of 7.1 µg/kg BW recommended by the ARC (1980); however, to reach this value, the ARC (1980) assumed an equation that uses Cu intake, hepatic Cu loss, and BW changes. Meanwhile, the Australian system (CSIRO, 2007) adopted 4 µg/kg BW as the Cu requirement for maintenance, based on the results of a single study (Suttle, 1974) that evaluated Cu bioavailability in sheep.

Cu absorption in ruminants is considered low (<1 to 10%) compared to that reported for non-ruminants (Underwood and Suttle, 1999). Calves absorb approximately 70% of their dietary Cu, while adult cattle absorb 1 to 5% (NRC, 2001). This is primarily due to the complex interactions that occur in the rumen (Sathler, 2015). However, Sathler (2015) found that the absorption coefficient of Cu varied from 38.2 to 61.2%, depending on whether macrominerals and/or trace elements were included in the diet. The lowest absorption occurred when macrominerals but no trace elements were supplied.

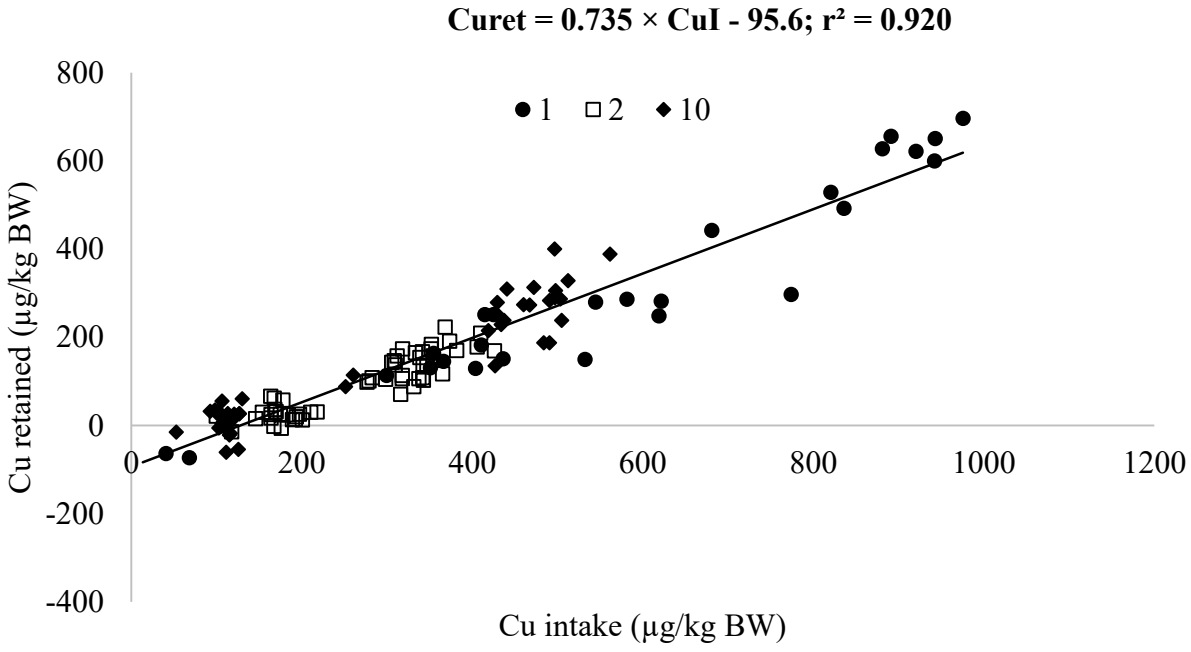


Figure 10.7 - Correlation between Cu retained (Curet) and Cu intake (CuI) in beef cattle. Data from Costa e Silva et al. (2015a - **1 and 2**) and Zanetti et al. (2017 – **10**).

Several factors can affect Cu absorption in ruminants, such as high dietary concentrations of Mo and S. These minerals interact with Cu, producing thiomolybdates, an insoluble complex, rendering Cu unavailable for absorption (Suttle, 1991). According to the NRC (2001), dietary requirements of Cu varied from 4 to 15 mg/kg DM depending on the dietary concentration of Mo and S. Thus, further studies that evaluate the interference of Mo and S in Cu absorption should be conducted to investigate the amount of Cu required to prevent its deficiency in animals. Furthermore, some studies have shown a decrease in ruminal absorption of Cu when Ca is added to the diet (Dick, 1954; Kirchgessner and Weser, 1965). Sathler (2015) reported that Cu absorption in the rumen, small intestine, and large intestine varied depending on the macromineral and/or trace element supplementation.

Costa e Silva et al. (2015a) suggested that the retention coefficient provides the most accurate estimate of dietary requirements and that the urinary excretion of mineral cannot be discarded. A total of 3.8% of Cu intake is excreted via urine (Costa e Silva et al., 2015a). Thus, the retention coefficient is 73.5% (Figure 10.7). This value is higher than 6% that is reported by the ARC (1980), which was recommended as the liver absorption coefficient, and found on studies with sheep.

The NRGCu was estimated as follows:

$$NRGCu = EBG \times (1.25 \times EBW^{0.33})$$

where EBG is the empty body gain (kg/d) and EBW is the empty body weight (kg, Costa e Silva et al., 2015a).

The exponent of the equation is positive, so, as S, we concluded that as the animal grows (increases EBW), the NRGCu increases.

Mullis et al. (2003) estimated dietary Cu requirements for Angus and Simmental heifers as 7 mg/kg DMI. The NRC (2000) recommends 10 mg/kg DMI dietary Cu for beef cattle. However, these recommendations do not consider the amount of Cu supplied in the basal diet but only the one used for supplementation. Costa e Silva et al. (2015a) evaluated the composition of the basal diet and found that the average dietary requirements of Cu for Nellore cattle were 9.53 mg/kg DMI and this BR-CORTE edition supports this recommendation. Nevertheless, Prados (2016) compared diets with (5.85 mg/kg DMI) and without Cu supplementation and found no difference in animal performance.

Iron

Iron (Fe) is an important component of various proteins that participate in the oxygen use and transport, such as hemoglobin, which contains 50% of all the Fe present in animals, myoglobin, cytochromes, and iron-sulfur proteins involved in the electron transport chain (NRC, 2000). In addition, an insufficient supply of Fe can decrease body reserves and Fe concentrations in the serum and blood hemoglobin (Thomas, 1970).

The NRC (2000) adopted results from two experiments (Bremmer and Dalgarno, 1973; Bernier et al., 1984), which evaluated Fe supplementation in calves fed milk to prevent anemia and concluded that 40 to 50 mg/kg DMI was adequate for animal growth and anemia prevention. Based on the data from Costa e Silva et al. (2015a) and Zanetti et al. (2017), the net requirements of Fe for maintenance and the retention coefficient in beef cattle are 2.9 mg/kg BW and 73.4%, respectively (Figure 10.8).

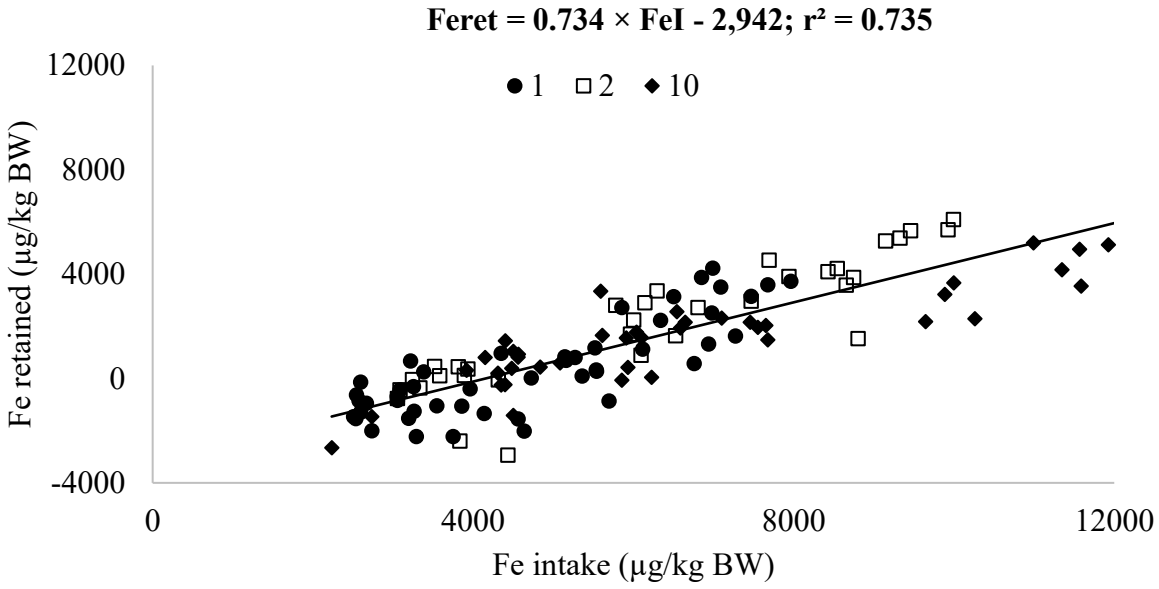


Figure 10.8 - Correlation between Fe retained (Feret) and Fe intake (FeI) in beef cattle. Data from Costa e Silva et al. (2015a - **1 and 2**) and Zanetti et al. (2017 – **10**).

For NRGFe, we used the equation suggested by Zanetti et al. (2017) :

$$NRGFe = EBG \times (10.4 \times EBW^{0.24})$$

where EBG is the empty body gain (kg/d) and EBW is the empty body weight (kg).

Thereby, the NRGFe increases as the animal grows, although at a slower rate. Similarly, the NRC (2000) suggests that as the animal grows, the relative requirements decrease because blood volume does not increase proportionally to BW.

The NRC (2000) recommended 50 mg/kg DMI as the dietary requirement of Fe. We suggest a higher average of 166 mg/kg DMI. However, we highlight that Fe concentration in the basal diet was considered in this BR-CORTE edition, while the NRC (2000) only evaluated Fe supplementation, discarding the amount of Fe provided by milk to the animals.

Manganese

Manganese (Mn) is widely distributed in the body tissues and fluids and its amount can vary according to species, age, organ, and the presence of other trace minerals in the diet. Some studies (Bentley and Phillips, 1951; Rojas et al, 1965; DiCostanzo et al, 1986) reported that Mn levels were associated with reproductive aspects but did not affect animal performance. Schroeder et al. (1966) recommended 20 to 25 mg/kg DMI of Mn for a good skeletal development.

The net requirements of Mn for maintenance and the retention coefficient were 184.9 µg/kg BW and 43.9%, respectively (Figure 10.9). The NRC (2001) suggests 2 µg/kg BW and 75% as the net requirements of Mn for maintenance and the absorption coefficient, respectively. However, some authors (Sansom et al, 1978; Sullivan et al, 1979; Van Bruwaene et al, 1984) suggest that only 1 to 4% Mn is absorbed regardless of its dietary concentration and that it is primarily absorbed in the small intestine. Sathler (2015) evaluated the partial absorption coefficients in the rumen, abomasum, and omasum and found that the main site of absorption was the rumen, where 35.1% of the Mn intake was absorbed. Furthermore, Hurley and Keen (1987) reported that high dietary concentrations of other minerals, such as Ca, P, and Fe, decrease Mn absorption. Sathler (2015) also reported that diets with high concentrations of macrominerals and trace minerals resulted in an absorption coefficient 15% lower than diets containing trace minerals without macrominerals. However, this author verified that the Mn absorption in the small intestine using the treatment with all minerals was greater compared to the treatment without macrominerals, with no differences in the coefficient of total apparent absorption.

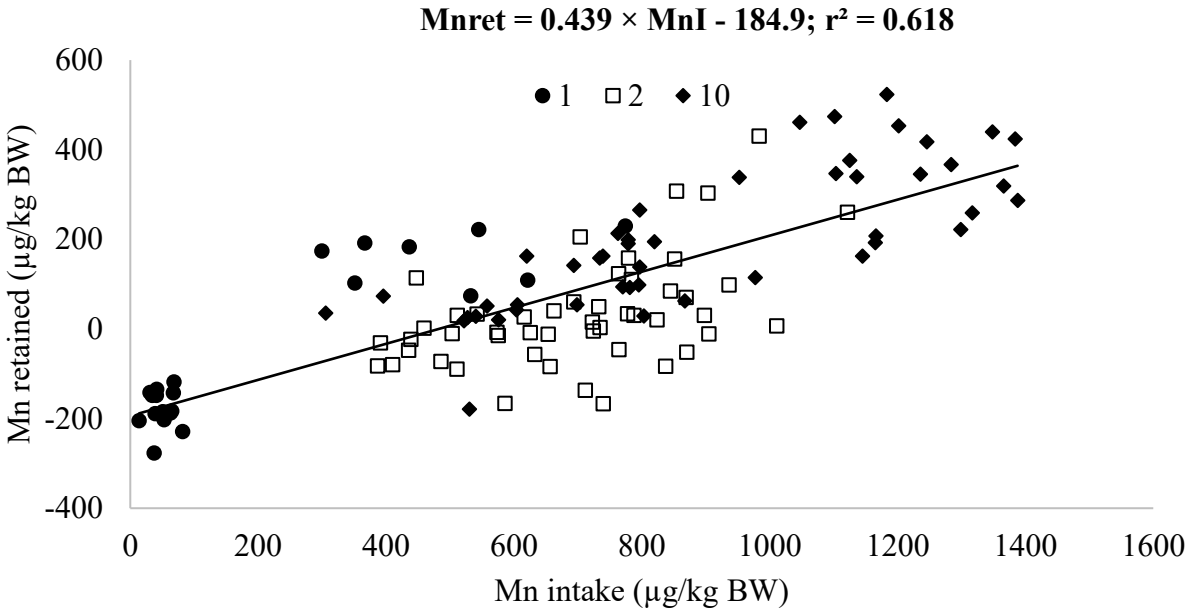


Figure 10.9 - Correlation between Mn retained (Mnret) and Mn intake (MnI) in beef cattle. Data from Costa e Silva et al. (2015a - **1 and 2**) and Zanetti et al. (2017 – **10**).

For NRGMn, Costa e Silva et al. (2015a) suggested the following equation:

$$NRGMn = EBG \times (0.07 \times EBW^{0.80})$$

where EBG is the empty body gain (kg/d) and EBW is the empty body weight (kg).

The NRC (2000) recommended 20 mg/kg DMI of dietary requirements of Mn and this was adopted by the BR-CORTE (2010). Hartmans (1974) fed cows with 2.5 to 3.5 years of age with diets containing 16 to 21 mg/kg DMI and did not observe symptons of Mn deficiency or improved animal performance. Possibly, the supply of Mn was above the requirements for optimal performance. Costa e Silva et al. (2015a) estimated dietary requirements of Mn as 9.59 mg/kg DMI and showed that similar animal performance was achieved when 10 mg/kg DMI was supplied.

Selenium

Se concentration in animals depends on the dietary amount of Se, its chemical form, and the tissue where the Se concentration is measured. According to Behne and Wolters (1983), high Se concentrations can occur in the liver and kidneys whereas the highest Se contents are captured by the muscles. In these tissues, Se activates enzymes involved in the production of thyroid hormones (T3 and T4), and as an antioxidant, decreasing hydrogen peroxide concentrations.

For the net requirements of Se for maintenance and the retention coefficient, we used the recommendations by Costa e Silva et al. (2015a) of 3.72 g/kg BW and 48.7%, respectively (Figure 10.10). This retention coefficient is higher than that by Wright and Bell (1966) who used a Se isotope in sheep and found an absorption coefficient of 35%. A similar value (30%) was suggested by the CSIRO (2007). However, the value found by Costa e Silva et al. (2015a) is within 40 to 50%, which is the range established by the NRC (2001).

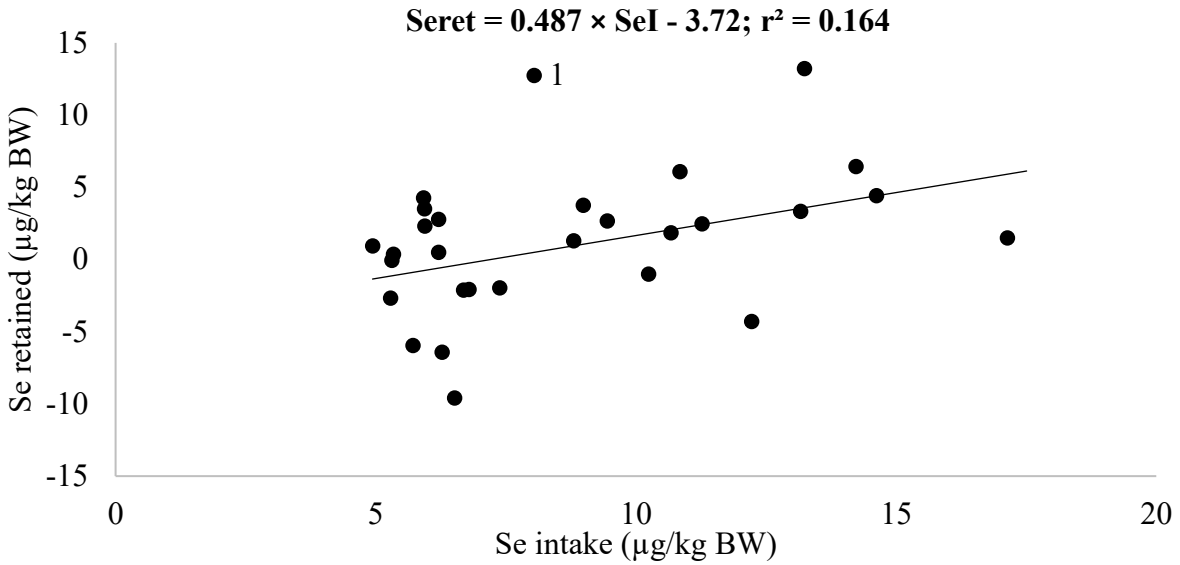


Figure 10.10 - Correlation between Se retained (Seret) and Se intake (SeI) in beef cattle. Data from Costa e Silva et al. (2015a - **1**).

For NRGSe, Costa e Silva et al. (2015a) suggested the following equation:

$$NRGSe = EBG \times (1.07 \times EBW^{-0.07})$$

where EBG is the empty body gain (kg/d) and EBW is the empty body weight (kg).

Thus, we conclude that NRGSe does not vary as the animal grows because the exponent of the equation is close to zero. Subclinical signs of Se deficiency have been reported in beef cows and calves fed forage containing 0.02 to 0.05 mg Se/kg DMI (Morris et al, 1984; Hidiroglou et al, 1985; Spears et al., 1986). In reference to these studies, the NRC (2000) recommended 0.1 mg/kg DMI as the dietary requirement of Se. However, Costa e Silva et al. (2015a) estimated 0.57 mg/kg DMI as the dietary requirements of Se. Moreover, this value is higher than that recommended by the CSIRO (2007) and the NRC (2001) of 0.05 and 0.30 mg/kg DMI, respectively. However, we emphasize that the values suggested by Costa e Silva et al. (2015a) were derived from only one experiment, containing 50 Nellore cattle, with BW varying between 121 and 300 kg. Therefore, we recommend further studies before the dietary requirements are conclusively defined.

Zinc

The functions of Zn in the body are mainly related to enzymatic action, either as a cofactor or by enzyme activation. Additionally, the development and functionality of the immune system are Zn-dependent. Some researchers (Delezenne, 1919; Bodansky, 1920; Weitzel et al, 1954) reported that the Zn concentrations in plants and animals are often comparable to Fe contents and are generally greater than other trace elements (Hambidge et al., 1986). The NRC (2000) used the average of three studies (Miller et al 1966; Hansard et al, 1968; Schwarz and Kirchgessner, 1975) to estimate Zn endogenous losses and estimated 12 µg/kg BW as the net requirements of Zn for maintenance. Weigand and Kirchgessner (1982) estimated the net requirements of Zn for maintenance in lactating cows as 53 µg/kg BW. Furthermore, the ARC (1980) and the NRC (2001) estimated the net requirements of Zn for maintenance as 55 µg/kg BW, while the CSIRO (2007) recommended 45 µg/kg BW. However, experiments conducted under tropical conditions and, adopted in the dataset of this BR-CORTE edition, suggest that the net requirements of Zn for maintenance is 334.4 µg/kg BW (Figure 10.11), which is higher than the above mentioned recommendations.

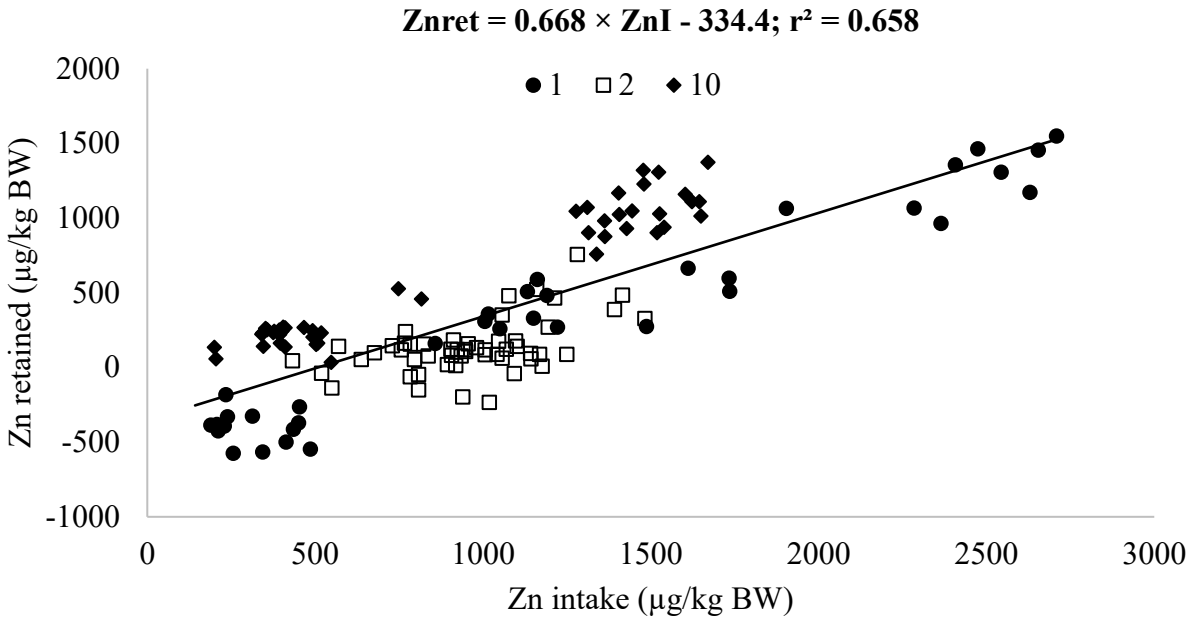


Figure 10.11 - Correlation between Zn retained (Znret) and Zn intake (ZnI) in beef cattle. Data from Costa e Silva et al. (2015a - **1 and 2**) and Zanetti et al. (2017 – **10**).

The ARC (1980) suggested two absorption coefficients for Zn, 30% for young ruminants and 20% for mature animals. The CSIRO (2007) adopted the true absorption coefficient of 60% for pre-ruminant calves and 40% for older animals with a functional rumen (SCA, 1990). However, from the BR-CORTE database, we observed a retention coefficient of 66.8% (Figure 10.11). Cragle and Miller (1965) suggested that Zn absorption occurs mainly in the abomasum and small intestine. However, Sathler (2015) verified that in diets with and without supplementation of trace elements, Zn was primarily absorbed in the rumen (approximately 43.7% of the Zn intake) and large intestine (an average of 27% of the Zn intake), respectively. Moreover, some studies (Mills et al, 1967; Perry et al, 1968) showed that Zn absorption is decreased when Ca is included in the diet. However, Sathler (2015) reported no differences in Zn absorption regardless of the dietary Ca. Nevertheless, Prados (2016) verified lower concentration of Zn in the liver when there was Ca supplementation in the diet, due to the interaction between Ca and Zn, lowering Zn absorption.

For NRGZn, Costa e Silva et al. (2015a) recommended the following equation:

$$NRGZn = EBG \times (1.16 \times EBW^{0.86})$$

where EBG is the empty body gain (kg/d) and EBW is the empty body weight (kg).

The ARC (1980) suggested that 16 to 31 mg Zn/kg BW can be incorporated into the body tissue for each kilogram of BW gain. The NRC (2000) considered the dietary requirements of Zn as 30 mg/kg DMI, while the CSIRO (2007) recommended 11.6 mg/kg DMI. However, the NRC (2000) recommendations were based on two studies (Perry et al, 1968; Pond and Otjen, 1988) that evaluated growth response to Zn supplementation when Zn concentration in the basal diet was unknown. However, Costa e Silva et al. (2015a) considered the Zn composition in the basal diet and reported 61 mg/kg DMI as the dietary requirement of Zn for Nellore cattle.

Cobalt

Co is the precursor of vitamin B_{12}, which is associated with energy metabolism. However, the amount of dietary Co that is converted to vitamin B_{12} varies from 3 to 13% of the Co intake (Smith, 1987). Furthermore, some studies (Monroe et al, 1952; Looney et al, 1976) found that 84 to 98% of the Co supplied in the diet is found in the feces approximately 5 to 14 days after intake. In this

BR-CORTE edition, the true retention coefficient was estimated as 86.8% (Figure 10.12) showing that only 13.2% of the Co intake was excreted via feces and urine. Additionally, the net Co requirements for maintenance in Nellore cattle was 13.5 µg/kg BW (Figure 10.12).

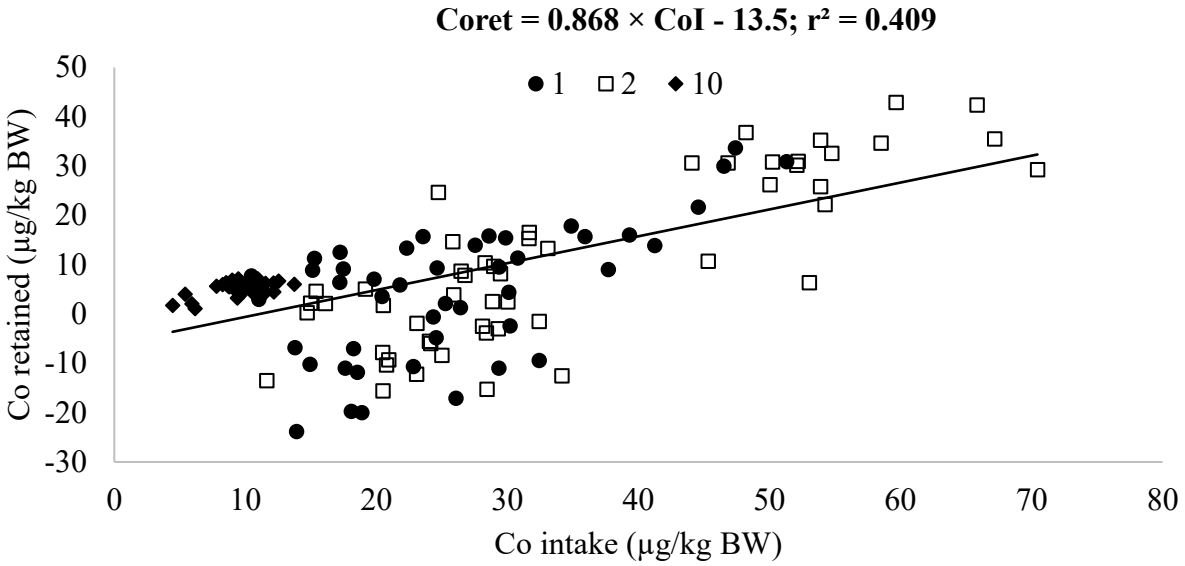


Figure 10.12 - Correlation between Co retained (Coret) and Co intake (CoI) in beef cattle. Data from Costa e Silva et al. (2015a - **1 and 2**) and Zanetti et al. (2017 - **10**).

The NRGCo was based on the equation suggested by Zanetti et al. (2017):

$$NRGCo = EBG \times (0.045 \times EBW^{-0.023})$$

where EBG is the empty body gain (kg/d) and EBW is the empty body weight (kg).

Thus, the NRGCo decreases as the EBW increases at an almost constant rate. Smith (1987) suggested 0.11 mg/kg DMI as the dietary requirement of Co, and this was adopted by the NRC (2000 and 2001). However, Smith (1987) did not consider the absorption coefficient or the Co content of the feeds. Thus, in this BR-CORTE edition, the dietary Co requirement was 0.63 mg/kg DMI, considering the retention coefficient and the contents of Co of the feeds.

Chromium

In the previous editions of BR-CORTE, the recommendations for the NRGCr and the retention coefficient were not suggested. However, Costa e Silva et al. (2015a) estimated the net Cr required for maintenance and the retention coefficient and the retention coefficient as 22.9 µg/kg BW and 78.4%, respectively (Figure 10.13).

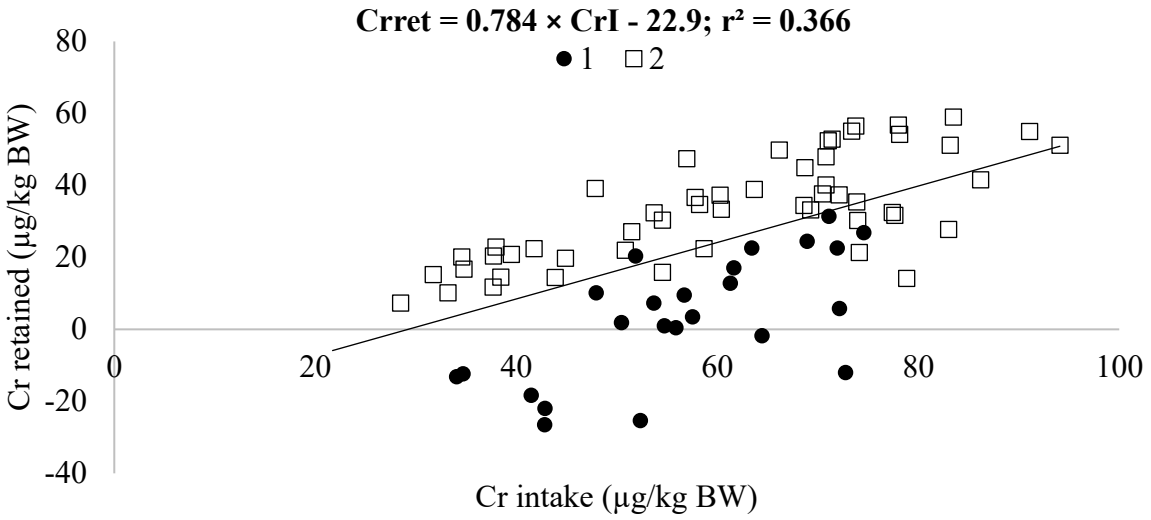


Figure 10.13 - Correlation between Cr retained (Crret) and Cr intake (CrI) in beef cattle. Data from Costa e Silva et al. (2015a - **1 and 2**).

Moreover, Costa e Silva et al. (2015a) estimated the NRGCr and suggested the following equation:

$$NRGCr = EBG \times (0.23 \times EBW^{0.61})$$

where EBG is empty body gain (kg/d) and EBW is the empty body weight (kg).

Bernhard et al. (2012) evaluated the effects of Cr supplementation on steer performance and observed a difference in the average daily gain (ADG) of non-supplemented steers compared to those receiving 0.3 mg/kg DMI. Additionally, some studies (Butting et al., 1994; Kegley and Spears, 1995) evaluated Cr supplementation in calves and suggested that 0.4 mg Cr/kg DMI inclusion increases glucose clearance rate. The NRC (2000) adopted this recommendation of 0.4 mg/kg DMI as the dietary requirement of Cr for beef cattle, despite being based on Cr supplementation and disregarding the Cr provided by the basal diet. However, Costa e Silva et al. (2015a) estimated 2.53 mg/kg DMI.

Molybdenum

Molybdenum (Mo) is an essential component of xanthine oxidase, aldehyde oxidase, and sulfite oxidase (Mills and Davis, 1987). Some authors have correlated Mo supplementation with improved microbial activity, increased cellulose digestion (Ellis et al., 1958), or increased disappearance rate of DM in the rumen (Sharif et al., 1990). Mo is related to the intra-ruminal synthesis of thio- or oxi-thiomolybdate, which can further react with Cu to inhibit the effects of dietary Mo and S sources by ruminants. However, studies evaluating the evidence of the direct and indirect production of thiomolybdates in ruminal contents of cattle remain inconclusive. Thus, it is necessary to verify the influence of changes in the dietary supply of Cu on the presence of soluble thiomolybdates in the rumen fluid and the Cu and Mo concentrations and distributions in the blood plasma. The NRC does not provide the dietary requirements of Mo, because its deficiencies are rarely observed. Zanetti et al. (2017) established the values of 3.27 µg/kg BW and 49.7% as the endogenous losses and the retention coefficient for Mo, respectively (Figure 10.14).

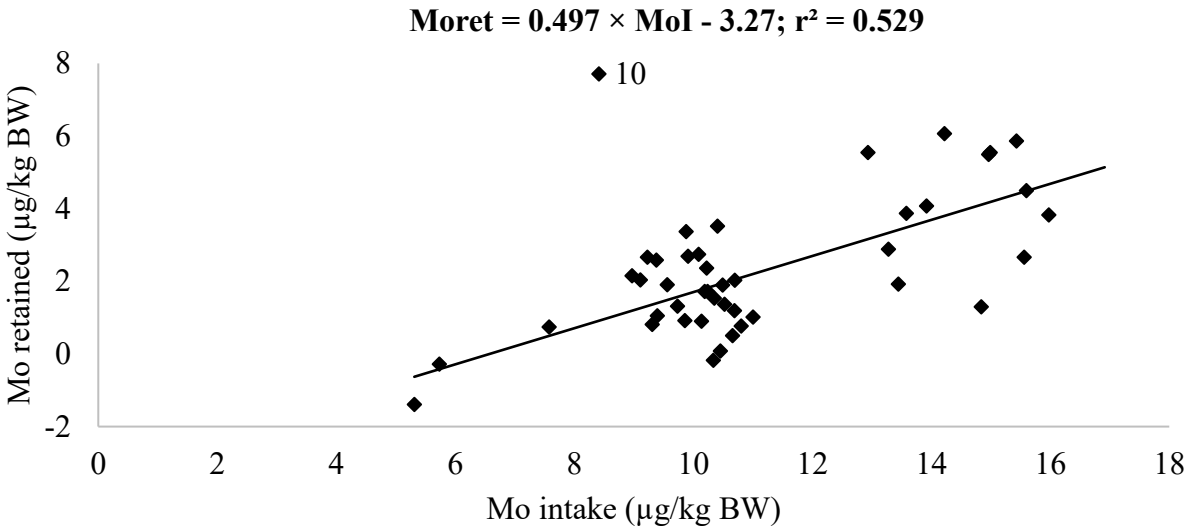


Figure 10.14 - Correlation between Mo retained (Moret) and Mo intake (MoI) in beef cattle. Data from Zanetti et al. (2017 - **10**).

Additionally, Zanetti et al. (2017) estimated the NRGCo and suggested the following equation:

$$NRGMo = EBG \times (0.00353 \times EBW^{0.4063})$$

where EBG is the empty body gain (kg/d) and EBW is the empty body weight (kg).

Iodine

Iodine (I) is an important component of thyroid hormones (thyroxine, T3, and triiodothyronine, T4), which regulates the energy metabolism rate in animals. Iodine is mostly absorbed as iodide (between 70 and 80%) in the rumen, presenting considerable secretion in the abomasum (Miller et al., 1988). However, its secretion in the abomasum is highly reabsorbed in the small and large intestines (NRC, 2000).

As for Cl, the dietary I requirements are not yet defined. The NRC (2000) suggested that 0.5 mg/kg DM could be adequate. According to the ARC (1980), dietary requirements of I can be estimated by measuring the thyroid hormone secretion rates. However, as there are no relevant studies of this mineral developed in Brazil, the BR-CORTE suggests the adoption of the recommendations from the NRC (2000) (0.5 mg/kg DM).

TOXICITY

When provided in large amounts, some inorganic elements can cause several adverse health issues in cattle. For the formulation of rations, we recommend that maximum dietary mineral levels are set at 120% of the dietary requirements to ensure a balance of dietary minerals without detrimental absorption and to avoid unnecessary losses. However, this balance is not always possible in practical conditions, The toxic mineral values obtained from the literature are presented in Table 10.13.

TABLES OF MINERAL REQUIREMENTS FOR BEEF CATTLE

Based on the estimated net requirements for maintenance and NRG, as well as the retention coefficient, net mineral requirements were obtained (Table 10.14).

Table 10.13 - Toxic mineral levels in beef cattle

Macromineral	Toxic level	Trace element	Toxic level
Calcium[1]	44 g/kg DM	Copper[4]	115 mg/kg DM
Potassium[4]	30 g/kg DM	Manganese[2]	1,000 mg/kg DM
Magnesium[1]	4 g/kg DM	Selenium[3]	5.0 mg/kg DM
Sodium[1]	65 g/kg DM	Zinc[3]	500 mg/kg DM
Sulfur[1]	4 g/kg DM	Cobalt[4]	1.0 mg/kg BW
		Chromium[2]	50 mg/kg DM
		Fluoride[3]	30 mg/kg DM
		Iodine[2]	50 mg/kg DM
		Molybdenium[3]	6.0 mg/kg DM
		Vanadium[2]	30 mg/kg DM

[1]NRC (2000); [2]McDonald et al. (2002); [3]McDowell (1992); [4]NASEM (2016). DM = dry matter.

Table 10.14 - Summary of the recommendations for calculation of net requirements of macrominerals and trace minerals for beef cattle

Mineral	Net requirements for maintenance	Retention coefficient	Net requirements for growth (NRG)[1]	EBW in the plateau
	mg/kg body weight	%	g/d	kg
Ca	11.7	56.8	Zebu cattle: $NRGCa = EBG \times (147 \times EBW^{-0.50})$ Crossbred cattle: $NRGCa = EBG \times (66.0 \times EBW^{-0.32})$	462 453
P	13.5	67.8	Zebu cattle: $NRGP = EBG \times (38.6 \times EBW^{-0.36})$ Crossbred cattle: $NRGP = EBG \times (25.4 \times EBW^{-0.25})$	445 479
Mg	5.9	35.5	Zebu cattle: $NRGMg = EBG \times (0.3466 \times EBW^{0.0113})$ Crossbred cattle: $NRGMg = EBG \times (1.0597 \times EBW^{-0.2386})$	- -
Na	6.3	37.1	Zebu cattle: $NRGNa = EBG \times (5.594 \times EBW^{-0.2998})$ Crossbred cattle: $NRGNa = EBG \times (1.977 \times EBW^{-0.058})$	- -
K	23.5	48.4	Zebu cattle: $NRGK = EBG \times (0.9463 \times EBW^{0.1216})$ Crossbred cattle: $NRGK = EBG \times (0.3418 \times EBW^{0.3200})$	- -
S	10.4	77.3	$NRGS = EBG \times (0.03 \times EBW^{0.8900})$	-
	mg/kg body weight	%	mg/d	
Cu	95.6	73.5	$NRGCu = EBG \times (1.25 \times EBW^{0.33})$	-
Co	13.5	86.8	$NRGCo = EBG \times (0.045 \times EBW^{-0.023})$	-
Cr	22.9	78.4	$NRGCr = EBG \times (0.23 \times EBW^{0.61})$	-
Fe	2,942	73.4	$NRGFe = EBG \times (10.4 \times EBW^{0.24})$	-
Mn	184.9	43.9	$NRGMn = EBG \times (0.07 \times EBW^{0.80})$	-
Mo	3.27	49.7	$NRGMo = EBG \times (0.0035 \times EBW^{0.41})$	-
Se	3.72	48.7	$NRGSe = EBG \times (1.07 \times EBW^{-0.07})$	-
Zn	334.4	66.8	$NRGZn = EBG \times (1.16 \times EBW^{0.86})$	-

[1]EBG = empty body gain (kg/d); EBW = empty body weight (kg); NRG = net mineral requirement for growth, where mineral Ca = calcium, P = phosphorus, Mg = magnesium, Na = sodium, K = potassium, S = sulfur, Cu = copper, Co = cobalt, Cr = chromium, Fe = iron, Mn = manganese, Mo = molybdenum, Se = selenium, Zn = zinc.

Therefore, considering a 400-kg Nellore bull with ADG of 1.0 kg/d, the dietary requirements of macrominerals and trace elements can be calculated as follows:

$SBW = 0.8915 \times BW^{1.0151} = 0.8915 \times 400^{1.0151} = 390.4$ kg
$EBW = 0.8126 \times SBW^{1.0134} = 0.8126 \times 390.4^{1.0134} = 344$ kg
$EBG = 0.963 \times ADG^{1.0151} = 0.963 \times 1.0^{1.0151} = 0.963$ kg

• Calcium:
Maintenance: $11.7 \times BW = 11.7 \times 400 = 4{,}680$ mg = 4.68 g/d
Growth: $EBG \times (147 \times EBW^{-0.50}) = 0.963 \times (147 \times 344^{-0.50}) = 7.63$ g/d
Total net requirements = maintenance + growth = 4.68 + 7.63 = 12.31 g/d
Dietary requirements = total net requirements/retention coefficient = 12.31/0.568 = 21.67 g/d

• Phosphorus:
Maintenance: $13.5 \times BW = 13.5 \times 400 = 5{,}400$ mg = 5.40 g/d
Growth: $EBG \times (38.6 \times EBW^{-0.36}) = 0.963 \times (38.6 \times 344^{-0.36}) = 4.54$ g/d
Total net requirements = maintenance + growth = 5.40 + 4.54 = 9.94 g/d
Dietary requirements = total net requirements/retention coefficient = 9.94/0.678 = 14.66 g/d
Ca/P ratio =21.67/14.66 = 1.48

• Magnesium:
Maintenance: $5.9 \times BW = 5.9 \times 400 = 2{,}360$ mg = 2.36 g/d
Growth: $EBG \times (0.3466 \times EBW^{0.0113}) = 0.963 \times (0.3466 \times 344^{0.0113}) = 0.36$ g/d
Total net requirements = maintenance + growth = 2.36 + 0.36 = 2.72 g/d
Dietary requirements = total net requirements/retention coefficient = 2.72/0.355 = 7.66 g/d

• Sodium:
Maintenance: $6.3 \times BW = 6.3 \times 400 = 2{,}511$ mg = 2.52 g/d
Growth: $EBG \times (5.594 \times EBW^{-0.2998}) = 0.963 \times (5.594 \times 344^{-0.2998}) = 0.94$ g/d
Total net requirements = maintenance + growth = 2.52 + 0.94 = 3.46 g/d
Dietary requirements = total net requirements/retention coefficient = 3.46/0.371 = 9.33 g/d

• Potassium:
Maintenance: $23.5 \times BW = 23.5 \times 400 = 9{,}400$ mg = 9.40 g/d
Growth: $EBG \times (0.9463 \times EBW^{0.1216}) = 0.963 \times (0.9463 \times 344^{0.1216}) = 1.85$ g/d
Total net requirements = maintenance + growth = 9.40 + 1.85 = 11.25 g/d
Dietary requirements = total net requirements/retention coefficient = 11.25/0.484 = 23.24 g/d

• Sulfur:
Maintenance: $10.4 \times BW = 10.4 \times 400 = 4{,}160$ mg = 4.16 g/d
Growth: $EBG \times (0.03 \times EBW^{0.89}) = 0.963 \times (0.03 \times 344^{0.89}) = 5.23$ g/d
Total net requirements = maintenance + growth = 4.16 + 5.23 = 9.39 g/d
Dietary requirements = total net requirements/retention coefficient = 9.39/0.773 = 12.19 g/d

• Copper:
Maintenance: $95.6 \times BW = 95.6 \times 400 = 38{,}240$ µg = 38.24 mg/d
Growth: $EBG \times (1.25 \times EBW^{0.33}) = 0.963 \times (1.25 \times 344^{0.33}) = 8.27$ mg/d
Total net requirements = maintenance + growth = 38.24 + 8.27 = 46.51 mg/d
Dietary requirements = total net requirements/retention coefficient = 46.51/0.735 = 63.28 mg/d

• Iron:
Maintenance: $2{,}942 \times BW = 2{,}942 \times 400 = 1{,}176.800$ µg = 1,177 mg/d
Growth: $EBG \times (10.4 \times EBW^{0.24}) = 0.963 \times (10.4 \times 344^{0.24}) = 40.7$ mg/d
Total net requirements = maintenance + growth = 1,177 + 40.7 = 1,218 mg/d
Dietary requirements = total net requirements/retention coefficient = 1,218/0.734 = 1,659 mg/d

Manganese:
Maintenance: 184.9 × BW = 184.9 × 400 = 73,960 µg = 73.96 mg/d
Growth: EBG × (0.07 × $EBW^{0.80}$) = 0.963 × (0.07 × $344^{0.80}$) = 7.21 mg/d
Total net requirements = maintenance + growth = 73.96 + 7.21 = 81.17 mg/d
Dietary requirements = total net requirements/retention coefficient = 81.17/0.439 = 184.9 mg/d

• **Selenium:**
Maintenance: 3.72 × BW = 3.72 × 400 = 1,488 µg = 1.49 mg/d
Growth: EBG × (1.07 × $EBW^{-0.07}$) = 0.963 × (1.07 × $344^{-0.07}$) = 0.68 mg/d
Total net requirements = maintenance + growth = 1.49 + 0.68 = 2.17 mg/d
Dietary requirements = total net requirements/retention coefficient = 2.17/0.487 = 4.46 mg/d

• **Zinc:**
Maintenance: 334.4 × BW = 334.4 × 400 = 133,760 µg = 133.8 mg/d
Growth: EBG × (1.16 × $EBW^{0.86}$) = 0.963 × (1.16 × $344^{0.86}$) = 169.6 mg/d
Total net requirements = maintenance + growth = 133.8 + 169.6 = 303.4 mg/d
Dietary requirements = total net requirements/retention coefficient = 303.4/0.668 = 454.2 mg/d

• **Cobalt:**
Maintenance: 13.5 × BW = 13.5 × 400 = 5,400 µg = 5.40 mg/d
Growth: EBG × (0.045 × $EBW^{-0.023}$) = 0.963 × (0.045 × $344^{-0.023}$) = 0.038 mg/d
Total net requirements = maintenance + growth = 5.40 + 0.038 = 5.438 mg/d
Dietary requirements = total net requirements/retention coefficient = 5.438/0.868 = 6.26 mg/d

• **Chromium:**
Maintenance: 22.9 × BW = 22.9 × 400 = 9,160 µg = 9.16 mg/d
Growth: EBG × (0.23 × $EBW^{0.61}$) = 0.963 × (0.23 × $344^{0.61}$) = 7.81 mg/d
Total net requirements = maintenance + growth = 9.16 + 7.81 = 16.97 mg/d
Dietary requirements = total net requirements/retention coefficient = 16.97/0.784 = 21.65 mg/d

• **Molybdenum:**
Maintenance: 3.27 × BW = 3.27 × 400 = 1,310 µg = 1.31 mg/d
Growth: EBG × (0.0035 × $EBW^{0.4063}$) = 0.963 × (0.0035 × $344^{0.41}$) = 0.037 mg/d
Total net requirements = maintenance + growth = 1.31 + 0.037 = 1.347 mg/d
Dietary requirements = total net requirements/retention coefficient = 1.347/0.497 = 2.71 mg/d

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11

Nutritional requirements for pregnant and non-pregnant beef cows

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INTRODUCTION

The only category that was lacking minimal knowledge about nutritional requirements of Zebu cattle is the pregnant cows. Although the importance of knowing the nutritional requirements of this category is clear, no study published prior to 2013 had quantified the nutritional requirements for Zebu cows maintenance and pregnancy. The first study designed to assess the nutritional requirements of adult Zebu cows was carried out in Brazil from 2010 to 2013, and the results form the basis of this chapter.

It is estimated that the Brazilian beef cow herd, though fluctuating, ranges from 65–70 million (ANUALPEC, 2015), resulting in a total herd of more than 210 million heads (IBGE, 2015). That is, numerically, about one-third of the Brazilian herd consists of cows, and the great majority is Zebu. As they are adult animals and are permanently in the system, the energy expenditure in the productive system and area used by these cows are fairly significant portions of the total used for beef production in Brazil. Several publications have already reported that the energy spent by the reproduction herd of beef cattle represents about 70% of the total energy spent for the entire system (Ferrell and Jenkins, 1984a; Ritchie, 1995). Something close to 50% of the energy of the system is spent on adult cow maintenance (Ferrell and Jenkins, 1984b).

We therefore needed to define references for nutritional levels for adult beef cows. Based on the current mean productive indexes of beef cattle herds in Brazil (Baruselli et al., 2012; ABIEC, 2013; Jank et al., 2014; Chiavegato et al., 2015), it is estimated that there is potential for 30–40% improvement in the production efficiency of beef calves (Gionbelli et al., 2015c), considering joint improvements in nutrition, reproduction and genetics.

Other feeding systems in use in the world (ARC, 1980; AFRC, 1993; NRC, 2000; CSIRO, 2007; INRA, 2007) base their recommendations to meet pregnant cow nutritional requirements on a few studies carried out previously or on indirect estimates and adaptations of values obtained in experiments involving other ruminant categories or species. The ARC (1980) based their recommendations in a study involving Ayrshire and Jersey cows carried out in 1975 and the AFRC (1993) did not adopt significant updating on how to calculate nutritional requirements for pregnancy. The NRC (2000) based its recommendations on studies by Calvin Ferrell and collaborators (Ferrell et al., 1976a; Ferrell et al., 1976b; Ferrell et al., 1976c) on Hereford animals, and it is one of a few experiments known in which there was comparative slaughter of pregnant cows. Furthermore, the NRC (2000) presented suggestions for adjustments based on the study by Prior and Laster (1979), which were carried out with Brown Swiss animals. The French system (INRA, 2007) published estimates for nutritional requirements during pregnancy in 1978. These recommendations were based on a study by Ferrell et al. (1976c) and a study on cattle fetus chemical composition (Cano, 1995). The recommendations for nutritional requirements during pregnancy presented by the Australian system (CSIRO, 2007) are based on the indexes made by the ARC (1980) and adjustments and adaptations of studies carried out on sheep, of which there are a greater number in the literature.

The present chapter will present the results of recent research carried out in Brazil to estimate the nutritional requirements for energy and protein for adults Zebu cows for maintenance and pregnancy. Discussions on the physiological aspects related to nutrient breakdown by pregnant cows as a function of homeorhesis, and review of the impacts of not meeting the nutritional requirements of pregnant cows on cattle progeny development are also presented

METHODOLOGY USED TO ESTIMATE THE REQUIREMENTS

It is known, clearly, that female pregnant mammals break down available nutrients to favor their offspring. This concept was first presented by Hammond (1947), who suggested that different tissues compete for circulating nutrients based on their respective metabolic rates. This idea was reinforced by the discovery of high metabolism rates in the gravid uterus as compared to the maternal body (Meschia et al., 1980). However, recent research has concentrated on the endocrine regulation of the tissues instead of competition as a general explanatory mechanism (Bauman, 2000; Mamontov, 2007). This way of thinking comes in the concept of "homeorhesis", elaborated by Bauman and Currie (1980). This concept suggests that there is simultaneous influence from multiple tissues implying extracellular mediation so that the metabolism meets the demands more coherently at levels that optimize the opportunity for the fetus to grow and survive after calving, and minimizing the excessive depletion of maternal energy and protein reserves.

Although there are mathematical models attempting to explain homeorhesis (Mamontov, 2007; Psiuk-Maksymowicz and Mamontov, 2008), their application to nutrient breakdown in pregnant cows is still far from what could be proposed to estimate nutritional requirements. It is known that there is wide interaction between maternal tissues and the gravid uterus that implies modification in the efficiency of use of the nutrients on the part of the maternal tissues. However, the base for estimating nutritional requirements for pregnant cows that will be used here is a factorial model, where requirements for maintenance, body reserve accumulation, gravid uterus growth and fetus formation do not interact but, rather, are considered additive. This methodology is similar to those used by the other nutritional systems. Therefore additional requirements will be presented for pregnancy in Zebu cows, in addition to the requirements for maintenance and body reserve accumulation. This does not mean, however, that the estimates used are not accurate. The methodology used here permits to estimate that the quantitative result of the interaction between maternal and gestation tissues is calculated as requirements for pregnancy, adding to the net accumulation in gestation tissues and the expenditure to synthesize the gestation tissues.

The base experiment of this chapter was carried out at the Federal University of Viçosa (UFV), from 2010 to 2011. (Gionbelli, 2013). Forty-nine Zebu cows, predominantly Nellore, were obtained from the UFV herd and from two other commercial herds, with the objective of representing the Brazilian beef cattle herd. These cows were used in a comparative slaughter experiment, with a design similar to that of the study carried out by Dr. Calvin Ferrell and collaborators (Ferrell et al., 1976a; Ferrell et al., 1976b; Ferrell et al., 1976c). The study estimated the nutritional requirements of pregnant cows in feed systems that use taurine cattle. A group of 17 cows was kept under the same treatment as the other 32 pregnant cows (at different feed levels), to estimate comparatively the requirements for maintenance, maternal tissue gain and pregnancy. The 32 cows were slaughtered at four different stages of pregnancy (136, 189, 239 and 269 d pregnant) to assess nutrient and energy accumulation in the gravid uterus and maternal tissues, and thus mathematical models were fitted that could be used to estimate the net requirements for pregnancy.

The concept of pregnant compound was adopted (PREG) to estimate the energy and protein accumulation rate related to pregnancy or to the maternal tissues, presented by Gionbelli et al. (2015a) and discussed in Chapter 1. The PREG represents the true quantities of components that grow directly related to pregnancy. This includes the gravid uterus less the estimated weight of the non-gravid uterus plus the growth of the mammary gland related to pregnancy. Thus, the energy and protein quantities in the total body of a pregnant cow follow the ratio:

$$CTB = MT + PREG \quad \text{Eq. 11.1}$$

where CTB = cow´s total body, MT = maternal tissues (carcass, viscera, leather, blood, head, hooves, udder, besides the non-gravid uterus less the addition of the udder related to pregnancy) and PREG = pregnant compound.

The estimates for the nutritional requirements for pregnant and non-pregnant

Zebu cows discussed next are derived from recently published studies (Gionbelli, 2013; Gionbelli et al., 2013; Gionbelli et al., 2014; Gionbelli et al., 2015a; Gionbelli et al., 2015b).

DRY MATTER INTAKE IN ADULT ZEBU COWS

In simple-stomach mammals, feed intake increases during pregnancy to coincide with the high nutritional requirements of large litters or even a single fetus. In pigs, this effect is very pronounced, to the point that fiber-rich diets are adopted to prevent excessive increases in body fat (Forbes, 2007). In ruminants, it is suggested that the females can increase voluntary feed intake in half of the gestation, but this increase is much lower than in pigs and very often is not observed (Ingvartsen and Andersen, 2000). Forbes (1996) also reported that cows and sheep tended to increase, because they were more selective, voluntary intake of feeds of higher nutritional quality when close to the end of pregnancy. However, there is a marked reduction in intake during the final weeks of pregnancy in cattle.

Ingvartsen et al. (1992) showed a table containing 20 groups of cows from nine publications, where variations were observed in intake in the last weeks ranging from 0.2% increase/week to 9.4% reduction /week. The same authors also verified that heifers reduced voluntary intake by 1.53%/week in the last 14 weeks pregnant, and this rate increased in the last two weeks, and there was an approximate 30% reduction in the five d preceding calving. The variations observed in intake during pregnancy can also be different for cow and heifers (Ingvartsen and Anderson, 2000).

Intake regulating factors in pregnant cows

Feed intake regulation by pregnant cows can present physical and physiological factors that are not considered in traditional models of feed intake regulation in ruminants (Forbes, 1980; Fisher et al., 1987). These aspects, such as the influence of the calf weight on reducing the rumen capacity, hormone regulation of pregnancy, or even the homeorhetic mechanism of using nutrients, are difficult to model and are the main causes of the variation in voluntary intake observed at this physiological stage of cattle. The various factors involved in regulating feed intake by pregnant cows include:

Physical factors: it has been suggested that reduced feed intake, observed in late pregnancy, may be caused by compression of the rumen by the growing uterus and aggravated by abdominal fat (Forbes, 2007). The displacement of the rumen as a function of fetus growth in sheep was graphically illustrated by Forbes (1968), who slaughtered ewes at different stages of pregnancy, froze the whole carcasses, and then cross-sectioned and photographed the abdomen. Forbes (1969) observed a negative relationship between the volume of ruminant content at slaughter (VR, liters) and the volume of compressible ruminal content (gravid uterus + abdominal fat, CCR, liters), in ewes fed hay, following the ratio: $VR = 10.3 - 0.37 \times CCR$. Further in the same study, the dry matter intake (DMI, kg/d) during the last two weeks before slaughter was positively related to the VR (liters) at slaughter: $DMI = 0.48 + 0.033 \times VR$. The reduction in feed intake was proportionally lower than that of the rumen volume, probably as a result of increased passage rate as a compensation factor for the reduction in ruminant volume. Later, other studies (Kaske and Groth, 1997; Gunter et al., 1990; Coffey et al., 1989) confirmed the theory that pregnancy increases the digestive passage rate in sheep, probably as a compensating factor for rumen compression by the gravid uterus.

Lagerlof (1929) reported increased quantities of abdominal fat and physical compression of the rumen by the uterus in cows. Lamberth (1969) carried out two experiments to compare the effect of pregnancy on dry matter voluntary intake, digestibility and passage rate in heifers. The two experiments were carried out using pairs of twin heifers, and one of each pair was pregnant and the other was open. The dry matter digestibility was decreased in pregnant heifers, also causing a reduction in the digestible dry matter intake. Measurements of rumen volume and passage rate did not give conclusive results.

This information gives sufficient evidence that there is a physical effect from pregnancy on reducing dry matter intake by cows and ewes in late pregnancy. But it is

unlikely that the decrease in ruminant volume is the only cause for reducing feed intake. Coppock et al. (1974) observed that reduction in dry matter intake by cows in late pregnancy was more pronounced when the diet contained high concentrate contents as compared to diets with lower contents. Therefore, it is probable that other factors are also involved in reducing intake in late pregnancy. Furthermore, it is important to observe that the effects of physical compression coincide with the changes in the endocrine factors and body reserves, mediated in response to the advance of the pregnancy and preparation for future lactation.

At the time of calving, the abdominal cavity is reduced in size due to the exit of the amniotic liquid, fetus and fetal membranes. This decrease is approximately 70 kg for dairy cows and 50 kg for beef cows. The disappearance of such a large mass from the abdominal cavity should permit rapid increase in voluntary feed intake in the first day after calving, if physical compression was the only factor that caused decrease in intake. Generally, no rapid increase in dry matter intake is observed shortly after calving, and the increase is relatively slow, even in relation to the increase in milk production (Friggens et al., 1998).

Physiological factors: several endocrine, metabolic and behavioral factors are related to variation in feed intake during pregnancy in cows. It is suggested that the main hormone acting on reducing intake is estrogen (Forbes, 2007). At the time of estrus of the cow, an estrogen peak coincides with low feed intake that in this case is temporary (Forbes, 2007). During pregnancy however, the plasma estrogen levels increase to about 300 pg/mL during the first pregnancy semester and remain stable until a month after the calving, when the levels rise to 4000-6000 pg/mL in the last d before calving. This increase in the d that proceed calving is correlated with reduction in intake.

Progesterone seems not to have a direct effect on feed intake in cattle (Ingvartsen and Andersen, 2000), but, because it blocks estrogen effects (Gagliostro et al., 1991), it may reduce the effects of this on feed intake. Bargeloh et al. (1975) administered 0.25 mg/BW/d progesterone in cows in late pregnancy and observed bigger dry matter intake in the treated cows as compared to those not treated (17.1 kg/d vs 11.7 kg/d, respectively) in the last six days pregnant. Pregnancy was also prolonged in some cows that received the progesterone doses, causing problems and hindering commercial use of some of this type of hormone infusion.

Metabolic factors: an imbalance among nutrients required by the mother and the fetus during late pregnancy can also reduce feed intake by female ruminants during this phase. Barry and Manley (1986) administered glucose and casein in the abomasum of pregnant ewes and observed increases in voluntary intake four weeks before lambing in the administered ewes. Later, there was a more pronounced reduction in intake than in the animals that did not receive glucose and casein. The authors suggested that the effect of greater intake in the administered animals caused greater prepartum reduction in intake, while for the non-infunded animals intake was limited by diet imbalance and other factors present at the end of the pregnancy.

Behavioral factors: concern and discomfort with the need to search for an adequate place for calving are also suggested as factors that reduce feed intake by pregnant cows in late pregnancy. Endocrine changes associated with calving (corticosteroids, prostaglandins, oxytocin, relaxin, etc.) may also be related (Forbes, 2007).

Dry matter intake by pregnant Zebu cows

A graphic representation of dry matter intake (DMI) by pregnant Zebu cows is shown in Figure 11.1 (Gionbelli, 2013). The effect of pregnancy on voluntary dry matter intake was assessed comparing intake of pregnant and open cows receiving a diet with high forage level (85%) for a similar period of duration. Segmented models were fitted to verify decrease in DMI after a determined period of pregnancy. Linear reduction was observed (quadratic and cubic effects were also tested) in dry matter intake in proportion to the body weight by pregnant Zebu cows ($P<0.05$) starting at 131 d pregnant (decrease of 0.0204 grams of dry matter per kg SBW for each d pregnant over 135 d). As described in the later items, for this edition of the BR-CORTE, it was chosen to consider the requirements for

pregnancy in Zebu cows after 135 d pregnant (4.5 months). Thus a model of DMI reduction as a function of day pregnant was fitted for adult Zebu cows, starting at 135 d of pregnancy. Therefore, the equations proposed to describe the DMI of pregnant Zebu cow should be:

$$DMIpreg\ (g/SBW) = DMInp - 0.02 \times (TG - 135) \quad \text{Eq. 11.2}$$

$$DMIpreg\ (kg/d) = DMInp - (SBW \times 0.00002 \times (TG - 135)) \quad \text{Eq. 11.3}$$

where: DMIpreg = dry matter intake after 135 d pregnant (in g/SBW or in kg/d), DMInp = dry matter intake in non-pregnant condition or up to 135 d pregnant (in g/SBW for Eq. 11.2 and in g/d for Eq. 11.3), TG = days pregnant and SBW = shrunk body weight (kg).

The equations presented above can be used for any herd in any situation, because they involve only fitting dry matter intake as a function of the advance of the pregnancy. There is no standardized equation with which to estimate the dry matter intake of adult non-pregnant Zebu cows that depends on the characteristics of the animal and forage quality and availability (and supplementation).

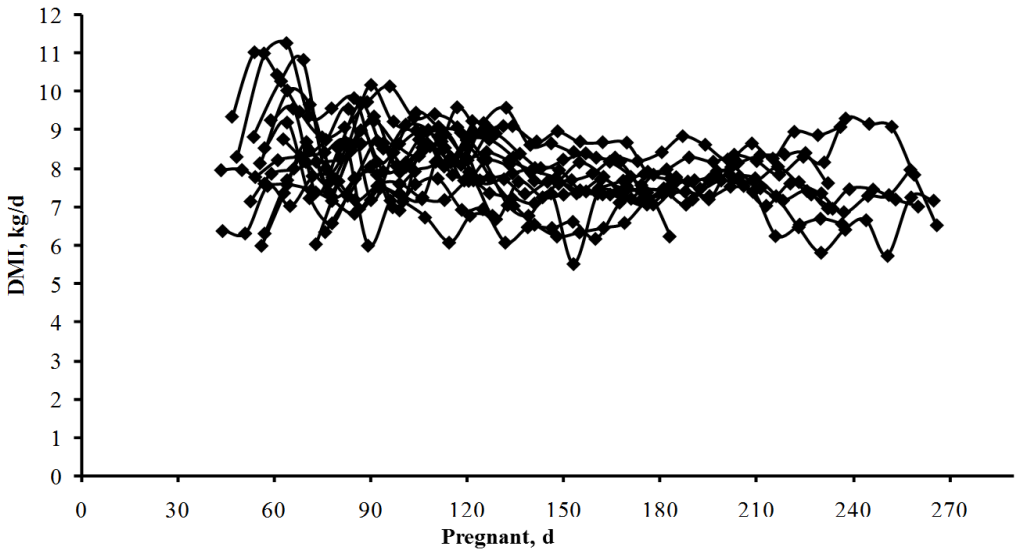


Figure 11.1 - Relationship between dry matter intake and days pregnant in Zebu cows.

REQUIREMENTS FOR MAINTENANCE

Energy requirement for maintenance

The net energy requirements for maintenance (NEm, kcal/EBWnp$^{0.75}$/d) were estimated from the ratio between heat production (HP, kcal/EBWnp$^{0.75}$/d) and metabolizable energy intake (MEI, kcal/EBWnp$^{0.75}$/d), using an exponential model, in the same way as for growing and finishing animals. The following model was obtained based on data reported by Gionbelli (2013):

$$HP = 85.9 \times \exp^{(MEI \times 0.0028)} \quad \text{Eq. 11.4}$$

The NEm value corresponds to the intercept of Eq. 11.4, representing the quantity of heat produced in absolute fasting. Further based on Eq. 11.4, the metabolizable energy requirements for maintenance (MEm, kcal/EBWng$^{0.75}$/d) are estimated, by an iterative process to equal the HP and MEI. The MEm is the point at which the heat produced by the animal is equal to the metabolizable energy consumed. Thus, the NEm and MEm values for adult Zebu cows can be obtained by the models presented below:

$$NEm\ (kcal/d) = 85.9 \times EBW^{0.75} \quad \text{Eq. 11.5}$$

$$MEm\ (kcal/d) = 120 \times EBW^{0.75} \quad \text{Eq. 11.6}$$

where EBW = empty body weight (kg).

The partial efficiency of use of metabolizable energy for maintenance (*km*) is obtained from the NEm/MEm ratio (85.9/120),

corresponding to 0.72 or 72%. Since it is very difficult to model the metabolizable energy requirements for maintenance for pregnant cows, similar to Ferrell et al. (1976c), it is assumed that the *km* does not vary among pregnant and open cows. Robinson et al. (1980) also suggested that the *km* value is similar among gestating animals and other categories.

The experiment used as base to estimate the metabolizable requirement for Zebu cows (Gionbelli et al., 2015a) was carried out with feedlot cows to ensure the experimental control necessary for a study of this type. The energy requirement estimates presented in Chapter 8 show that pastured-raised beef cattle under tropical conditions MEm 8.5% higher to those reared on feedlot. As beef cows are routinely kept on pasture in tropical conditions, an 8.5% increase is suggested in the MEm value calculated for this category (120 × 1.085):

$$MEm\ (kcal/d) = 130 \times EBW^{0.75} \qquad \text{Eq. 11.7}$$

where EBW = empty body weight (kg).

The MEm value established for open and pregnant Zebu cows in this edition of the BR-CORTE (Eq. 11.7) is equal to the MEm of a growing Zebu heifer, with 0.375 kg average daily gain (*km*, used to calculate the MEm in growing animals takes into consideration the weight gain rate – see Chapter 8). A growing heifer with 1 kg average daily gain has MEm equal to 119 kcal/EBWnp$^{0.75}$/d, a lower value than the MEm of an adult non-pregnant or pregnant cow.

Although there is evidence that requirements for maintenance (per metabolic size unit, EBW$^{0.75}$) can reach up to 50% in late pregnancy in beef cattle (Brody, 1945; Ferrell et al. 1976c; NASEM, 2016), such an increase has not been directly considered in comparative slaughter experiments carried out on pregnant cows (Ferrell et al. 1976c; Gionbelli et al. 2015b). In these cases, the additional energy spent on maintenance relative to pregnancy is quantified in the calculation of the nutritional requirements for pregnancy. Thus it becomes possible to calculate separately the nutritional requirements in a factorial manner, for maintenance, maternal tissue accumulation and pregnancy, as previously discussed.

When compared to the MEm for lactating Zebu cows (135.4 kcal/EBW$^{0.75}$/d; see Chapter 12), the MEm value presented for open or pregnant cows is 4% lower. A compilation of the of studies carried out by the NASEM (NASEM, 2016) suggests that the maintenance requirement for lactating cows is about 20% higher (10 to 49% variation) than for beef cattle breed non-lactating cows.

The MEm values estimated for open and pregnant Zebu cows are about 5% lower than the MEm values estimated for taurine cows (Angus-Hereford crossbreds) of the same category (Table 11.1). Comparing to the ME values estimated for large size (continental) taurine cows, the ME values of open and non-lactating Zebu cows are about 14% lower, for cows of the same weight (considering data by C.L. Ferrell and T.G. Jenkins, unpublished, quoted in the NASEM, 2016).

Table 11.1 - Metabolizable energy requirements for maintenance, estimated for Zebu and taurine beef cows with 450 and 600 kg body weight, respectively

Sub-species	BW, kg	SBW, kg	EBW, kg	EBW$^{0.75}$, kg	MEm, Mcal/d	%
Bos taurus indicus	450	438[1]	397[3]	89[5]	11.6[5]	94[7]
Bos taurus taurus	450	432[2]	368[4]	98[6]	12.3[6]	100
Bos taurus indicus	600	589[1]	536[3]	111[5]	14.5[5]	95[7]
Bos taurus taurus	600	576[2]	490[4]	121[6]	15.3[6]	100

BW = body weight, SBW = shrunk body weight, EBW = empty body weight, MSU = metabolic size unit and MEm = metabolizable energy requirement for maintenance; [1]SBW = 0.8084 × BW$^{1.0303}$ (see Chapter 1); [2]SBW = 0.96 × BW (NRC); [3]EBW = 0.8424 × SBW$^{1.0122}$ (see Chapter 1); [4]EBW = 0.851 × SBW (NRC); [5]MEm = 1.30 × EBW$^{0.75}$ / 1000; [6]MEm = 1.26 × BW$^{0.75}$ / 1000. for Angus-Hereford cow data by C.L. Ferrell and T.G. Jenkins, unpublished, quoted in the NRC (2000); [7]As % of taurine cow MEm.

Protein requirements for maintenance

Similar to the energy requirements for maintenance, the protein requirements for maintenance were calculated from the database of open and non-lactating cows in the experiment by Gionbelli (2013). The metabolizable protein requirement for maintenance (MPm, g/d) was obtained from the relationship among metabolizable protein intake (MPI, g/d), protein retained in maternal tissues (RP_{MT}, g/d) and metabolic shrunk body weight ($SBW^{0.75}$, kg), as shown in Eq. 11.8. Based on Eq. 11.8, the MPI necessary to maintain the protein body content stable is equal to 3.93 grams per kg $SBW^{0.75}$ that is the MPm value for open and non-lactating Zebu cows. This value is very close to the MPm value recommended for growing animals raised on pasture (see Chapter 9, MPm, g/d = 3.9 × $SBW^{0.75}$). Due to the small numerical difference, the same MPm value is also suggested for Zebu cows (Eq. 11.9).

$$MPI\ (g/d) = 3.93 \times SBW^{0.75} + 2.63 \times RP_{MT} \quad \text{Eq. 11.8}$$

$$MPm\ (g/d) = 3.9 \times SBW^{0.75} \quad \text{Eq. 11.9}$$

where MPI = metabolizable protein intake (g/d), SBW = shrunk body weight (kg) and RP_{MT} = retained protein in the maternal tissues (g/d).

REQUIREMENTS FOR MATERNAL TISSUE GAIN

The nutritional requirements for maternal tissue gain were estimated according to the daily maternal tissue accumulation rate (ADG relative to maternal tissue - see Chapter 1) and the body condition score (BCS). Therefore the estimates can be used for herds with variable weights at maturity. In spite of representing a parameter of a set of subjective assessments, the BCS is a tool with great practical and proven significance related to the variations in the body composition of adult cows (NRC, 2000).

It should also be pointed out that the requirements for weight gains of pregnant and open cows are considered similar, although there may be an effective homeorhetic metabolism (Hammond, 1947). However, Gionbelli et al. (2015b) did not observe effect of pregnancy on the dynamic of maternal tissue deposition (P = 0.388), indicating that quantitatively, the composition of maternal tissue gain in pregnant and open cows is similar. This sustains the use of the factorial model to calculate the nutritional requirements of Zebu cows, in which requirements for maintenance, maternal tissue gain and pregnancy are calculated independently and added to calculate the total requirements.

Energy requirements for gain

The net energy nutritional requirements for adult cow weight gain (NEg, Mcal/d), are calculated by the following equation:

$$NEg\ (Mcal/d) = 3.82 \times EBGnp^{1.07} \times BCS^{0.35} \quad \text{Eq. 11.10}$$

where EBGnp = non-pregnant empty body weight gain (kg), that considers the weight gain for maternal tissues of the cow (for open cows it is equal to the EBG) and BCS = body condition score (scale 1 to 9).

Based on Eq. 11.10, the net energy required for weight gain of two adult cows, with 5 BCS, but with different weights (ex.: 500 and 600 kg) is the same, because it is assumed that the body composition of both is proportional to the BCS and if the weight of the same BCS is different, it means that the mature weight of its herd is different. This occurs when the NEg is calculated based on the variations in the body composition and, consequently on the gain composition. The exponential 1.07 of the EBG means that the gain composition varies as a function of the daily reserve accumulation rate. For higher ADG rates, a higher proportion of fat will be deposited and consequently, the NE will be greater for each kilo of gain. An example of applying Eq. 11.10 is shown in Table 11.2.

Table 11.2 - Net energy requirements for weight gain of adult cows with different body condition scores and different weight gain rates

BCS	ADG, kg	EBG, kg[1]	NEg, Mcal/d	NEg, Mcal/kg EBG
3	0.2	0.19	0.94	4.99
3	0.5	0.48	2.54	5.33
3	0.8	0.77	4.23	5.51
5	0.2	0.19	1.12	5.97
5	0.5	0.48	3.04	6.37
5	0.8	0.77	5.06	6.59
7	0.2	0.19	1.26	6.71
7	0.5	0.48	3.41	7.17
7	0.8	0.77	5.69	7.41

BCS = body condition score, ADG = average daily gain, EBG = empty body weight gain and NEg = net energy requirement for weight gain; [1]EBG = $0.963 \times ADG^{1.0151}$ (see Chapter 1).

The energy concentration in the weight gain for adult cows presented in Table 11.2 is usually larger for growing animals (Chapter 8) for BCS ≥ 4. Cows with BCS < 4 have a considerable proportion of lean tissue in the gain composition. This fact occurs probably because although they have theoretically reached physiological maturity, the quantity of skeletal muscle tissue in the carcass is below the usual, due to mobilization to meet the requirements of pregnancy, lactation or even maintenance. There is evidence of large skeletal muscle tissue mobilization in the carcass of adult female ruminants to meet the high demand for amino acids by the placenta in the final stages of pregnancy (Bell et al., 2000; Bell and Ehrhardt, 2000; Bell et al., 2005).

The net energy requirements for reserve accumulation presented here for Zebu cows are similar to those for taurine cows presented by the NRC/NASEM System (NASEM, 2016), considering the BCS variations. According to the NASEM (2016), an adult cow with BCS = 5, regardless of weight at maturity, requires 6.38 Mcal for each kg EBG. The data presented in the present edition of the BR-CORTE for Zebu cows show that an adult Zebu cow with BCS = 5, regardless of weight at maturity, requires between 5.97 and 6.69 Mcal per kg EBG, depending on the weight gain rate (in this case, 5.97 Mcal/kg EBG for EBG = 0.2 kg/d and 6.69 Mcal/kg EBG for EBG = 1.0 kg/d). This variation in the gain composition as a function of the gain rate, however, is not considered by the NASEM System.

The partial efficiency for conversion of metabolizable energy to net energy (*kg*) for weight gain suggested for adult Zebu cows is 0.53 (Gionbelli et al., 2015b). Thus the metabolizable energy requirements for maternal tissue weight gain (MEg, Mcal/d) for adult Zebu cows can be calculated according to Eq. 11.11:

$$MEg\ (Mcal/d) = NEg/0.53 \qquad \text{Eq. 11.11}$$

where NEg = net energy requirement for gain (Mcal/d).

Protein requirements for gain

The net protein requirements for gain for adult cows (NPg, g/d) were estimated by a linear model that takes into consideration the EBG and NEg. The BCS effect was also contemplated on the protein composition in the gain, that decreases as the BCS increases. The following equation describes the NPg:

$$NPg\ (g/d) = 307 \times EBGnp - 34 \times NEg \qquad \text{Eq. 11.12}$$

where EBGnp = non-pregnant empty body weight gain (kg) and NEg = net energy requirement for gain (Mcal/d).

An example of applying Eq. 11.12 is presented in Table 11.3. Comparison of the NPg of an adult Zebu cow and a growing heifer (350 kg) with average daily gain of 0.5 kg/d shows that the mean NPg value of a cow with BCS = 5 is about 40% lower than that of a growing Zebu heifer. This fact is explained by the variation in the gain composition, because growing heifers have a larger proportion of

lean tissue gain than adult cows in average BCS. Further, Eq. 11.12 and Table 11.3 show that the larger the BCS, the smaller the proportional daily protein gain that reaches negligible values with BCS > 6.

Table 11.3 - Net protein required for weight gain of adult cows with different body condition scores and different weight gain rates

BCS	ADG, kg	EBG, kg[1.]	NPg, g/d	% of Protein in the EBG
3	0.2	0.19	26	13.7
3	0.5	0.48	60	12.6
3	0.8	0.77	92	12.0
5	0.2	0.19	20	10.4
5	0.5	0.48	43	9.0
5	0.8	0.77	64	8.3
7	0.2	0.19	15	7.9
7	0.5	0.48	30	6.3
7	0.8	0.77	42	5.5

BCS = body condition score, ADG = average daily gain, EBG = empty body gain and NPg = net protein required for weight gain; [1.]EBG = $0.963 \times ADG^{1.0151}$ (see Chapter 1).

The efficiency of use of absorbed proteins (k) is used to convert the net protein required for maternal tissue accumulation to metabolizable protein requirements that for adult Zebu cows is 0.474. Thus the metabolizable protein required for maternal tissue weight gain (MPg, g/d) for adult Zebu cows can be calculated according to Eq. 11.13:

$$MPg\ (g/d) = NPg/0.474 \qquad \text{Eq. 11.13}$$

where NPg = net protein required for gain (g/d).

REQUIREMENTS FOR PREGNANCY

The nutritional requirements for pregnancy in the current edition of the BR-CORTE were estimated based on the only comparative slaughter experiment using pregnant and open Zebu cows (Nellore) carried out to date (Gionbelli, 2013; Gionbelli et al., 2015b). To estimate the quantities of energy and protein retained in constituents related to pregnancy, the compound pregnancy or pregnant compound concept (PREG) was adopted. The PREG concept was presented by Gionbelli et al. (2015a) and also described in Chapter 1 of the BR-CORTE. Based on the PREG, the quantities of energy and protein used to calculate the net requirements for pregnancy are those truly related to the pregnancy, which include: the gravid uterus minus the non-pregnant uterus (estimated) and the addition of the udder relative to the pregnancy. Thus the quantities of energy and protein considered as maternal tissues were those present in the carcass, internal organs, blood, head, limbs, non-pregnant udder and non-pregnant uterus. That is, the quantities of energy and protein retained in the maternal constituents or the compound pregnancy followed the same guidelines used for the weight of these compartments (described in the Chapter 1). The PREG concept did not address, however, the possible effect of pregnancy that makes maternal body components such as bones, skeletal muscular tissue, adipose tissue and internal organs vary. These variations occur as a function of the homeorhetic effect of the pregnancy (Hammond, 1947), in which peripheral tissues and organs can work to support the growth and metabolism of an organ, tissue or priority system. Such interaction is extremely difficult to model. In the study by Gionbelli et al. (2015b), however, significant evidence was not observed of the dynamic of maternal tissue deposition (variations in the gain composition of maternal tissues of pregnant and open cows).

Energy requirements for pregnancy

The equation used in the present edition of the BR-CORTE to describe the net energy and tissue growth requirements related to pregnancy in pregnant Zebu cows was created from the first derivate of a potency-type model between time pregnant and energy accumulation in PREG. Later the equation was adapted to contemplate

variable calf weights at birth (CBW, in kg), so that it can be applied to herds with different phenotypes. Therefore, the net energy requirements for pregnancy (NEpreg, Mcal/d) for adult Zebu cows can be calculated by the following equation:

$$NEpreg(Mcal/d) = \frac{CBW \times 0.000000793 \times TG^{3.017}}{1000}$$

Eq. 11.14

where CBW = mean weight of the calves in the herd at calving (kg) and TG = days pregnant.

A potency-type model was used instead of a logistic model (used to estimate the gravid uterus weight in Chapter 1) to make it easier to apply the estimates because it presents non-significant differences in the estimated values. Compared to the NEpreg requirements adopted by the NRC System (NASEM, 2016) for pregnancy with the same estimated calving weight, the requirements estimated for gestation in Zebu cows are about 30% lower (Figure 11.2).

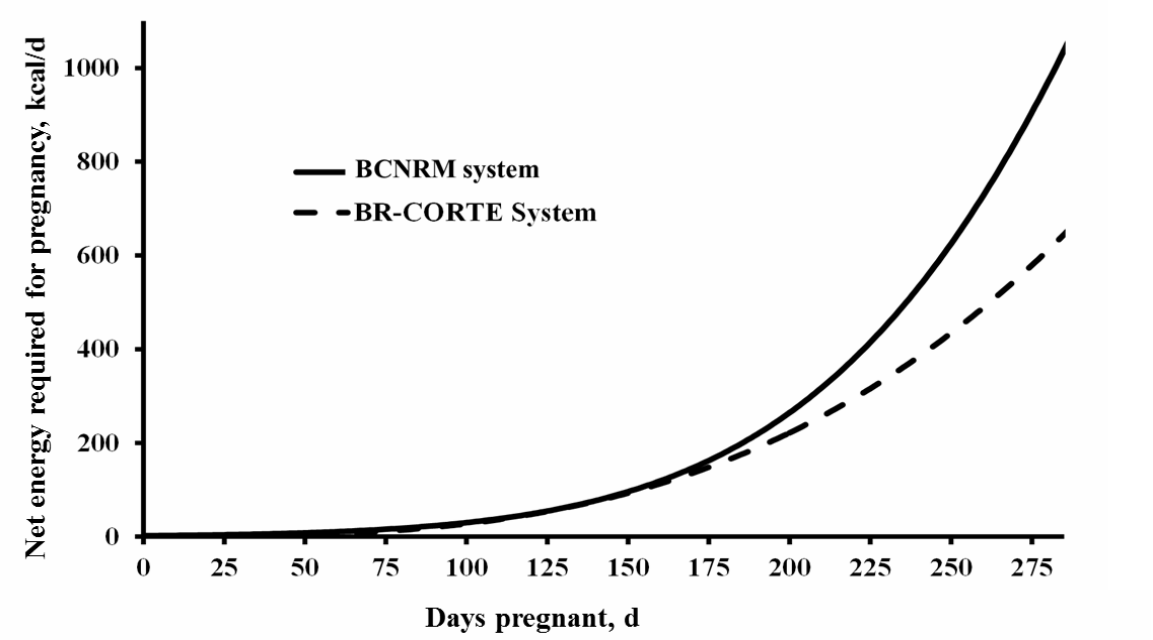


Figure 11.2 - Net energy requirements for pregnancy of an Angus-Hereford cow carrying a calf with estimated 32 kg calving weight (continuous line, NASEM, 2016) and of a Zebu cow carrying a calf with estimated 32 kg calving weight (dotted line, BR-CORTE, 2016).

To convert the NEpreg requirement to the metabolizable energy requirement for pregnancy (MEpreg, Mcal/d), the NEpreg value should be divided by the efficiency of use of the metabolizable energy for pregnancy (*kpreg*), for which Gionbelli et al. (2015b) reported a value of 0.12. The *kpreg* value of 12% is fairly close to the average value of 14% obtained by Ferrell et al. (Ferrell et al., 1976c) for taurine cow gestation and also close to the value of 13% adopted by the NASEM System (based on a mean of results from studies involving sheep and cattle). Thus MEpreg should be calculated as follows:

MEpreg (Mcal/d) = NEpreg/0.12 Eq. 11.15

where NEpreg = net energy requirement for pregnancy (Mcal/d).

Considering a Zebu cow with 500 kg BW in the last week pregnant (TG = 285) carrying a calf with 32 kg estimated calving weight, the metabolizable energy requirements for maintenance and pregnancy correspond, respectively to 12.6 and 5.4 Mcal/d. That is, at the maximum of nutritional requirements for pregnancy, the MEpreg value can reach 43% of the MEm value, considering a medium-sized cow. In small sized cows the metabolizable energy requirement for pregnancy can be greater than 50% of the maintenance requirement. Considering the last 90 d pregnancy, the average

metabolizable energy requirement for pregnancy of a Zebu cow with 500 kg BW carrying a calf with 32 kg estimated calving weight is 3.4 Mcal/d, which corresponds to 28% of its maintenance requirement. That is, a 28% increase is considered necessary in the maintenance requirements for a cow of 500 kg BW to maintain a stable BCS in the last 90 d of pregnancy.

Taking as base Eq. 11.14 and Eq. 11.15, by iteration, it is observed that the MEpreg requirement becomes larger than 5% of the MEm at 140 d pregnant, when MEpreg = 0.63 Mcal/d (considering a cow with 500 kg BW carrying a calf with estimated 32 kg calving weight and MEm = 12.6 Mcal/d).

Protein requirements for pregnancy

A potency-type model was adopted in this edition of the BR-CORTE to estimate the net protein requirements for pregnancy in Zebu cows, similar to that described in Eq. 11.14 to estimate the net energy requirements for pregnancy.

$$NPpreg\ (g/d) = CBW \times 0.0000001773 \times TG^{2.945} \quad \text{Eq. 11.16}$$

where CBW = mean calf birth weight of the herd (kg) and TG = days pregnant.

The Figure 11.3 presents a comparison of the NPpreg values for taurine and Zebu cows carrying calves of the same estimated calving weight. To estimate the metabolizable protein requirement for pregnancy (MPpreg, g/d), the NPpreg value should be divided by the partial efficiency of use of the protein absorbed for pregnancy, which for adult Zebu cows is 0.474. Thus, the metabolizable protein requirement for pregnancy can be calculated as:

$$MPpreg\ (Mcal/d) = NPpreg/0.474 \quad \text{Eq. 11.17}$$

where NPpreg = net protein requirement for pregnancy (g/d).

The metabolizable protein requirement for pregnancy calculated according to Eq. 11.16 and Eq. 11.17 for a 500 kg Zebu cow carrying a calf with 32 kg estimated calving weight, at 285 d pregnant, is 203 g/d, that corresponds to 50% of the protein requirement for maintenance of the same cow (MPm = 405 g/d). Considering the last 90 days of pregnancy, the mean MPpreg requirement for the same cow is 143 g/d, which corresponds to an average increase in protein requirement of 35%, in comparison to maintenance (not considering maternal tissue gain). These values are representative of the great increase in protein requirements as a function of days pregnant. The utero-placental and fetal metabolism rates in late pregnancy are very high (Battaglia and Meschia, 1988; Bell et al., 2005). Previous studies reported a great increase in the demand for glucose and amino acids by the placenta of ruminants during pregnancy (McNeill et al., 1997; Freetly and Ferrell, 1998, 2000). Although little is known about the breakdown of amino acids for pregnancy, it is estimated that for female ruminants in late pregnancy fed 110 to 140% of the protein requirements for pregnancy, about 80% of the digested protein passes through the gravid uterus (Bell and Ehrhardt, 1998). In female ruminants fed protein quantities close to or below the requirements for pregnancy, the levels of circulating amino acid necessary for good pregnant status are maintained by mobilizing skeletal muscle tissue (Bell and Ehrhardt, 2000). There is evidence of great maternal skeletal muscle tissue mobilization to meet the pregnancy requirements when the diet protein requirements are not met (McNeill et al., 1997).

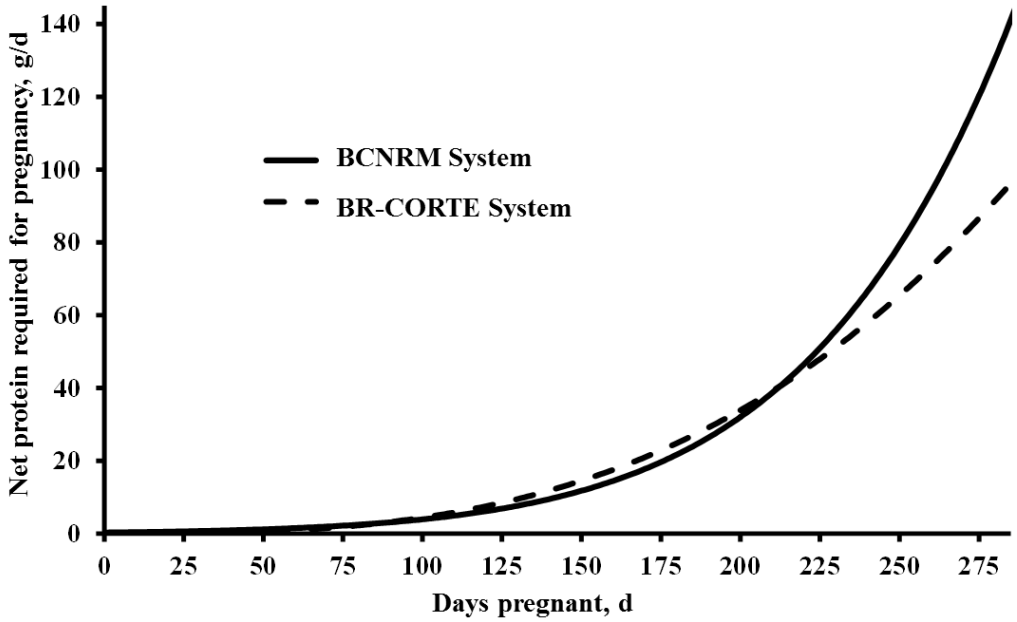


Figure 11.3 - Net protein requirements for pregnancy of an Angus-Hereford cow carrying a calf with estimated 32 kg calving weight (continuous line, NASEM, 2016) and a Nellore cow carrying a calf with estimated 32 kg calving weight (dotted line, BR-CORTE, 2016).

MEETING GESTATIONAL REQUIREMENTS AND THE IMPACTS ON OFFSPRING

In addition to the discussion above, meeting, or not, the nutritional requirements for gestation can alter the development course of the offspring, impacting on its performance during postnatal life. Seasonal variation in pasture quantity and quality is a key factor reducing production efficiency. Consequently, pregnant cows reared on pasture are frequently submitted to variations in forage offer and quality especially in the dry season. To reduce this problem, some producers look for different supplementation strategies that are usually restricted to late gestation that is indicated as the main stage at which feed restriction of the dam can affect calf development, because nutrient capturing by the fetus becomes qualitatively important in the second half of the pregnancy.

However, feed restriction during early pregnancy also causes decrease in muscle and adipose tissue and calf performance, even if decreased weight and size are not observed at calving (Wu et al., 2006). This occurs as the result of specific changes in mammals during the intra-uterine development that alters development quantitatively and/or qualitatively with results that persist throughout the life of the individual. Based on this premise, studies have been carried out to understand the processes involved in tissue growth and development, since beef animal production aims to maximize their performance and muscular growth along with adequate fat deposition (Table 11.4). This understanding makes it feasible to adopt feed strategies during the different pregnancy stages that may result in increased offspring performance.

In the fetal phase, the skeletal muscle has less priority in nutrient participation compared to vital organs such as the brain and heart. In this way is, in challenging situations to the fetus during its development, the skeletal muscle tissue becomes vulnerable to the mother's nutritional deficiency. The fetal phase is critical for muscle development, because there is no increase in the number of muscle cells after calving. Muscle fiber formation is called myogenesis, a process in which multipotent mesenchymal cells are converted to muscle cells. Muscle fibers are formed from two events at different times. First, during embryo development, the primary myofibers are formed, a process that extends through the first two months of pregnancy (Russell and Oteruelo, 1981). These myofibers are used as support for later secondary

myofiber formation, that occurs during the fetal phase and that contributes most to muscle mass increase in the pre-natal phase. However, most of the muscle fibers are formed between the second and eighth month of pregnancy and decrease in muscle fiber formation during this stage of fetal development causes persistent negative physiological effects in the animal during the postnatal stage (Zhu et al., 2006).

Considering that muscle cells such as adipocytes and fibroblasts are derived from the same non-differentiated mesenchymal cell pool, maternal nutrition during pregnancy has been reported as one of the key factors that affects myogenesis and consequently fetal muscle growth and development (Wu et al., 2006). Pregnancy nutrition causes modifications in the cell signaling pathway and can direct the non-differentiated mesenchymal cell pool to damage muscle cell formation by forming muscle cells, adipocytes or fibroblasts (Duarte et al., 2014).

In this way, variations in meeting the dam's nutritional requirements can be used to maximize skeletal muscle tissue development in detriment to adipose and connective tissue formation. Similarly, if it is of interest to produce animals with greater potential for body fat deposition, intra-uterine intervention can be used by gestational nutrition to maximize adipocyte development so that the animal has bigger deposition of this tissue in the postnatal phase in detriment to skeletal muscle tissue deposition.

It is pointed out that the pregnant period when the dam is not submitted to nutritional stress is crucial for programming the muscle development of the offspring. From knowledge of when muscle cell development is priority during the fetal stage will inform the time when the diet should be manipulated to maximize this tissue formation in the fetus. Similarly, if there is interest in forming more adipogenic cells to enhance fat deposition by the animal, knowledge of when there is maximum adipocyte formation will enable intervention in the development via maternal nutrition to maximize the formation of this tissue. Recent studies have shown that adipogenesis in ruminant animals starts at the same time as secondary myogenesis in midgestation (Muhlhausler et al., 2007). Thus, adopting adequate dam nutrition during pregnancy can result in a greater number of adipocytes, as a function of the increase in mesenchymal cell damage with adipogenesis, resulting in a larger quantity of intramuscular fat in the offspring.

Finally, the evidence found to date should further be emphasized that the meeting or not of the dam's nutritional requirements during pregnancy can affect the energetic metabolism of the animal during the postnatal phase. Studies have shown that fetuses of overfed ewe dams (150% NRC recommended values) presented lower activity of the main signaling pathway for the regulation of energetic metabolism in skeletal muscle tissue (known as the AMPK signaling pathway) compared to fetuses of dams receiving 100% maintenance requirements according to NRC recommendations (Zhu et al., 2008). This fact leads us to believe that, due to the possibility of perpetuating the effect throughout postnatal life, these animals could present altered growth efficiency due to changes in energy metabolism.

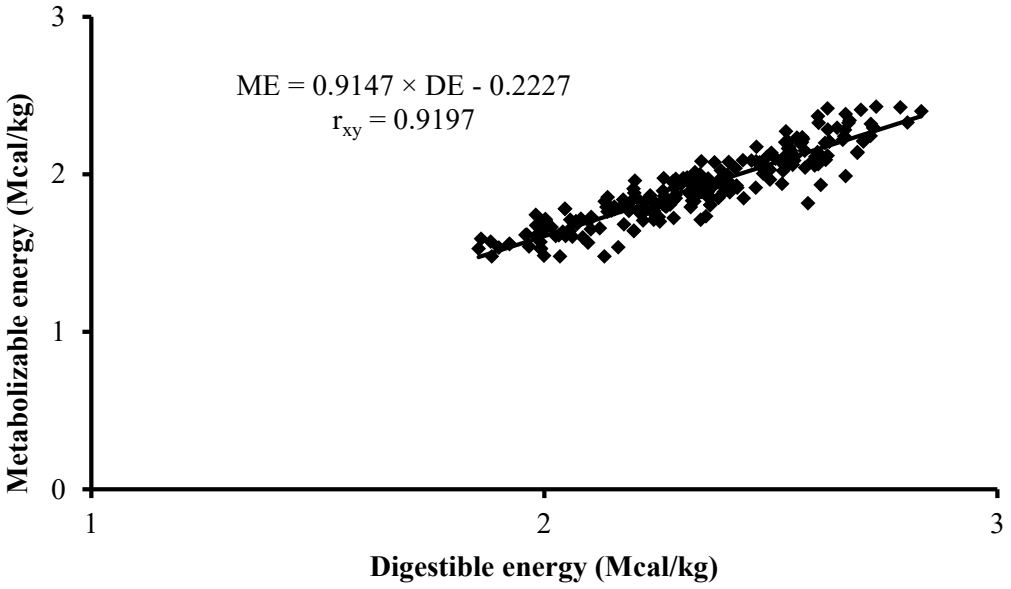


Figure 11.4 - Metabolizable energy and digestible energy ratio in adult Zebu cows (Gionbelli et al., work in progress).

Table 11.4 - Selection of scientific studies published in the last years that used ruminant animals as biological models and demonstrated alterations in fetal and/or offspring skeletal muscle development as a function of whether or not the dam's nutritional requirements were met during pregnancy

Reference	Relevant observations
Raja, JS. et al. Restricted maternal nutrition alters myogenic regulatory factor expression in satellite cells of ovine offspring, *Animal*, 2016. DOI: 10.1017/S1751731116000070	Supplying 50% of the dam maintenance requirements during gestation reduced the expressions of myogenic regulation factors in satellite cells isolated from fetal skeletal muscle tissue.
Reed, S. et al. Poor maternal nutrition inhibits muscle development in ovine offspring. *Journal of Animal Science and Biotechnology*, 2014. DOI: 10.1186/2049-1891-5-43	Supplying 60% or 140% of the dam maintenance requirements during gestation harmed offspring skeletal muscle growth
Duarte, MS. et al. Maternal overnutrition enhances mRNA expression of adipogenic markers and collagen deposition in skeletal muscle of beef cattle fetuses, *Journal of Animal Science,* 2014. DOI: 10.2527/jas.2014-7568	Supplying 140% of the dam maintenance requirements during gestation did not alter the fetal skeletal muscle development. However, the expression increased of fetal intramuscular adipogenesis markers and collagen content.
Peñagaricano, F. et al. Maternal nutrition induces gene expression changes in fetal muscle development and adipose tissues in sheep, *BMC Genomics*, 2014. DOI: 10.1186/1471-2164-15-1034	Supplying diets to dams containing different crude protein levels from mid to late gestation caused alterations in the expressions of genes involved in fetal skeletal muscle and adipose tissue development.
Yan et al. Maternal obesity downregulates microRNA let-7g expression, a possible mechanism for enhanced adipogenesis during ovine fetal skeletal muscle development, *International Journal of Obesity*, 2013. DOI: 10.1038/ ijo.2012.69	Supplying 150% of the dam´s nutritional requirements during gestation altered the expression of microRNA's favoring intramuscular fat deposition in the offspring.
Huang, Y. et al. Maternal obesity enhances collagen accumulation and cross-linking in skeletal muscle of ovine offspring, *PLoS One*, 2012. DOI: 10.1371/ journal.pone.0031691	Supplying 150% of the dam´s nutritional requirements during gestation caused greater intramuscular collagen deposition and quantity of cross-linking present in the collagen molecule.
Yan, X. Maternal obesity-impaired insulin signaling in sheep and induced lipid accumulation and fibrosis in skeletal muscle of offspring, *Biology of Reproduction*, 2011. DOI: 10.1095/biolreprod. 110.089649	Supplying 150% of the dam´s energy requirements from two months before gestation until offspring weaning diminished the signal pathway of insulin in the skeletal muscle tissue and increased fibrogenesis and intramuscular fat deposition.

DIET REQUIREMENTS AND PRACTICAL CONSIDERATIONS FOR GESTATIONAL NUTRIENT REQUIREMENTS

Diet energy requirements for open and pregnant cows

The total metabolizable energy requirements (MEtotal, Mcal/d) for adult Zebu pregnant and open cows are represented by the sum of the requirements for maintenance, maternal tissue gain and gestation, as follows:

Open cows
MEtotal = MEm + MEg Eq. 11.18

Pregnant cows
MEtotal = MEm + MEg + MEpreg Eq. 11.19

where MEm = metabolizable energy requirement for maintenance (Mcal/d), MEg = metabolizable energy requirement for maternal tissue gain (Mcal/d) and MEpreg = metabolizable energy requirement for pregnancy (Mcal/d).

To convert the metabolizable energy requirements to the digestible energy requirements for adult Zebu cows, when the energy concentration of the diet (or only the forage, for pasture-raised cows without supplementation) is known (Mcal DE/kg or TDN) the first three equations below can be used (Eq. 11.20, Eq. 11.21, or Eq. 11.22). When the energetic concentration of the diet is not known, Eq. 11.23 should be used:

$$[ME] = 0.9147 \times [DE] - 0.2227 \quad \text{Eq. 11.20}$$

$$[DE] = \frac{0.2227 + [ME]}{0.9147} \quad \text{Eq. 11.21}$$

$$ME / DE = 0.65 + 0.44 \times TDN - 0.24 \times TDN^2 \quad \text{Eq. 11.22}$$

$$DE = ME / 0.82 \quad \text{q. 11.23}$$

where [ME] = metabolizable energy concentration (Mcal/kg), [DE] = digestible energy concentration (Mcal/kg), ME = metabolizable energy (Mcal/d), DE = digestible energy (Mcal/d) and TDN = total digestible nutrients (in centesimal scale, from 0 to 1).

Equations Eq. 11.20 and Eq. 11.21 are derived from the ME and DE ratio obtained in diets of pregnant and open adult Zebu cows (Figure 11.4). Eq. 11.22 is a variation on the previous equations, considering 1 kg de TDN = 4.4 Mcal of DE. Eq. 11.23 represents the standard value of the DE to ME conversion efficiency used historically by the feeding systems (NASEM and BR-CORTE). For adult Zebu cows, the coefficient of 0.82 represents, according to Eq. 10.23, a diet with 55% TDN. The ratio presented in Figure 10.4 does not differ greatly from that obtained by Galyean et al. (2016) for growing and finishing *Bos taurus taurus* cattle (ME = 0.9611 × DE – 0.2999).

To convert the total digestible energy requirements to diet energy requirements, represented by TDN, the DEtotal value should be divided by 4.4, considering the relationship 1 kg TDN = 4.4 Mcal of DE.

Protein diet requirements for pregnant and open cows

The total metabolizable protein requirements (MPtotal, g/d) for adult Zebu pregnant or open cows are represented by the sum of the requirements for maintenance, maternal tissue gain and pregnancy, as follows:

Open cows
MEtotal = MPm + MPg Eq. 11.24

Pregnant cows
MPtotal = MPm + MPg + MPpreg Eq. 11.25

where MPm = metabolizable protein requirement for maintenance (g/d), MPg = metabolizable protein requirement for maternal tissue gain (g/d) and MPpreg = metabolizable protein requirement for pregnancy (g/d).

The same procedures described for growing and finishing animals are used to convert the total metabolizable protein requirements to rumen degradable protein (RDP), rumen undegradable protein (RUP) and total crude protein (CP) requirements, (see Chapter 9). In this sense, the crude protein requirements are represented by the sum of the RDP and RUP requirements.

In the present edition of the BR-CORTE, the RDP diet requirements are considered equal to the daily microbial crude protein production (MCP), because the estimates of N that returns to the rumen by N recycling could compensate quantitatively the inefficiency of degradable protein conversion in the rumen to MCP,

estimated at 10% in the previous editions of the BR-CORTE. Thus we have that RDP = MCP. Daily MCP production is estimated by the equation below (presented in chapter 3 of this edition of the BR-CORTE):

$$MCP\ (g/d) = -53.07 + 304.9 \times CPI + 90.8 \times TDNI - 3.13 \times TDNI^2 \quad \text{Eq. 11.26}$$

where: CPI = crude protein intake (kg/d) and TDNI = TDN intake (kg/d). In this equation, the TDNI should be the diet requirement of TDN in (kg/d) calculated as described in the previous item.

The RUP (kg/d) diet requirements for adult Zebu open and pregnant cows can be calculated by the equation below (see Chapter 9):

$$RUP\ (g/d) = (MPtotal - (MCP \times 0.64))/0.80 \quad \text{Eq. 11.27}$$

where MPtotal = total metabolizable protein requirement (g/d) and MCP = daily microbial crude protein production (g/d).

Practical considerations for nutritional requirements for pregnancy

Based on the models used in this chapter to estimate the energy and protein requirements for pregnancy, it was observed that the quantities required to support growth of the gravid uterus constituents during early gestation are small. Quantitatively, the metabolizable energy and protein requirements for pregnancy represent more than 5% of the metabolizable energy and protein requirements for maintenance starting at 141 and 131 d of gestation, respectively (considering a cow with 500 kg BW carrying a calf with estimated 32 kg calving weight). To facilitate the practical application of the requirements proposed here for pregnancy, it is important to consider the requirements for pregnancy starting at the time when they represent a significant percentage of the cow diet. Thus, for the present edition of the BR-CORTE, it was considered that the requirements for pregnancy are significant from the practical point of view after 135 d of gestation (4.5 months pregnant) when the energy and protein requirements represent, on average, increase over the maintenance requirements (4.5% for energy and 5.5% for protein). This point was chosen because it is the time when the energy or protein requirements come to represent more than 5% of the maintenance requirements. Before 135 d pregnant, the requirements for pregnancy can be considered insignificant and do not need to be considered. Thus the protein and energy requirements for gestation are considered significant in the 135 d of gestation (considering a 290 d pregnant in Zebu).

The requirements for pregnancy and how they should be considered in the nutritional programs applied to pregnant cows vary throughout pregnancy. It is known that in practice it is not feasible to adjust the diet of pregnant cows in short periods of time (weekly, for example). Thus a step-type scheme is proposed to meet the gestation requirements, containing three stages, divided according to the variations in the nutritional requirements for pregnancy. These three stages, called early, mid and late pregnancy have distinct durations and are best visualized in Figure 11.5 and Table 11.5

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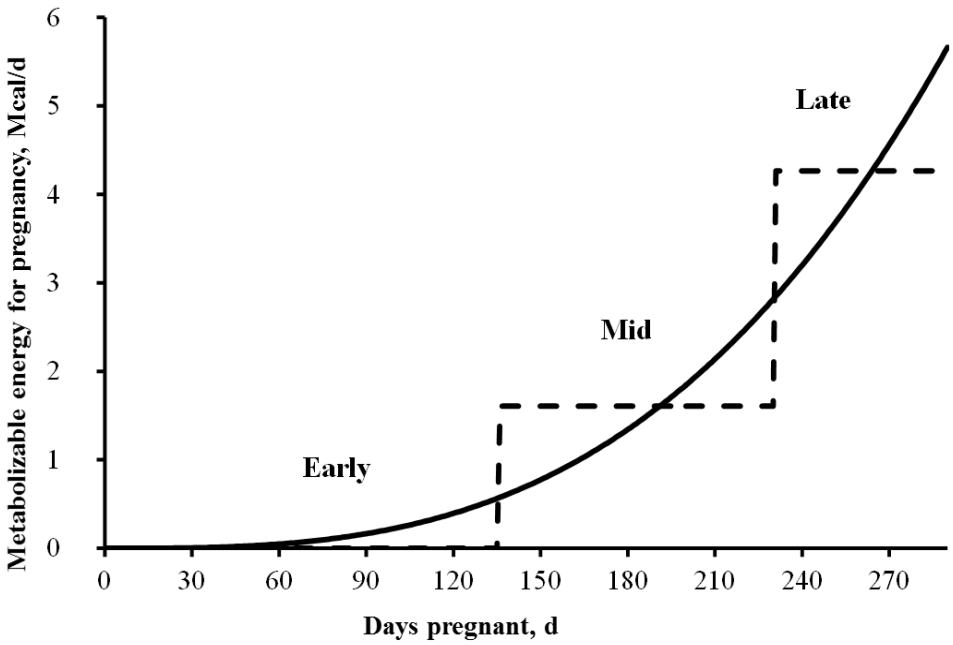


Figure 11.5 - Metabolizable energy requirements for pregnancy of an adult Zebu cow (500 kg BW carrying a calf with estimated 32 kg calving weight) divided into three pregnant periods (early, mid and late). The continuous line represents the requirements calculated daily and the dotted line represents the mean requirements to be considered in each period.

Table 11.5 - Description and duration of the gestation periods for practical application of the nutritional requirements for pregnancy of adult Zebu cows

Pregnant period		Pregnancy requirements (equivalents)[1.]
Name	Duration (d)	
Early	135 (0 to 135th)	-
Mid	95 (136 to 230th)	191 d pregnant
Late	60 (231 to 290th)	264 d pregnant

[1.]Up to 135 d pregnant: pregnancy requirements are considered not significant. In mid gestation (136 to 230 d), the mean requirements are equivalent to the requirements at 191 d pregnant. In late pregnancy (231 to 290 d), the mean requirements are equivalent to the requirements at 264 d pregnant. That is, the pregnancy requirements in mid and late pregnancy should be calculated using, respectively, 191 and 264 d pregnant and the models described in this Chapter.

According to the production system and technical recommendation, a larger number of steps can be used to elaborate nutritional programs for pregnant cows. The steps presented above are adopted in this edition of the BR-CORTE.

Zebu cow nutritional requirements over a productive cycle (period between two calvings) can be better understood according to Table 11.6. This means that, in the case of a cow with a 12-month calving interval from calving to weaning, the nutritional requirement should be calculated according to Chapter 12 of this edition of the BR-CORTE (nutritional requirements for lactating Zebu cows and their calves). After weaning, the nutritional requirements for this cow should be calculated according to the requirements for midgestation, because with a 12-month calving interval, the cow would have conceived at 75 d of lactation and at weaning will be with 135 d pregnant. If the calving interval is 14 months, there will be a period (60 d) of the productive cycle when the cow will not be lactating and in early pregnancy, when the requirements for gestation are not significant. In this case, during this period, the total requirements of such a cow should be calculated as maintenance requirements + maternal gain tissue requirements, as described in this Chapter.

Table 11.6 - How to calculate the nutritional requirements for Zebu cows according to the stage of the productive cycle when the calving interval is 12, 14, 16 or 18 months

Calving interval, months (d)	Productive cycle phase (duration and justification)			
	Lactation	Non-lactating, open or early pregnancy	Midgestation	Late pregnancy
12 (365)	210 d (calving to weaning)	0 d, because it will have been conceived at 75 d lactation and at weaning it will be at 135 d pregnant	95 d (136 to 230th d pregnant)	60 d (231st d pregnant until calving)
14 (425)	210 d (calving to weaning)	60 d, because it will have conceived at 135 d lactation and it will be 75 d pregnant at weaning	95 d (136 to 230th d pregnant)	60 d (231st d pregnant until calving)
16 (485)	210 d (calving to weaning)	120 d, because it will have conceived at 195 d lactation and it will be 15 d pregnant at weaning	95 d (136 to 230th d pregnant)	60 d (231st d pregnant until calving)
18 (545)	210 d (calving to weaning)	180 d, because it will have conceived at 45 after weaning	95 d (136 to 230th d pregnant)	60 d (231st d pregnant until calving)
How to calculate the nutritional requirements?	**Requirements for lactating cows (Chapter 12)**	**Requirements for open cows (maintenance+ maternal tissue gain)**	**Requirements for cows at midgestation (maintenance+ maternal tissue gain + requirements for 191 d pregnant)**	**Requirements for cows at late pregnancy (maintenance+ maternal tissue gain + requirements for hundred 264 d pregnant)**

Based on Table 11.6 the duration of the period when the cow requirements should be calculated for non-lactating, open or early pregnancy (maintenance + maternal tissue gain) should be estimated based on the calving to conception interval and during lactation (age at weaning adopted for the herd) as follows:

$$PX = 135 + CCI - LACT \quad \text{Eq. 11.28}$$

where PX = duration of the period (d) when the requirements of the cow should be considered equal to the requirements of maintenance + maternal tissue gain (non-lactating and open or with non-specific requirements for pregnancy), CCI = calving- to-conception interval (d) and LACT = duration of the lactation (d).

Taking as base Eq. 11.28, a cow that conceives at 100 d after calving (CCI = 100), in a production system with calf weaning age of seven months (LACT = 210), will have a 25 d of PX (PX = 135 + 100 – 210). A cow that conceives at 80 d after calving (CCI = 80), in a production system that adopts early weaning with three-month-old calves (LACT = 90), will have a 125-d PX (PX = 135 + 80 – 90). Thus, in the case of this last example, after weaning, the cow should receive a diet that meets its requirements for maintenance + maternal tissue gain for a period of 125 d after weaning and it should then receive a diet that meets the maintenance requirements, maternal gains and requirements for the midgestation.

Mineral requirements for pregnant and open cows

Data on the mineral requirements for pregnancy in adult Zebu cows are not yet available for this edition of the BR-CORTE. Thus, it is suggested that the estimates and mineral requirements for maintenance of beef Zebu heifers presented in Chapter 10 of this edition of the BR-CORTE should be adopted. For pregnant cows, an increase of 20% in the mineral requirements is suggested during mid- and late pregnancy. Thus the mineral requirements for open and pregnant Zebu cows can be calculated according to Table 11.7.

Table 11.7 - Suggestion for calculating mineral nutritional requirements for adult Zebu open and pregnant cows

Category	Mineral requirements
Open cows and up to 135 d pregnant	Maintenance
Midgestation (136 to 230 d pregnant)	Maintenance × 1. 2
Late pregnancy (231 d pregnant to calving)	Maintenance × 1.2

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12

Nutrient requirements of lactating beef cows and their calves

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INTRODUCTION

In beef cattle production, the breast-feeding phase is important for the meat production chain to provide future animals that will be utilized for other phases of the production system. Additionally, it is characterized by the use of a large number of animals, with 31% of the production herd being represented by the cows (Calegare, 2004). It is estimated that approximately 70% of the energy required for meat production is utilized for functions involved with cow maintenance (Ferrell and Jenkins, 1985). Thus, nearly 50% of the energy required to raise an animal until slaughter is utilized for cow maintenance.

In this context, Brazilian livestock has been pressured to develop an efficient, competitive, and continuous meat production program based on the areas currently used for livestock, which are mandatorily based on the reduction of the production cycle. Thereby, the production systems have intensified to reduce the age of animal at slaughter, increasing the amount and quality of products offered. In this way, knowledge of the potential dry matter intake (DMI) of cows and calves is essential for adequate planning and technology used to achieve production targets established in the system.

During the breast-feeding phase, the correct measurement of milk yield (MY) is indispensable because this parameter represents the amount of nutrients that cows are secreting into the milk. Furthermore, this estimate will be considered to calculate the amount of nutrients that the calf is consuming from the milk, which will be considered to meet the nutrient requirements of these animals, being a factor that directly interferes with the performance of calves. MY can be measured directly and indirectly; the most common methods are differences in calf weights before and after suckling (Williams et al., 1979), manual milking (Totusek et al., 1973; Ferreira et al., 2020) and machine milking procedures after injection of oxytocin (Lopes et al., 2014: Almeida et al., 2018; Ferreira et al., 2021).

Regardless of the method, estimating MY of beef cows is laborious as it demands extensive and intensive calf separation management. These circumstances explain not only the scarcity of studies but also the low number of data points for fitting an equation describing milk production for grazing beef cows.

The energy requirements of the animal correspond to the sum of the needs for maintenance and production, which is divided into energy required for growth, lactation, and pregnancy (Webster, 1979). However, few studies (Fonseca, 2012 a; b) have been conducted in Brazil to estimate the nutrient requirements of animals during the breast-feeding phase, or those of lactating cows and suckling calves.

Thereby, from the knowledge of MY and nutrients requirements of calves, the amount of energy and protein secreted by the milk can be determined, which allows estimating the moment that the milk does not provide enough nutrients and the exact moment for calf supplementation.

The metabolizable energy intake (MEI) that does not incur energy changes in the body will influence the dietary energy required for maintenance, making this parameter considered a characteristic with moderate to high heritability (Carstens et al., 1988). Thereby, energy efficiency, from 60 to 70% of the total energy required for maintenance of the animals (Bottje e Carstens, 2009), has been attributed to protein turnover, ion pumps (Na^+ e K^+) and the uncoupling of oxidative phosphorylation in the mitochondria. Thus, the selection of animals that have lower nutrient

requirements could be adopted, with the aim of obtaining more efficient animals.

In this chapter, the discussion about equations developed to estimate DMI and milk production and composition of lactating Nellore cows will be presented, as well as the DMI of suckling Nellore calves. Also, the requirements of energy, protein, and minerals will be presented for lactating Nellore cows and their calves.

DRY MATTER INTAKE OF LACTATING BEEF COWS

In the edition of BR-CORTE (2016), we used the Wilmink model (1987) plus the variable average daily gain (ADG), based on the study by Costa e Silva (2015), who evaluated five models available to estimate the DMI of Nellore cows during seven months of lactation. In this study, the cows received a diet with a high amount of corn silage, in order to simulate a pasture diet, obtaining the following model:

$$DMI\ (g/kg\ BW) = 27.259 - 13.861 \times \exp^{(-0.836 \times WL)} - 0.317 \times WL + 0.606 \times ADG$$

where: DMI = dry matter intake, WL = week of lactation, ADG = average daily gain (kg/d)

Although it showed better estimate of DMI than the BR-CORTE (2010) issue, which considered a constant value of 2.39% of BW for lactating Nellore cows during the first six months of lactation, the suggested equation did not correctly estimate DMI from an independent database with 372 observations (Table 12.2), probably due to the fact that the equation was generated using data from Nellore cows consuming corn silage (Costa e Silva, 2015).

However, considering that grazing cows are subject to variations in the availability and nutritional value of forage, a new equation was developed from data of 3 experiments conducted with lactating Nellore cows under pasture (Table 12.1), containing 372 observations.

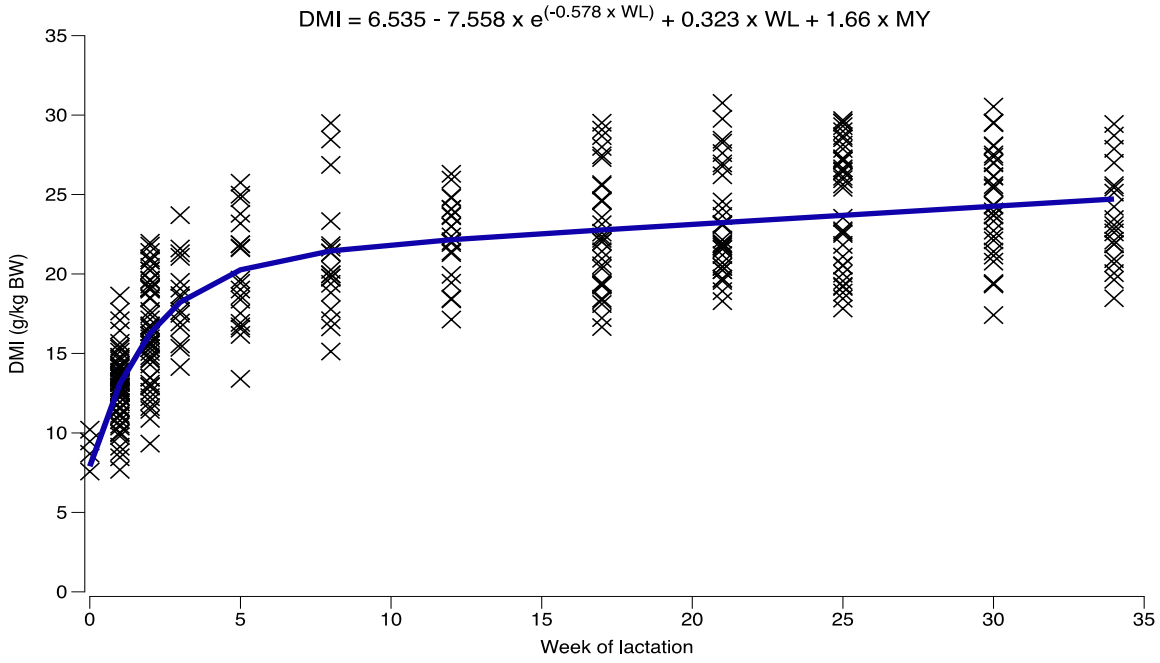


Figure 12.1 - Dry matter intake (g/kg BW) of Nellore cows during lactation period.

Thus, the new equation obtained was:

$$DMI\ (g/kg\ BW) = 6.535 - 7.558 \times \exp^{(-0.578 \times WL)} + 0.323 \times WL + 1.66 \times MY,$$

where DMI = Dry mater intake, WL = Week of lactation, MY = Milk yield (kg/d).

Considering the values predicted by the new suggested equation and the recommendation

of BR-CORTE (2016), it can be seen that the equation recommended by BR-CORTE (2016) overestimates the DMI by 6.1 g/kg BW (13.4 *vs*. 7.3 g/kg BW) on the day of calving (Week 0) and underestimates by 6.4 g/kg BW (17.8 *vs*. 24.2 g/kg BW) at week 30.

An independent database containing 92 observations (Table 12.1), was used to validate the suggested equation, by Wilmink (1987).

From the evaluations described in Table 12.2, it is observed that the intercept and the slope of the equation were not different from 0 and 1, respectively. Furthermore, the average prediction error was close to zero, being associated with random error (Table 12.2).

Thus, in the current edition, BR-CORTE recommends that the DMI of Nellore cows be estimated from the following equation:

$$DMI\ (g/kg\ BW) = 6.535 - 7.558 \times \exp^{(-0.578 \times WL)} + 0.323 \times WL + 1.66 \times MY$$

Table 12.1 - Descriptive statistics from the independent database utilized to evaluate dry matter intake (DMI) and milk yield prediction equations of beef cows

Study	Item	n	Means	DP	Maximum	Minimum
Data for development of the equation						
Matos (2023)	Week lactation	217	22.1	7.8	34	8
	Milk yield[1]	217	5.8	0.8	7.2	4.6
	DMI	217	23.3	3.6	30.8	15.1
	Body weight	217	527	65	680	416
	Average daily gain	217	0.11	0.13	0.35	-0.17
David (2022)	Lactation week	37	4.4	1.4	6	3
	Milk yield[1]	37	7.4	0.1	7.5	7.4
	DMI	37	20	2.6	25.7	13.4
	Body weight	37	518	74.1	639	407
	Average daily gain	37	-0.11	0.35	-0.07	-0.17
Ferreira (2022)	Week lactation	118	1.7	1	3	0
	Milk yield[1]	118	6.4	1.4	7.6	-
	DMI	118	14	3.1	23.7	7.6
	Body weight	118	495	9.7	528	455
Data for equation validation						
Lopes (2012)	Week lactation	-	26.5	5.45	37	12
	Milk yield[1]	143	6.97	1.58	9.99	4.24
	DMI	32	11.8	2.35	17	7.95
	Body weight	32	481	50.6	558	359
	Average daily gain	32	-0.34	0.35	0.22	-1.38
Cardenas (2012)	Week lactation	-	28.1	6.38	40	12
	Milk yield[1]	170	7	1.36	9.87	4.21
	DMI	60	12.9	1.45	16.7	9.94
	Body weight	60	450	51.6	567	362
	Average daily gain	60	0.2	0.09	0.4	-0.04

[1] Estimated milk yield, using data from the equation described in Figure 12.2.

MILK YIELD AND COMPOSITION OF BEEF COWS

As previously described, the correct measurement of MY from beef cows is important for calculating nutritional requirements for both cows and calves. In this sense, it is necessary to understand the milk collections methodologies for these estimates.

In the first studies, milk production in beef cows were based on an indirect estimate, weighing calves before and after suckling. This technique generates great stress in the animals due to excess handling, in addition to greater variation and error in the collection,

since any factor at the time of weighing (scale, calves that urinate and defecate at the time of suckling) will cause great variation in MY estimates.

Over the years, hand or machine milking has become the most used methodology for this type of assessment (Ferreira et al., 2021).

Table 12.2 - Mean (kg) and descriptive statistics for the relationship between observed and predicted values of dry matter intake (DMI) of lactating Nellore beef cows

Item	Total DMI of cows		
	OBS[1]	BR-CORTE 2016[2]	BR-CORTE 2023[3]
Mean	19.8	21.5	22.7
SD	5.45	2.69	1.95
Maximum	30.7	25.4	20.2
Minimum	6.07	13.4	16.2
R	-	0.04	0.52
CCC[4]	-	-0.15	0.44
Regression			
Intercept			
Estimate	-	28.48	-1.88
SE	-	2.31	3.32
P-value[5]	-	<0.0001	0.57
Slope			
Estimate	-	-0.40	1.19
SE	-	0.11	0.15
P-value[6]	-	<0.0001	0.57
MSEP[7]	-	45.19	11.48
Mean bias	-	3.07	5.9
Systematic bias	-	2.54	0.13
Random errors	-	27.9	5.45

[1]OBS = observed values; [2]BR-CORTE 2016 = values predicted by the equation generated from model proposed by Wilmink (1987) added to average daily gain (ADG); [3]BR-CORTE 2023 = values predicted by the equation generated from model proposed by Wilmink (1987) added to milk yead(MY); [4]CCC = concordance correlation coefficient; [5]H_0: $\beta_0 = 0$; [6]H_0: $\beta_1 = 1$; [7]MSEP = mean square error of prediction.

However, there are two ways to estimate the MY of beef cows without a consensus in the literature: (1) milking in the morning and correct up to 24 hours (M24), (2) milking in the morning and afternoon (AM_PM). In the M24 methodology, recording the times of separation of the calf from the mother on the day before and at the end of milking on the following day are fundamental (Costa e Silva, 2015).

Thus, this edition was based on the meta-analytical approach of Lopes et al. (2022), who collected information from 16 experiments with Nellore cows grazing between 2014 and 2021, totaling 1,503 observations (Table 12.3). This study brough results about the methodology to estimate MY, as well as new equations to estimate the composition and production of milk of Nellore cows.

Firstly, the authors compared MY estimated by the M24 method (Valente et al., 2013; Lopes et al., 2014), and the AM_PM method (Almeida, et al., 2018; Ferreira et al., 2021; Table 12.3). The M24 method was applied to studies that milked in the morning and in the afternoon, and both methods were compared within the AM_PM method. No difference was observed in MY regardless of the method of milk collection. The average was 6.51 and 6.70 kg (±0.098), respectively. Thus, it is recommended to measure the morning milk and correct it for a 24-hr period to estimate the daily milk yield of Nellore cows

as described in the studies by Valente et al. (2013) and Lopes et al. (2014), due to less labor and interference in the behavior of animals.

The last edition of BR-CORTE (2016) was based on the study developed by Costa e Silva (2015), suggesting an equation to estimate the MY of Nellore cows. The author evaluated five models to estimate the MY of Nellore cows during seven months of lactation. In this study, cows were fed a diet with a high amount of corn silage (85%) in order to simulate a pasture diet.

The equation that presented the best estimate was the one adjusted using the model proposed by Cobby and Le du (1978). Thus, the BR-CORTE (2016) adopted the following equation:

$$MY = 8.819 - 0.069 \times WL - 8.819 \times \exp^{(-3.211 \times WL)},$$

Where MY = milk yield and WL = week lactation.

Despite presenting a better estimate than the previous edition, the suggested equation overestimates MY as it was generated using data from feedlot Nellore cows (Ferreira et al.,2021).

Table 12.3 - Statistical description of the dataset used to develop and validate the equations to estimate milk yield of beef cows

Study	Estimation method	n[2]	Milk yield				Week lactation		
			mean	DP	minimum	maximum	mean	minimum	maximum
Multiparous									
Lopes et al. (2014)	Corrected for 24 hours	84	6.4	1.6	1.4	10.5	28	12	40
Lopes et al. (2016)	Corrected for 24 hours	17	7.8	1.6	4.3	10.7	7	4	12
Carvalho (2018) [1]	Corrected for 24 hours	30	5.7	1.6	2.1	9.3	26	21	32
Lage (2019) [1]	Morning and afternoon	70	5.0	1.8	1.5	8.8	29	23	35
de Paula et al. (2022)	Morning and afternoon	65	5.5	1.4	2.4	8.7	25	17	32
Moreira (2022) [1]	Morning and afternoon	71	7.1	1.8	2.5	10.3	25	17	32
Saraiva (2023)[1]	Morning and afternoon	104	6.9	2.1	1.7	11.4	19	6	32
Ferreira et al. (2020)	Morning and afternoon	74	7.8	1.3	4.1	10.4	5	3	7
Ferreira et al. (2021)	Morning and afternoon	99	6.6	1.6	2.6	10.1	12	1	30
Souza (2021) [1]	Corrected for 24 hours	178	4.9	1.6	2.0	9.7	17	4	30
Nascimento (2021)[1]	Corrected for 24 hours	139	5.5	2.0	0.6	10.9	17	4	30
Rodrigues (2021)[1]	Morning and afternoon	134	5.9	1.6	2.5	9.8	10	1	29
Primiparous									
Melo (2018)	Corrected for 24 hours	55	5.0	1.5	2.4	8.6	5	2	9
Ferreira et al. (2021)	Morning and afternoon	164	5.9	1.5	2.5	9.18	12	1	30
Rodrigues (2021)[1]	Morning and afternoon	124	6.0	1.3	2.9	8.8	10	1	29
Vital (2021)	Corrected for 24 hours	95	5.3	1.5	1.6	9.2	5	2	9

[1]unpublished data. [2]cow-day observations. Adapted from Lopes et al. (2022).

Thus, Ferreira et al. (2021) developed new equations considering calving order to estimate MY of Nellore cows under grazing conditions. However, considering that grazing cows are subject to variations in forage availability and nutritional value, a robust equation that included a larger amount of data from different regions and herds for greater reliability was needed.

In the study by Lopes et al. (2022), nine studies were used to generate new equations for multiparous cows and 3 studies were randomly chosen for independent validation of the equation (Table 12.3). Considering that multiparous and primiparous cows differ in milk production potential (Ferreira et al., 2021), other four studies were used to develop

an equation to estimate MY of primiparous separately (Table 12.3).

The equation by BR-CORTE (2016) did not correctly estimate the milk yield of the dataset and presented greater bias and prediction error (Table 12.4). Thereby, the equation for estimating MY for multiparous beef cows was readjusted and validated using database from the meta-analysis.

The inclusion of an equation for primiparous cows was suggested. However, due the low number of studies and data regarding milk yield of primiparous cows, it was not possible to use an external database to perform an independent validation for this category. However, the unprecedent equation for this category of cows make it relevant to the scientific literature, suggesting it to be used until more data are available for its validation.

The new suggested equations were also based on the model proposed by Cobby and Le Du (1978), being:

$MY = 7.996 - 0.101 \times WL - 7.996 \times \exp^{(-1.447 \times WL)}$, obtained for multiparous cows (> 3 years) and the equation:

$MY = 6.431 - 0.072 \times WL - 6.431 \times \exp^{(-2.188 \times WL)}$ found for primiparous cows (≤ 3 years).

Table 12.4 - Mean (kg) and statistic description for the relationship between predicted and observed milk yield values

Item	Milk yield		
	OBS[1]	Cobby and Le Du (1978)[2]	BR-CORTE (2016)[3]
Mean	6.39	6.52	7.88
SD	1.84	0.95	0.67
Maximum	10.9	7.59	8.67
Minimum	2.33	4.97	6.75
R	-	0.53	0.57
CCC[4]	-	0.42	0.15
Regression			
Intercept			
Estimate	-	-0.34	-6.08
SE	-	0.664	1.07
P-value[5]	-	0.600	< 0.0001
Slope			
Estimate	-	1.03	2.38
SE	-	0.100	0.13
P-value[6]	-	0.769	< 0.0001
MSEP[7]	-	2.57	4.84
Mean bias	-	0.024	2.32
Systematic bias	-	0.0008	0.15
Random errors	-	2.55	2.36

[1]OBS = independent values; [2]Cobby and Le Du (1978) = predicted values by the equation generated from the model proposed by the proposed by Cobby and Le Du (1978); [3]BR-Corte (2016) = predicted values by the equation suggested by Valadares Filho et al. (2016); [4]CCC = correlation and concordance coefficient; [5]H_0: $\beta_0 = 0$; [6]H_0: $\beta_1 = 1$; [7]MSEP = mean square error of prediction.

According to the new equations developed, it is estimated that the MY at the peak of production is 7.59 kg and 6.22 for multiparous and primiparous cows, respectively, taking 3 to 5 weeks until the peak (Lopes et al., 2022).

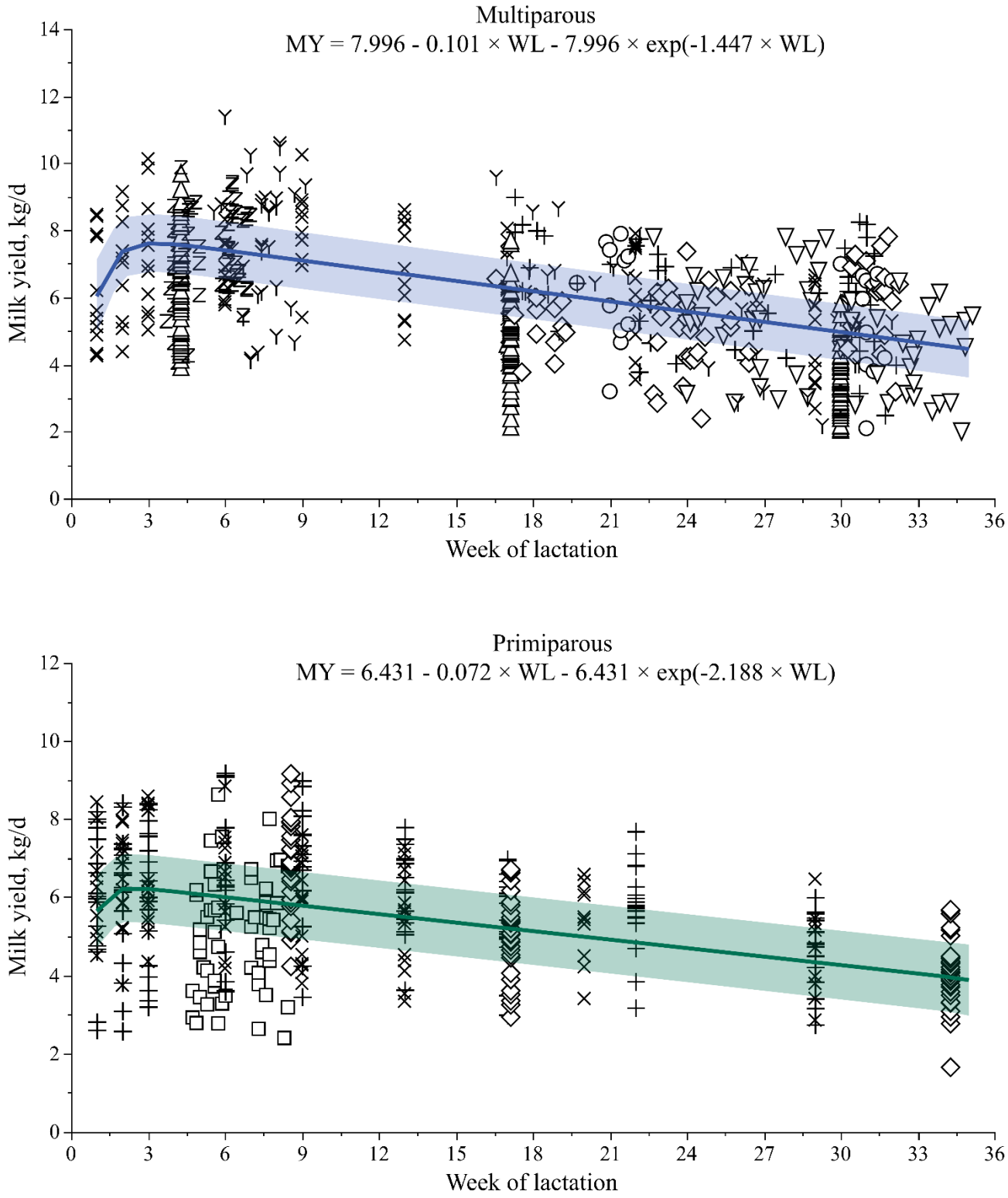


Figure 12.2 - Milk yield versus week of lactation plots for predictions (solid line) and observations (individual cow data, point markers differ in study) for multiparous and multiparous cows under grazing conditions.

The same studies used in the meta-analysis (Lopes et al., 2022) were the basis for estimating milk composition throughout lactation. Thereby, an average was generated for each milk component, as well as linear equations to estimate milk composition according to the lactation week (Table 12.5).

The updated values were close to those recommended by the edition of BR-CORTE (2016), except for fat (5.60 *vs.* 4.76%) and total solids (15.00 *vs.*13.92%).

The greatest fat percentage found in the previous edition may be explained by data coming from cows kept in feedlot system and fed corn silage (Costa e Silva, 2015). The higher energy intake in the diet possibly led to an increase in acetate production providing a greater amount of substrate for new fat synthesis in the mammary gland. Thus, the higher percentage of fat also impacted the total solids values.

The mineral composition of milk from Nellore cows presented was based on the study by Costa e Silva et al. (2015a), with the following average concentrations: 1.11% Ca, 0.76% P, 0.20% Na, 0.25% S, 0.23 ppm Co, 3.20 ppm Cr, 29.9 ppm Fe, 1.40 ppm Mn and 35.4 ppm Zn (Table 12.6).

Table 12.5 - Mean (%) and estimate of milk composition according to the lactation week

Components	mean	Equations
Fat, %	4.76	4.52 + 0.018 x WL[1]
Protein, %	3.56	3.37 + 0.010 x WL
Lactose, %	4.56	4.81 – 0.010 x WL
Total solids, %	13.92	13.6 + 0.021 x WL

[1]WL = Week lactation. Adapted from Lopes et al. (2022).

Table 12.6 - Mineral composition of milk from Nellore cows during lactation

Components	Days of lactation							SEM	P value
	28	56	84	112	140	168	196		
Ca (g/kg)	1.13	1.10	1.10	1.10	1.12	1.11	1.10	0.03	0.46
P (g/kg)	0.81^{a}	0.74^{b}	0.73^{b}	0.76^{ab}	0.77^{ab}	0.77^{ab}	0.76^{ab}	0.02	0.01
Mg (g/kg)	0.06^{c}	0.07^{c}	0.07^{c}	0.07^{bc}	0.08^{ab}	0.08^{a}	0.08^{a}	0.01	<0.001
K (g/kg)	0.71^{ab}	0.70^{ab}	0.71^{ab}	0.73^{a}	0.73^{ab}	0.69^{ab}	0.65^{b}	0.03	0.04
Na (g/kg)	0.22^{a}	0.20^{b}	0.19^{b}	0.19^{b}	0.19^{b}	0.19^{b}	0.20^{ab}	0.01	<0.001
S (g/kg)	0.26	0.24	0.25	0.25	0.26	0.26	0.26	0.01	0.08
Co (ppm)	0.23^{ab}	0.26^{a}	0.20^{b}	0.22^{ab}	0.25^{ab}	0.22^{ab}	0.23^{ab}	0.02	0.03
Cr (ppm)	3.19	3.33	3.24	3.03	3.28	3.27	3.05	0.02	0.12
Cu (ppm)	3.01^{a}	2.28^{b}	1.98^{b}	1.78^{b}	1.73^{b}	1.55^{b}	1.54^{b}	0.20	<0.001
Fe (ppm)	27.9	29.9	27.4	29.3	30.1	32.5	32.0	3.1	0.58
Mn (ppm)	1.47	1.26	1.24	1.36	1.47	1.53	1.47	0.2	0.21
Zn (ppm)	41.1^{a}	35.5^{b}	34.1^{b}	33.9^{b}	34.6^{b}	34.7^{b}	33.8^{b}	1.8	<0.001

Adapted from Costa e Silva et al. (2015a).

DRY MATTER INTAKE OF SUCKLING BEEF CALVES

The BR-CORTE (2010) recommended the constant value of 2.35% BW for total DMI of suckling Nellore calves during the first six months of age, being this recommendation was from the study conducted by Fonseca (2009).

However, Costa e Silva (2015) evaluated five models available in the literature to estimate the DMI of roughage and concentrate for Nellore calves during the breast-feeding phase. Also, by knowing the milk intake from MY of cows and multiplying it by its DM content, we can obtain DMI of milk.

Thereby, from the sum of DMI of milk and solid feedstuff, we can access the total DMI of calves during the breast-feeding

period. Thus, in this edition, the following equation proposed by Costa e Silva (2015) was adopted to estimate DMI of roughage and concentrate for suckling beef calves:

$$DMIrc = 0.353 - 0.532 \times DMImilk + 0.01065 \times BW + 0.3497 \times ADG,$$

where DMIrc = Dry matter intake of roughage and concentrate (kg/d), DMImilk = Dry matter intake of milk (kg/d), BW = Body weight (kg), ADG = average daily gain (kg/d).

Additionally, from an independent database that contained 232 observations from five studies conducted on pasture (Table 12.7), this equation was evaluated, resulting in the correct estimate of DMI of roughage and concentrate of suckling beef calves (Table 12.8); being this equation suggested by the BR-CORTE.

Table 12.7 - Descriptive statistics of the independent database utilized to predict dry matter intake of roughage and concentrate of suckling beef calves

Study	Item	n	Mean	DP	Maximum	Minimum
Lopes (2012)	Age (days)		170	-	-	-
	DMI of concentrate	53	0.63	0.32	0.80	0.00
	DMI of roughage	53	2.02	0.59	3.34	0.79
	Body weight	53	188	31.0	256	123
	Average daily gain	53	0.85	0.12	1.14	0.64
Cardenas (2012)	Age (days)		192	33.2	245	120
	DMI of concentrate	62	0.46	0.2	0.97	0.04
	DMI of roughage	62	1.86	0.47	3.04	0.88
	Body weight	62	217	30.2	285	154
	Average daily gain	62	0.67	0.09	0.92	0.42
Márquez (2013)	Age (days)		150	-	-	-
	DMI of concentrate	28	1.08	0.56	2.63	0.28
	DMI of roughage	28	2.17	1.15	6.31	0.77
	Body weight	28	202	21.6	255	151
	Average daily gain	28	0.94	0.09	1.13	0.74
Lopes (2015)	Age (days)		190	-	-	-
	DMI of concentrate	42	0.84	0.61	1.62	0
	DMI of roughage	42	2.01	0.41	3.21	1.38
	Body weight	42	203	29.0	264	148
	Average daily gain	42	0.84	0.12	1.14	0.56
Martins (2016)	Age (days)		182	-	-	-
	DMI of concentrate	47	0.75	0.63	2.79	0.00
	DMI of roughage	47	2.32	1.05	5.63	1.00
	Body weight	47	212	28.1	296	161
	Average daily gain	47	0.81	0.17	1.08	0.43

Table 12.8 - Mean (kg) and statistics description for the relationship between the predicted and the observed values of dry matter intake of roughage and concentrate of calves

Item	DMI of roughage and concentrate	
	OBS[1]	BR-CORTE (2016)[2]
Mean	2.51	2.34
SD	0.64	0.34
Maximum	3.99	3.37
Minimum	0.99	1.35
R	-	0.44
CCC[3]	-	0.33
Regression		
Slope		
Estimate	-	0.55
SE	-	0.29
P-value[4]	-	0.05
Slope		
Estimate	-	0.85
SE	-	0.12
P-value[5]	-	0.24
MSEP[6]	-	0.40
Mean bias	-	0.04
Systematic bias	-	0.002
Random errors	-	0.35

[1]OBS = observed values; [2]BR-Corte (2016) = predicted values by the equation suggested by Valadares Filho et al. (2016); [3]CCC = concordance correlation coefficient; [4]H_0: $\beta_0 = 0$; [5]H_0: $\beta_1 = 1$; [6]MSEP = mean square error of predction.

SUPLEMENTATION OF CALVES DURING BREAST-FEEDING PERIOD

Considering the lactation curve of Nellore cows, the average milk composition, and according to the nutrient requirements obtained for calves through breast-feeding phase, we will be able to estimate the moment that milk is not sufficient to provide the nutrient demanded for calf growth. Also, considering energy and protein as the most limiting nutrients, we showed that after the 12th week or so, at around 80 days of age, the milk does not provide all energy necessary for the calf which has an ADG close to 1 kg/d. However, protein becomes limiting only after the 14th week, approximately at 100 days of age. Therefore, in order for Nellore calves to maintain body weight gain close to 0.9 kg/d until weaning, we recommend the use of multiple supplements through creep feeding after the third month of age, or else using cows with greater potential for milk yield (Table 12.9).

Nevertheless, even increased milk yield due to the greater genetic capacity of cows allows for greater body weight gain at weaning, and the level of nutrients in most pasture systems is limited to supporting high levels of milk yield (Paulino et al., 2012). Additionally, in the 3th and 4th months of age, there are considerable changes in the gastrointestinal tract of the calf, and this is the period when this animal effectively becomes a ruminant (Porto et al., 2009), being more dependent on pasture. However, these processes occur during the wet-dry transition period in most Brazilian productions systems, which causes a decrease in quality and quantity of forage available for grazing. Consequently, the difference between the nutrient requirements of the calf and the amount of nutrients supplied by milk and forage tends to increase, provoking an unfavorable situation in calves concerning nutrient balance. Thus, for the intensive production systems of cattle, which require greater nutrient supply, the supplementation of suckling calves under

creep feeding system is recommended. Creep feeding refers to the supply of additional feed for calves during the breast-feeding phase in restricted location (Paulino et al., 2012).

Studies regarding creep feeding in tropical conditions have consistently shown an increase in BW at weaning (Table 12.10), showing the importance of creep feeding to reduce the age at slaughter and the beginning of reproduction activity in animals raised on grazing conditions (Paulino et al., 2010). However, the additional body weight gain with the use of creep feeding is variable. Factors, such as the amount and quality of forage, milk yield of cows, grow potential of calves, breed, sex, age of calves at weaning, and even type of supplement and time of use of creep feeding influence animal performance.

Table 12.9 - Milk yield of Nellore cows, availability of metabolizable energy (ME) and protein (MP) in milk, total requirements of ME and MP of suckling Nellore calves, and the need of milk to meet ME requirements of calves according to the week of lactation and the body weight of the animals

WL[1]	BW[2]	MY[3]	ME milk[4]	MP milk[5]	MEt[6]	MPt[7]	NM[8]
1	36.3	6.01	6.85	303.56	3.47	227.08	3.04
2	42.6	7.35	8.37	371.08	3.92	236.91	3.44
3	48.9	7.59	8.64	383.07	4.34	246.39	3.81
4	55.2	7.57	8.62	381.99	4.76	255.59	4.18
5	61.5	7.49	8.52	377.84	5.16	264.56	4.53
6	67.8	7.39	8.41	372.96	5.55	273.34	4.87
7	74.1	7.29	8.30	367.92	5.93	281.96	5.20
8	80.4	7.19	8.19	362.83	6.31	290.44	5.53
9	86.7	7.09	8.07	357.73	6.68	298.81	5.86
10	93.0	6.99	7.96	352.64	7.04	307.07	6.17
11	99.3	6.88	7.84	347.54	7.39	315.25	6.48
12	105.6	6.78	7.73	342.44	7.74	323.36	6.78
13	111.9	6.68	7.61	337.34	8.35	331.40	7.32
14	118.2	6.58	7.50	332.24	8.70	339.39	7.63
15	124.5	6.48	7.38	327.15	9.05	347.33	7.90
20	156	5.98	6.81	301.65	10.71	386.59	9.40

[1]WL = week lactation; [2]BW = body weight of calf, kg: considering body weight at birth of 30 kg and ADG of 0.9 kg/d;
[3]MY = milk yield; [4]ME milk: amount of metabolizable energy available to calf from milk (Mcal/d); [5]MP milk: amount of metabolizable protein available to calf from milk (g/d); [6]MEt = total requirements (maintenance + growth) of metabolizable energy of calf; [7]MPt: total requirements (maintenance + growth) metabolizable protein of calf; [8]NM: need of milk (kg/d) to meet total requirements of ME and calf. Adaptada do BR-CORTE (2016).

Therefore, when the limit imposed by genetics is obeyed, and the capacity of pasture and/or milk to supply the nutrient demand of the calves is lower, the response relative to the use of creep feeding will be greater, reflecting positively on the efficiency and profitability of this technique.

Lopes et al. (2017) evaluated nutritional plans (0,3,6 or 9 g/kg BW) of supplement with 25% CP for suckling beef calves from 4 to 8 months of age. It was observed that animals that received 6 g of supplement /kg BW had higher ADG (0.92 kg/d) and BW at weaning (275 kg). Following these animals in feedlot (Prados et al., (2017) with the animals being slaughtered at 15-16 months, it was observed that the difference in weight at slaughter can be attributed to the additional weight gain with creep feeding.

In a meta-analytical approach, Carvalho et al. (2018) gathered data from 18 studies with creep feeding (between 2007 and 2017). The authors found maximum responses with the use of supplements in the amounts of

7.6 g/kg BW for males and 5.5 g/kg BW for females, with a CP content in the supplement of 22.5%. The maximum additional ADG was 0.2 and 0.1 kg/d for males and females, respectively. Considering these gains and a supplementation period of 150 days, the additional gain obtained with creep feeding would be 30 kg for males and 15 kg for females, corroborating the results of Lopes et al. (2017).

Table 12.10 - Summary of data from studies on creep feeding

Study[a]	Experimental period (d)	Calf sex	Supplement intake (g/d)[b]	CP content in the supplement (g/kg)	ADG[c]	
					NS	SUP
De Paula et al. (2012)	112	Male	583	300	662	728
Valente et al. (2013)	112	Male	530	150-550	608	804
Barros et al. (2014)	112	Female	500	250	687	769
Lopes et al. (2014)	140	Male	900	80-410	727	880
Cardenas et al. (2015)	140	Female	500	80-400	619	677
Barros et al. (2015)	140	Male	850	250	731	843
Marquez et al. (2014)	150	Female	450	250	628	677
Lopes et al. (2017)	140	Male	1200	250	720	873
Almeida (2017)	140	Female	800	250	642	732
Martins et al. (2017)	140	Male	1600	250	500	900

[a/] Data processed; to access individual data, consult references
[b/] Mean intake of supplement from supplemented animals
[c/] ADG = average daily gain (g/d), NS = calves that received only mineral supplementation; or SUP = calves that received multiple supplements.

In relation to breastfeeding behavior, research results have not shown a reduction in milk intake due to the adoption of creep feeding. Valente et al. (2013) evaluated the behavior of beef calves with free access to creep feeding, receiving 5 g/kg BW of supplements and did not observe differences in suckling time between supplemented and non-supplemented calves. Similar results were found by Lopes et al. (2017) and Martins et al. (2017). In these studies, a decrease in grazing time was observed with the supplementation, indicating that there was a substitution in the forage DMI by the supplement, corroborating the absence of change in milk intake. Other studies (Barros et al., 2014; Lopes et al., 2014; Cardenas et al., 2015; Lopes et al., 2017) evaluated the effects of the adoption of creep feeding on intake and did not observe a change in milk intake. However, forage intake was lower in supplemented animals. Therefore, it seems unlikely that calves will replace milk for the supplement. This fact shows that order of preference of the calves is 1st milk, 2nd concentrate, and 3rd forage.

ENERGY REQUIREMENTS FOR LACTATING BEEF COWS

The calculations utilized for nutrient requirements of lactating Nellore cows and their calves followed the same recommendations suggested in the previous chapters. Due to the lack of experiments using lactating beef cows and their calves since the BR-CORTE 2010, the nutrient requirements of these animals were based on the experiment conducted by Fonseca (2009).

The relationship between empty body weight (EBW) and shrunk body weight (SBW) of lactating cows followed the recommendation from chapter 1:

$$EBW = 0.8507 \times SBW^{1.0002},$$

With the relationship between empty body gain (EBG) and ADG being 0.963. Accordingly explained in the chapter of energy requirements for beef cattle, heat production was indirectly obtained by the difference between metabolizable energy intake (MEI) and retained energy (RE), which were

determined by comparative slaughter techniques and energy secreted in the milk. Thereby, the net energy required for maintenance (NEm) of beef cows was obtained by the following equation:

$HP = 97.8 \times \exp^{(0.0024 \times MEI)}$, $S_{XY} = 0.5578$,

Where HP = heat production (kcal/$EBW^{0.75}$/d) e MEI = metabolizable energy intake (kcal/$EBW^{0.75}$/d). Thus, from the previous equation, when MEI is equivalent to heat production in fasting, we can obtain the value of 97.8 kcal/$EBW^{0.75}$/d, that is the net energy required for the maintenance of lactating Nellore cows.

The NRC (1996) established the NEm for beef cattle as 77 kcal/$EBW^{0.75}$/d, obtained from the data of Lofgreen e Garret (1968). Also, this system recommended reduction of 10% for zebu cattle and increase of 20% for lactating beef cows. Therefore, adopting these recommendations, the net energy required for the maintenance of lactating Nellore cows, according to NRC (1996), would be 83.2 kcal/$EBW^{0.75}$/d. Buskirk et al. (1992) estimated the NEm to be 72.5 kcal/$SBW^{0.75}$/d for Angus cows.

Utilizing the recommendations of the BR-CORTE (2010), the NEm for Zebu cattle of different sexes was estimated as 74.2 kcal/$EBW^{0.75}$/d. Considering the increase of 20% for lactating cows (NRC, 1996), the value obtained for this animal category should be 89.0 kcal/$EBW^{0.75}$/d, which is below the result obtained by Fonseca (2009), 97.8 kcal/$EBW^{0.75}$/d.

Therefore, due to the lack of information for this animal category, we recommended the use of 97.8 kcal/$EBW^{0.75}$/d as the NE required for the maintenance of lactating Nellore cows.

The metabolizable energy required for the maintenance (MEm) of lactating Nellore Cows was obtained when the MEI was equal to the heat production using the iterative model in the previously proposed equation, which resulted in MEm of 135.4 kcal/$EBW^{0.75}$/d. From these values, the efficiency of the use of metabolizable energy (ME) for maintenance (*km*) was estimated as 72% (97.8/135.4). In a study developed by Freetly et al. (2006) using lactating primiparous beef cows (Hereford × Angus × Redpoll × Pinzgauer), the Mem was estimated as 146 kcal/$EBW^{0.75}$/d and the efficiency of the use of ME for maintenance was 72%. Nevertheless, Calegare et al. (2007) estimated MEm of 141.3 kcal/$BW^{0.75}$/d for lactating Nellore cows, with this value being close to that observed by Fonseca (2009).

The energy loss related to body reserves was obtained from the body composition of cows slaughtered after calving as baseline and those fed at maintenance level during the first 90 days of lactation that lost body weight. Then, the negative retained energy was 2.1 Mcal/d divided by body weight losses of 0.48 kg/d, resulting in a mean value of 4.3 Mcal/BW loss. This value is below those recommended by other nutrient requirement systems that utilized *Bos taurus taurus* cattle as a baseline for the calculations which could explain the differences between them (Table 12.11). The efficiency of the use of energy from body reserves for MY obtained by Freetly et al. (2006) was 78%, while the AFRC (1993) and the CSIRO (2007) considered this efficiency as 84%.

Table 12.11 - Energy loss related to body weight mobilization (Mcal/kg BW loss) according to different nutrient requirement systems

Characteristic	Fonseca (2009)	NRC (1996)	CSIRO (2007)		INRA (1989)	AFRC (1993)
			British breeds	European breeds		
Body reserve mobilization	4.3	5.8	6.4	5.5	6.0	4.5

However, few studies involving the estimate of nutrient requirements of Zebu female cattle were conducted in Brazil (Calegare et al., 2007; Fonseca, 2009; Marcondes et al., 2009; Costa e Silva et al., 2015b). Also, these studies were conducted in feedlot, where the animals were housed in individual pens to allow for a better control of

important variables such as metabolizable energy intake, which is utilized for the estimates.

Thereby, we believe that there is an underestimation of the energy required for the maintenance of animals raised in feedlot as it is not considered an extra energy expense that would be observed for animals raised on pasture. In an extensive scenario, the heat production of animals is influenced by several interrelated factors such as forage availability and quality, environment conditions, and animal behavior when raised on pasture, as described in the chapter about energy requirements for beef cattle.

According to studies conducted with animals raised on pasture where heat production was estimated from the heartbeat rate, energy expenditure related to activities of grazing and locomotion, both horizontal and vertical plans in pasture areas, corresponded to 8 and 11.2% of the total energy production, respectively (Brosh, et al., 2010). Thus, research evaluating the increase in requirements for maintenance that grazing activities can cause in the lactating herd can be conducted in Brazil to improve the understanding of variations in the energy efficiency of animals (Kelly et al., 2010).

The net energy required for growth (Neg) of lactating Nellore cows was calculated from equations described by Fonseca (2009)

$$NEg = EBG \times (1.0076 \times EBW^{0.2389}),$$

where NEg = net energy requirement for gain (Mcal/d) e EBW = empty body weight (kg/d). The efficiency of metabolizable energy (ME) utilization for gain (kg) of lactating Nellore cows was 0.44, equivalent to the slope of the line produced from the relationship between RE (kcal/$EBW^{0.75}$/d) and MEI (kcal/ $EBW^{0.75}$/d) described in Figure 12.3. Flatt et al. (1967), working with lactating Holstein cows, found a value of 0.64 for kg. If we consider a retained energy equal to zero in this equation, we can estimate the ME requirements for lactation of 140.1 kcal/ $EBW^{0.75}$, a value close to that obtained by the iterative

The energy required for lactation (NE*l*) was considered as the net energy from milk, which resulted in 0.75 Mcal/kg milk in the study of Fonseca (2009). Considering the efficiency of the use of metabolizable energy for lactation (*kl*) equal to *km* (NASEM, 2016) of 0.72, the requirements of ME for lactation (MEl) are 1.04 Mcal/kg milk.

In addition, NE per kg of milk can be obtained from milk constituents, with each component multiplied by its respective energy value. Thus, using the average milk composition from table 12.5, 3.56% CP, 4.56% lactose e 4.76% fat, the requirements of NE for lactation, using the equation proposed by NRC (2001), are NEl (Mcal/ kg milk) = 0.0929 × % fat + 0.0547 × % protein + 0.0395 × % lactose, which results in 0.82 Mcal/kg milk. Moreover, Mel can be calculated as 1.14 Mcal/kg milk (0.82/0.72), which is higher than that found by Fonseca (2009), possibly due to the greater fat content in milk (Table 12.5). Alternatively, if there is no complete milk composition, or when there is only knowledge of the fat content of milk, the equation from the NRC (2001) can be used: NEl (Mcal/kg milk) = 0.36 + 0.0969 × % fat.

To convert ME to TDN, the equation suggested in this edition was (for more details, see chapter 8): ME 0.9455 × DE – 0.3032, and then to convert from DE to TDN, the factor of 4.4 was utilized. Thereby, the NE_l would result in TDN requirements of 0.35 kg/kg milk when ME_l is 1.14 Mcal/kg milk.

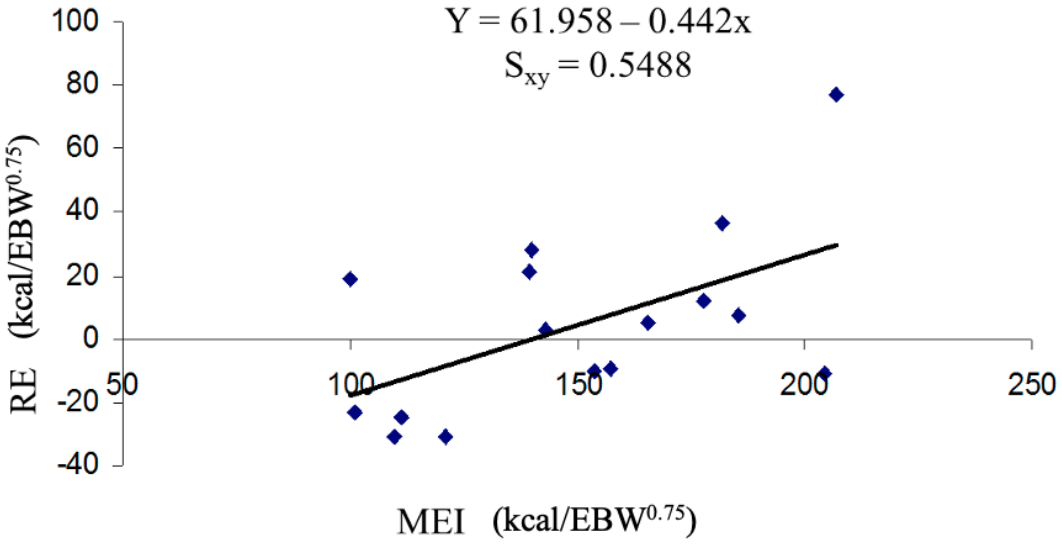


Figure 12.3 - Retained energy as a function of metabolizable energy intake. Adapted from Fonseca et al. (2012).

ENERGY REQUIREMENTS FOR SUCKLING BEEF CALVES

The conversion of SBW to empty body weight (EBW) of suckling beef calves can be obtained by the ratio EBW/SBW, which is equal to 0.962. Also, ADG can be converted to empty body gain (EBG) by the ratio EBG/ADG equal to 0.958 for suckling calves (Fonseca et al., 2012b). Due to the lack of adjustment from the study by Fonseca et al. (2012b), the requirements of ME for the maintenance of suckling calves were not estimated. However, Costa e Silva et al. (2015b) evaluated the requirements of NEm of Nellore calves with body weight varying from 121 to 300 kg and suggested the following equation:

$$HP = 0.294 \times \exp^{(1.0530 \times MEI)}$$

where HP = heat production is given as MJ/EBW$^{0.75}$/d and MEI = metabolizable energy intake (MJ/EBW$^{0.75}$/d).

Thus, from the previous equation, the NEm can be obtained as 294 kJ/EBW$^{0.75}$/d, or 70.3 kcal/EBW$^{0.75}$/d for Nellore calves. For the requirements of ME for maintenance, when MEI is equal to the heat produced at fasting, using the same equation, the value obtained was 118.6 kcal/EBW$^{0.75}$/d. Therefore, dividing NEm by MEm, the efficiency of the use of metabolizable energy for maintenance was 59.3%. The net energy required for growth (NEg) of suckling Nellore calves (Fonseca et al., 2012b) was estimated using the following equation:

$$NEg = 0.0932 \times EBW^{0.75} \times EBG^{0.9157},$$

where NEg = net energy required for growth (Mcal/d), EBW$^{0.75}$ = metabolic empty body weight, and EBG = empty body gain.

To convert the net energy required for growth (NEg) to the metabolizable energy required for growth (MEg), two factors of the efficiency of the use of Meg were utilized, with *kg* = 0.69 for milk intake and *kg* = 0.57 for solid feedstuff intake according to the recommendations by the NRC (2001). Then, in the period from 0 to 90 days of age, the *kg* of 0.62 was considered (77 × 0.69 + 23 × 0.57) corresponding to the body weight of the animals weighing up to 100 kg; in the period from 90 to 180 days (> 100 kg body weight), the *kg* of 0.62 was considered (43 × 0.69 + 57 × 0.57), with 77 and 23%, and 43 and 57% being the relationships between milk intake and solid feedstuff consumed by calves in the respective periods (Fonseca, 2009).

DE requirements were calculated as: ME/0.96 (NRC, 2001) for suckling calves) and the TDN requirements were calculated as DE/4.4.

PROTEIN REQUIREMENTS FOR LACTATING BEEF COWS

The requirements of metabolizable protein for maintenance (MPm) were calculated from the equation suggested by the BR-CORTE (2016) (for more details, see chapter 9) for animals raised on pasture:

$$MPm = 3.9 \times SBW^{0.75},$$

where $SBW^{0.75}$ = metabolic shrunk body weight.

The net requirements of protein for growth (NPg) of primiparous Nellore cows were calculated from the equation proposed by Fonseca (2009):

$$NPg\ (g/d) = EBG \times (376.4 \times EBW^{-0.1839}).$$

To convert the NPg for the requirements of metabolizable protein for growth (MPg), the efficiency (*k*) was calculated utilizing the recommendation suggested by the BR-CORTE (2010):

$$k = 47.4\%.$$

The protein required for lactation is based on the amount of protein secreted in the milk. The amount of protein produced in the milk can be estimated from the equation presented to estimate milk yield. The NRC (2001) suggests an equation to calculate the requirements of metabolizable protein for lactation (MP_l):

$$MP_l = CPmilk/0.67 \times 1000,$$

where CPmilk = crude protein in the milk (kg/d), and 0.67 = efficiency of the use of metabolizable protein for lactation.

Considering the average content of CP in milk of 3.56; this CP content was multiplied by the percentage of true protein in milk (AFRC, 1993), which is 95%, resulting in the value of 3.38% or 33.8 g of true protein/ kg milk. Schroeder and Titgemeyer (2008) performed a review regarding the efficiency of the use of MP and said that the efficiencies of the use of digestible protein for body protein growth observed in calves were lower than the fixed value of 67% adopted by the NRC (2001).

Furthermore, this efficiency can be affected by several factors, such as the level of protein and energy intake, BW, age, genotype of animals, and feeding frequency (Schroeder and Titgemeyer, 2008). Due to the lack of consistent values, we considered the efficiency of the use of metabolizable protein for lactation to be 0.67 (NRC, 2001), which resulted in the value of 50.5 g MP/ kg milk, corresponding to the requirements of MP for lactation. This value is greater than 44.8 g de MP/ kg milk presented for milk with 3.15 % CP (AFRC, 1993; NRC, 2001). Therefore, we suggested that requirements of MP for lactating beef cows might be 50.5 g/kg milk.

The microbial crude protein synthesis (MCP) was calculated considering the recommendation presented in chapter 3, where microbial crude protein synthesis (MCP) was calculated as function of the intake of CP and TDN as follows:

$$MCP\ (g/d) = -53.07 + 304.9 \times CPI + 90.8 \times TDNI - 3.13 \times TDNI^2,$$

where CPI = crude protein intake (kg/d) and TDNI = intake of total digestible nutrients (kg/d).

Thus, the requirements of rumen degradable protein (RDP) were calculated from the recommendations of this edition, where microbial protein synthesis equals RDP requirements (for more details, see chapter 9):

$$RDP = MCP,$$

where the requirements of rumen undegradable protein (RUP) were obtained from the following equation:

$$RUP = (Total\ metabolizable\ protein - (MCP \times 0.64))/0.80.$$

So, the requirements of CP would be equal to the sum of RDP and RUP.

PROTEIN REQUIREMENTS FOR SUCKLING BEEF CALVES

The recommendations for the requirements of metabolizable protein for maintenance (MPm) were based on the equation suggested by the BR-CORTE (2016) for animals raised on pasture (for more details, see Chapter 9):

$MPm = 3.9 \times SBW^{0.75}$.

The requirements of protein for the growth of suckling beef calves were calculated from the equation developed by Fonseca (2009):

$$NPg\ (g/d) = EBG \times (139.7 \times EBW^{0.0351}).$$

To convert the NPm for the requirements of metabolizable protein for growth (MPg), the efficiency (k) was calculated using the equation described by the BR-CORTE (2010):

$$k = 84.665 - 0.1179 \times EQEBW.$$

The same way as for cows, the microbial crude protein synthesis (MCP) was calculated considering the recommendation presented in Chapter 3, in which microbial synthesis was calculated as a function of CP (CPI) and TDN (TDNI) intakes.

However, when consuming milk, calves present reflex for the formation of an esophageal groove, making milk go directly into the abomasum without suffering the action of microorganisms in the rumen. In this case, considering that protein and energy from milk interfere with MCP would not be the most correct. Thus, for suckling calves, we recommended that the intakes of CP and TDN from milk should be removed from the calculation of MCP, because, otherwise, there will be an overestimation of RDP and an underestimation of RUP. Therefore, to calculate MCP of suckling calves, we recommended the use of the following equation:

$$MCP\ (g/d) = -53.07 + 304.9 \times (total\ CPI - CPImilk) + 90.8 \times (totalTDNI - TDNImilk) - 3.13 \times (totalTDNI - TDNImilk)^2,$$

where total CPI = total crude protein intake in the diet (kg/d), CPImilk = crude protein intake from milk (kg/d), total TDNI = total digestible nutrient intake in the diet (kg/d), and TDNImilk = total digestible intake from milk (kg/d).

For the calculation of CPImilk, the milk yield of cows might be quantified and multiplied by the CP content of the milk. For TDN, initially, the contents of CP, lactose and fat in the milk might be quantified. According to the publication by Maynard et al. (1979), which states that the digestibility of milk constituents is 0.98 (carbohydrates), 0.95 (fat) and NASEM (2016) of 0.95 (protein), we considered the sum of the digestible constituents of the milk to account for the TDN intake of milk as shown in the following equation:

$$TDNmilk = MY \times ((\%\ CP \times 0.95 + \%\ lactose \times 0.98) + (2.25 \times \%\ fat \times 0.95)).$$

Considering the mean milk composition in the study by Costa e Silva et al. (2015a) as 3.56 % CP, 4.56% lactose and 4.76 % fat, the TDN content this milk would be approximately 18% on a natural basis or 129.6% on a milk dry matter basis (18.0/0.139).

However, considering that calves with a BW less than 100 kg presenting low microbial activity in the rumen due to the intake almost exclusively from milk, and data for this animal category beyond this point being scarce for this body weight range, this edition adopted the same recommendation as the BR-CORTE (2010) to estimate microbial protein synthesis (MCP) of 120 g MCP/kg TDN. However, we highlight the need to discount TDN from milk, otherwise, the estimate of MCP would be overestimated.

Additionally, the requirements of rumen degradable protein (RDP) were calculated from the recommendation of this edition, for which microbial protein synthesis is equal to the RDP requirements (for more details, see Chapter 9):

$$RDP = MCP,$$

where the requirements of rumen undegradable protein (RUP) were obtained from the following equation:

$$RUP = (total\ metabolizable\ protein - (MCP \times 0.64))/0.80.$$

To obtain CP requirements, the sum of the requirements of RDP and RUP should be considered.

MINERAL REQUIREMENTS FOR LACTATING BEEF COWS AND THEIR CALVES

Due to the lack of data related to mineral requirements for maintenance and retention coefficient of lactating beef cows and suckling

calves, these estimates were calculated according to recommendations presented in Chapter 10 about the mineral requirements for beef cattle. Regarding the net requirements of macrominerals (Ca, P, Mg, Na, and K) for growth, the amounts of each mineral present in the animal body were regressed as a function of EBW from the following model:

$$Mi = a \times EBW^{b},$$

where Mi = the amount of each micromineral (ca, P, Mg, Na, and K; g) present in the animal body and EBW = empty body weight (kg).

From the derivative of the equation above, the net requirements of macrominerals (Ca, P, Mg, Na, and K) for growth of lactating beef cows and suckling calves were calculated from the following model:

$$Y = a \times b \times EBW^{b-1},$$

where Y = net requirements of each mineral for growth (g/d), EBW = empty body weight (kg).

Thus, the equations of the net requirements of each mineral for growth considering each animal category are shown in the Table 12.12. Due to the lack of adjustment to Ca data from lactating cows (Fonseca, 2009), the recommendation of Chapter 10 was used to estimate the net requirements for the growth of this mineral. Furthermore, due to the lack of sulfur and microminerals recommendations for both cattle categories (Fonseca, 2009), the equations described in Chapter 10 were adopted.

Table 12.12 - Net requirements of macrominerals for growth of lactating beef cows and their calves

Item	Equations	
	Cows[1]	Calves
Ca	EBW < 462 kg: EBG × (147 × EBW$^{-0.50}$) EBW ≥ 462 kg: NCag (kg) = 0	EBG × (54.8 × EBW$^{-0.3981}$)
P	EBG × (54.4 × EBW$^{-0.4484}$)	EBG × (8.6 × EBW$^{-0.0371}$)
Mg	EBG × (1.4 × EBW$^{-0.3227}$)	EBG × (0.4 × EBW$^{-0.0173}$)
Na	EBG × (1.4 × EBW$^{-0.0575}$)	EBG × (1.2 × EBW$^{-0.0209}$)
K	EBG × (3.1 × EBW$^{-0.2142}$)	EBG × (1.5 × EBW$^{-0.0636}$)

[1]Recomendation for calcium of chapter 10. Other equations adapted from Fonseca (2009). EBW = empty body weight (kg); EBG = empty body gain (kg/d). Considering cows heavier than 544 kg BW, the net Ca required for growth is equal to zero (for more details, see Chapter 10)

TABLES OF NUTRIENTS REQUIREMENTS FOR LACTATING BEEF COWS AND THEIR CALVES

Dietary nutrients requirements can be calculated from estimates of the requirements of energy, protein, and macrominerals for growth of lactating beef cows and suckling calves. The equations utilized for the calculations of nutrient requirements of lactating beef cows and suckling calves can be seen in Tables 12.13, 12.14 and 12.15, respectively, with the equation utilized to calculate microbial N described in Chapter 3, for maintenance, retention coefficient, and dietary requirements of microminerals described in Chapter 10.

Table 12.13 - Summary of the equations to estimate energy and protein requirements for lactating beef cows and their calves

Item	Equations		Unidad
	Cows	Calves	
DMI	$6.535 - 7.558 \times \exp^{(-0.578 \times WL)} + 0.323 \times WL + 1.66 \times MY$	0.353 - 0.532 × DMImilk + 0.01065 × BW + 0.3497 × ADG	
MY	Multiparous cows (> 3 years) $MY = 7.996 - 0.101 \times WL - 7.996 \times \exp^{(-1.447 \times WL)}$, Primiparous cows (≤ 3 years) $MY = 6.431 - 0.072 \times WL - 6.431 \times \exp^{(-2.188 \times WL)}$,	-	kg/d
SBW	$0.8915 \times BW^{1.0151}$	-	kg
EBW	$0.8507 \times SBW^{1.0002}$	0.962 × SBW	kg
EBG	$0.963 \times ADG^{1.0151}$	0.958 × ADG	kg/d
NEm	$97.8 \times EBW^{0.75}$	$70.3 \times EBW^{0.75}$	kcal/d
MEm	$135.0 \times EBW^{0.75}$	$118.6 \times EBW^{0.75}$	kcal/d
km	NEm/MEm		%
NEg	EBG × (1.0076 × $EBW^{0.2389}$)	$0.0932 \times EBW^{0.75} \times EBG^{0.9157}$	Mcal/d
kg	0.44	Milk = 0.69 Solids = 0.57	-
MEg	NEg/kg		Mcal/d
NE_l	0.82	-	Mcal/kg milk
k_l	*km*	-	-
ME_l	NE_l / k_l		Mcal/d
MEt	MEm + MEg + ME_l	MEm + MEg	Mcal/d
DE	(((MEt/DMI) + 0.3032)/0.9455) × DMI	MEt/0.96	Mcal/d
TDN	DE / 4.4		kg/d
MPm	$3.9 \times SBW^{0.75}$		g/d
NPg	EBG × (376.4 × $EBW^{-0.1839}$)	EBG × (139.7 × $EBW^{0.0351}$)	g/d
k	47.4	84.665 – 0.1179 × EQEBW	%
MP_l	50.5	-	g/kg milk
MPt	MPm + MPg + MP_l	g/d	MPt
CPImilk	-	MY × 0.0356	g/d
TDNImilk	-	MY × 0.18	kg/d
MCP	-53.07 + 304.9 × CPI + 90.8 × TDNI – 3.13 × $TDNI^2$	SBW <150 kg: 120 g/kg TDN – TDNImilk SBW ≥ 150 kg: -53.07 + 304.9 × (CPI – CPImilk) + 90.8 × (TDNI – TDNImilk) – 3.13 × (TDNI – TDNImilk)^2	g/d
RDP	MCP		g/d
RUP	(MPt - (MCP × 0.64))/0.80		g/d
CP	RDP + RUP		g/d

Table 12.14 - Summary of the equations to estimate net requirements of macrominerals (Ca, P, Mg, Na, and K) for growth (g/d) of lactating beef cows and their calves

Item	Equations	
	Cows	Cows
Ca	EBW < 462 kg: EBG × (147 × EBW$^{-0.50}$) EBW ≥ 462 kg: NRGCa (kg) = 0	EBG× (54.8 × EBW$^{-0.3981}$)
P	EBG × (54.4 × EBW$^{-0.4484}$)	EBG × (8.6 × EBW$^{-0.0371}$)
Mg	EBG × (1.4 × EBW$^{-0.3227}$)	EBG × (0.4 × EBW$^{-0.0173}$)
Na	EBG × (1.4 × EBW$^{-0.0575}$)	EBG × (1.2 × EBW$^{-0.0209}$)
K	EBG × (3.1 × EBW$^{-0.2142}$)	EBG × (1.5 × EBW$^{-0.0636}$)

[11]EBW = empty body weight (kg); EBG = empty body gain (kg/d). NRGCa = net Ca required for growth is equal to zero (for more details, see Chapter 10)

Table 12.15 - Summary of the equations utilized for the calculation of net requirements of S and microminerals (Cu, Co, Cr, Fe, Mn, Mo, Se e Zn) for beef cattle (Adopted from Chapter 10)

Mineral	Net requirements for maintenance	Retention coefficient	Net requirements for growth (NRG)[1]
	µg/kg body weight	%	mg/d
S	10.4	77.3	NRG_S = EBG × (0.03 × EBW$^{0.8900}$)
Cu	95.6	73.5	NRG_{Cu} = EBG × (1.25 × EBW$^{0.33}$)
Co	13.5	86.8	NRG_{Co} = EBG × (0.045 × EBW$^{-0.023}$)
Cr	22.9	78.4	NRG_{Cr} = EBG × (0.23 × EBW$^{0.61}$)
Fe	2,942	73.4	NRG_{Fe} = EBG × (10.4 × EBW$^{0.24}$)
Mn	184.9	43.9	NRG_{Mn} = EBG × (0.07 × EBW$^{0.80}$)
Mo	3.27	49.7	NRG_{Mo} = EBG × (0.0035 × EBW$^{0.41}$)
Se	3.72	48.7	NRG_{Se} = EBG × (1.07 × EBW$^{-0.07}$)
Zn	334.4	66.8	NRG_{Zn} = EBG × (1.16 × EBW$^{0.86}$)
	mg/kg body weight	%	g/d
S	10.4	77.3	NRG_S = EBG × (0.03 × EBW$^{0.8900}$)

[1]EBG = empty body gain (kg/d); EBW = empty body weight (kg)

Thereby, considering lactating beef cows with 450 kg in the 10th week of lactation with average daily gain of 0.2 kg/d, we have:

• MY = 7.996 – 0.101 × WL – 7.996 × exp$^{(-1.447 \times WL)}$ = 7.996 – 0.101 × 10 – 7.996 × exp$^{(-1.447 \times 10)}$ = 6.99 kg/d.
• DMI = 6.535 – 7.558 × exp$^{(-0.578 \times 10)}$ + 0.323 × 10 + 1.66 × 6.99 = 21.34 g/kg BW
• DMI = 21.34 g/kg BW × 450 kg = 9.6 kg/d
• SBW = 0.8915 × BW$^{1.0151}$ = 0.8915 × 450$^{1.0151}$ = 439.9 kg
• EBW = 0.8507 × SBW$^{1.0002}$ = 0.8507 × 439.9$^{1.0002}$ = 374.7 kg
• EBG = 0.963 × ADG$^{1.0151}$ = 0.963 × 0.2$^{1.0151}$ = 0.188 kg/d

- Energy requirements:

• NEm = 97.8 × EBW$^{0.75}$ = 97.8 × 374.7$^{0.75}$ = 8329.4 kcal/d = 8.33 Mcal/d
• NEm = 135.0 × EBW$^{0.75}$ = 135.0 × 374.7$^{0.75}$ = 11497 kcal/d = 11.50 Mcal/d
• NEg = 1.0076 × EBW$^{0.2389}$ × EBG = 1.0076 × 374.7$^{0.2389}$ × 0.188 = 0.78 Mcal/d

• MEg = NEg/*kg* = 0.78/0.44 = 1.77 Mcal/d
• NE_l = 0.82 Mcal/kg milk = 0.82 × 6.99 = 5.73 Mcal/dia
• $ME_l = NE_l/k_l$ = 5.73/0.72 = 7.96 Mcal/dia
• MEt = MEm + MEg + ME_l = 11.50 + 1.77 + 7.96 = 21.23 Mcal/dia
• DE = (((MEt/DMI) + 0.3032)/0.9455) × DMI = (((21.23/9.6) + 0.3032)/0.9455) × 9.6 = 25.53 Mcal/d
• TDN = DE/4.4 = 25.53/4.4 = 5.80 kg/d

- Protein requirements:
• MPm = 3.9 × $SBW^{0.75}$ = 3.9 × $439.9^{0.75}$ = 374.6 g/d
• NPg = 0.3764 × $EBW^{-0.1839}$ × EBG = 0.3764 × $374.7^{-0.1839}$ × 0.188 = 0.0238 kg/d = 23.80 g/d
• MPg = NPg/*k* = 23.80/0.474 = 50.2 g/d
• MP_l = 50.5 g/kg milk = 50.5 × 6.99 = 353 g/d
• MPt = MPm + MPg + MP_l = 374.6 + 50.2 + 353 = 777.8 g/d
• MCP = -53.07 + 304.89 × CPI + 90.8 × TDNI – 3.13 × $TDNI^2$ = -53.07 + 304.89 × 1.11 + 90.8 × 5.80 – 3.13 × $(5.80)^2$ = 706.9 g/d
• RDP = MCP = 706.9 g/d
• RUP = (MPt – (MCP × 0.64))/0.80 = (777.8 – (706.9 × 0.64))/0.80 = 406.7 g/d
• PB = RDP + RUP = 706.9 + 406.7 = 1.11 kg/d

To obtain the concentration required of TDN and CP (% DM in the diet), the requirements of TDN (5.83 kg/d) and CP (1.11 kg/d) might be divided by the DMI of the animal.

• TDN (% DM in the diet) = TDN/DMI = 5.80/9.6 = 60.4%
• CP (% DM in the diet) = CP/DMI = 1.11/9.6 = 11.6%

- Macromineral requirements:

• Calcium:
- Net requirements for maintenance = 11.7 × 450/1000 = 5.27 g/d
- Net requirements for gain = EBG × (147 × $EBW^{-0.50}$) = 0.188 × (147 × $374.7^{-0.50}$) = 1.42 g/d
- Net requirements for lactation = 1.1 g/kg milk = 1.1 × 6.99 = 7.68 g/d
- Dietary requirements = (Net requirements for maintenance + gain + lactation) / retention coefficient = (5.27 + 1.42 + 7.68)/0.568 = 25.30 g/d

• Phosphorus:
- Net requirements for maintenance = 13.5 × 450/1000 = 6.08 g/d
- Net requirements for gain = EBG × (54.4 × $EBW^{-0.4484}$) = 0.188 × (54.4 × $374.7^{-0.4484}$) = 0.71 g/d
- Net requirements for lactation = 0.77 g/kg milk = 0.77 × 6.99 = 5.38 g/d
- Dietary requirements = (Net requirements for maintenance + gain + lactation) / retention coefficient = (6.08 + 0.71 + 5.38)/0.678 = 17.95 g/d

Ca:P ratio = 25.30/17.95 = 1.41

• Magnesium:
- Net requirements for maintenance = 5.9 × 450/1000 = 2.66 g/d
- Net requirements for gain = EBG × (1.4 × $EBW^{-0.3227}$) = 0.188 × (1.4 × $374.7^{-0.3227}$) = 0.039 g/d
- Net requirements for lactation = 0.07 g/kg milk = 0.07 × 6.99 = 0.49 g/d
- Dietary requirements = (Net requirements for maintenance + gain + lactation)/retention coefficient = (2.66 + 0.039 + 0.49)/0.355 = 8.97 g/d

• Sodium:
- Net requirements for maintenance = 6.3 × 450/1000 = 2.84 g/d
- Net requirements gain = EBG × (1.4 × $EBW^{-0.0575}$) = 0.188 × (1.4 × $374.7^{-0.0575}$) = 0.186 g/d
- Net requirements for lactation = 0.2 g/kg milk = 0.2 × 6.99 = 1.39 g/d
- Dietary requirements = (Net requirements for maintenance + gain + lactation)/retention coefficient = (2.84 + 0.186 + 1.39)/0.371 = 11.91 g/d

• Potassium:
- Net requirements for maintenance = 23.5 × 450/1000 = 10.58 g/d
- Net requirements for gain = EBG × (3.1 × $EBW^{-0.2142}$) = 0.188 × (3.1 × $374.7^{-0.2142}$) = 0.164 g/d
- Net requirements for lactation = 0.7 g/kg milk = 0.7 × 6.99 = 4.89 g/d
- Dietary requirements = (Net requirements for maintenance + gain + lactation)/retention coefficient = (10.58 + 0.164 + 4.89)/0.484 = 32.3 g/d

• Sulfur:
- Net requirements for maintenance = 10.4 × 450/1000 = 4.68 g/d
- Net requirements for gain = EBG × (0.03 × $EBW^{0.89}$) = 0.188 × (0.03 × $374.7^{0.89}$) = 1.10 g/d
- Net requirements for lactation = 0.3 g/kg milk = 0.3 × 6.99 = 2.10 g/d
- Dietary requirements = (Net requirements for maintenance + gain + lactation)/retention coefficient = (4.68 + 1.10 + 2.10)/0.773 = 10.2 g/d

- **Micromineral requirements**:

• Cobalt:
- Net requirements for maintenance = 13.5 × 450/1000 = 6.08 mg/d
- Net requirements for gain = EBG × (0.045 × $EBW^{-0.023}$) = 0.188 × (0.045 × $374.7^{-0.023}$) = 0.007 mg/d
- Net requirements for lactation = 0.23 mg/kg milk = 0.23 × 6.99 = 1.608 mg/d
- Dietary requirements = (Net requirements for maintenance + gain + lactation)/retention coefficient = (6.08 + 0.007 + 1.608)/0.868 = 8.86 mg/d

• Copper:
- Net requirements for maintenance = 95.6 × 450/1000 = 43.02 mg/d
- Net requirements for gain = EBG × (1.25 × $EBW^{0.33}$) = 0.188 × (1.25 × $374.7^{0.33}$) = 1.66 g/d
- Net requirements for lactation = 1.99 mg/kg milk = 1.99 × 6.99 = 13.91 g/d
- Dietary requirements = (Net requirements for maintenance + gain + lactation)/retention coefficient = (43.02 + 1.66 + 13.91)/0.735 = 79.7 mg/d

• Chromium:
- Net requirements for maintenance = 22.9 × 450/1000 = 10.31 mg/d
- Net requirements for gain = EBG × (0.23 × $EBW^{0.61}$) = 0.188 × (0.23 × $374.7^{0.61}$) = 1.61 mg/d
- Net requirements for lactation = 3.2 mg/kg milk = 3.2 × 6.99 = 22.37 g/d
- Dietary requirements = (Net requirements for maintenance + gain + lactation)/retention coefficient = (10.31 + 1.61 + 22.37)/0.784 = 43.7 g/d

• Iron:
- Net requirements for maintenance = 2942 × 450/1000 = 1324 mg/d
- Net requirements for gain = EBG × (10.4 × $EBW^{0.24}$) = 0.188 × (10.4 × $374.7^{0.24}$) = 8.10 mg/d

- Net requirements for lactation = 29.9 mg/kg milk = 29.9 × 6.99 = 209 mg/d
- Dietary requirements = (Net requirements for maintenance + gain + lactation)/retention coefficient = (1324 + 8.10 + 209)/0.734 = 2099 mg/d

• **Manganese:**
- Net requirements for maintenance = 184.9 × 450/1000 = 83.21 mg/d
- Net requirements for gain = EBG × (0.07 × $EBW^{0.80}$) = 0.188 × (0.07 × $374.7^{0.80}$) = 1.50 mg/d
- Net requirements for lactation = 1.41 mg/kg milk = 1.41 × 6.99 = 9.85 mg/d
- Dietary requirements = (Net requirements for maintenance + gain + lactation)/retention coefficient = (83.21 + 1.50 + 9.85)/0.439 = 215.44 mg/d

• **Zinc:**
- Net requirements for maintenance = 334.4 × 450/1000 = 150.5 mg/d
- Net requirements for gain = EBG × (1.16 × $EBW^{0.86}$) = 0.188 × (1.16 × $374.7^{0.86}$) = 35.64 mg/d
- Net requirements for lactation = 35.4 mg/kg milk = 35.4 × 6.99 = 247.44 mg/d
- Dietary requirements = (Net requirements for maintenance + gain + lactation)/retention coefficient = (150.5 + 35.64 + 247.44)/0.668 = 649 mg/d

To exemplify the nutrient requirements of suckling beef calves, a 150 kg calf, at its 19^{th} week of life, with ADG of 0.80 kg/d and consuming a diet consisting of 43% milk and 57% forage + concentrate on DM basis:

• DMImilk = MY × % DM milk = 6.08 × 0.139 = 0.85 kg/d
• DMIrc = 0.353 – 0.532 × 0.85 + 0.01065 × 150 + 0.3497 × 0.80 = 1.78 kg/d
• DMItotal = DMIrc + DMImilk = 1.78 + 0.85 = 2.63 kg/d
• EBW = 0.962 × SBW = 0.962 × 150 = 144 kg
• EBG = 0.958 × ADG = 0.958 × 0.80 = 0.77 kg/d

- **Energy requirements**:
• NEm = 70.3 × $EBW^{0.75}$ = 70.3 × $144^{0.75}$ = 2.93 Mcal/d
• MEm = 118.6 × $EBW^{0.75}$ = 118.6 × $144^{0.75}$ = 4.94 Mcal/d
• NEg = 0.0932 × $EBW^{0.75}$ × $EBG^{0.9157}$ = 0.0932 × $144^{0.75}$ × $0.77^{0.9157}$ = 3.04 Mcal/d
• kg = 43 × 0.69 + 57 × 0.57 = 0.62
• MEg = NEg/kg = 3.04/0.62 = 4.9 Mcal/d
• MEt = MEm + MEg = 4.94 + 4.9 = 9.84 Mcal/d
• DE = ME/0.96 = 9.84/0.96 = 10.25 Mcal/d
• TDN = DE/4.4 = 10.25/4.4 = 2.33 kg/d

- **Protein requirements:**
• MPm = 3.9 × $SBW^{0.75}$ = 3.9 × $150^{0.75}$ = 167.2 g/d
• NPg = 0.1397 × $EBW^{0.0351}$ × EBG = 0.1397 × $144^{0.0351}$ × 0.77 = 0.1275 kg/d = 127.5 g/d
• k = 84.665 – 0.1179 × EQEBW = 84.665 – 0.1179 × 144 = 67.7%
• MPg = NPg/k = 127.5/0.677 = 188.4 g/d
• MPt = MPm + MPg = 167.2 + 188.4 = 355.6 g/d
• CPImilk = MY × 0.0356 = 6.09 × 0.0356 = 0.22 kg
• TDNImilk = MY × 0.18 = 6.09 × 0.18 = 1.10 kg

• MCP = -53.07 + 304.89 × (CPI – CPImilk) + 90.79 × (TDNI – TDNImilk) – 3.13 × (TDNI – TDNImilk)^2 = -53.07 + 304.9 × (0.471 – 0.22) + 90.79 × (2.33 – 1.10) – 3.13 × (2.33 – 1.10)^2 = 132.03 g/d
• RDP = MCP = 132.03 g/d
• RUP = (MPt – (MCP × 0.64))/0.80 = (355.6 – (132.03 × 0.64))/0.80 = 338.9 g/d
• CP = RDP + RUP = 132.03 + 338.9 = 471 g/d

As for cows, to obtain the concentration required of TDN and CP (%DM in the diet), the requirements of TDN (2.33 kg/ d) and CP (471 g/d) can be divided by the DMI of the animal.

• TDN (% DM in the diet) = TDN/DMI = 2.33/2.63 = 88.7%
• CP (% DM in the diet) = CP/DMI = 0.471/2.63 = 17.9%

- Mineral requirements:

• Calcium:
- Net requirements for maintenance: 11.7 × 150/1000 = 1.76 g/d
- Net requirements for gain = EBG × (54.8 × EBW$^{-0.3981}$) = 0.77 × (54.8 × 144$^{-0.3981}$) = 5.83 g/d
- Dietary requirements = (Net requirements for maintenance + gain)/retention coefficient = (1.76 + 5.83)/0.568 = 13.4 g/d

• Phosphorus:
- Net requirements for maintenance: 13.5 × 150/1000 = 2.03 g/d
- Net requirements for growth = EBG × (8.6 × EBW$^{-0.0371}$) = 0.77 × (8.6 × 144$^{-0.0371}$) = 5.51 g/d
- Dietary requirements = (Net requirements for maintenance + growth)/retention coefficient = (2.03 + 5.51)/0.678 = 11.1 g/d

Ca:P ratio= 13.4/11.1 = 1.20

• Magnesium:
- Net requirements for maintenance: 5.9 × 150/1000 = 0.89 g/d
- Net requirements for growth = EBG × (0.4 × EBW$^{-0.0173}$) = 0.77 × (0.4 × 144$^{-0.0173}$) = 0.28 g/d
- Dietary requirements = (Net requirements for maintenance + growth)/retention coefficient = (0.89 + 0.28)/0.355 = 3.29 g/d

• Sodium:
- Net requirements for maintenance: 6.3 × 150/1000 = 0.95 g/d
- Net requirements for growth = EBG × (1.2 × EBW$^{-0.0209}$) = 0.77 × (1.2 × 144$^{-0.0209}$) = 0.83 g/d
- Dietary requirements = (Net requirements for maintenance + growth)/retention coefficient = (0.95 + 0.83)/0.371 = 4.80 g/d

• Potassium:
- Net requirements for maintenance: 23.5 × 150/1000 = 3.53 g/d
- Net requirements for growth = EBG × (1.5 × EBW$^{-0.0636}$) = 0.77 × (1.5 × 144$^{-0.0636}$) = 0.84 g/d
- Dietary requirements = (Net requirements for maintenance + growth)/retention coefficient = (3.53 + 0.84)/0.484 = 9.03 g/d

We emphasize that there are no studies that aim to evaluate dietary requirements of S and microminerals for this animal category, being suggested the use of the same recommendations of Chapter 10.

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13

Prediction of nitrogen and phosphorus excretion for beef cattle

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INTRODUCTION

Beef cattle retain only a portion of the nutrients they consume. The remainder is lost in feces, urine, respiration, eructation, and flatulence (NASEM, 2016). The excretion distributed on well-managed pastures (extensive systems) represents little or no impact because the soil-plant system is able to use and to retain most of the nutrients in the manure. However, in the areas of drinking, resting or supplementation, there is an agglomeration of animals and soil compaction and the accumulated manure can represent an environmental problem. In feedlot, due the large concentration of animals, the large amounts of feces and urine that accumulate on the surfaces of the pens can drain into surface waters, leaching into soil or volatilizing into gases such as methane, ammonia, nitrous oxide and, in some situations, hydrogen sulfite.

Precision feeding is a great opportunity to reduce nutrient excretion. Feedlot nutrition will play an important role in addressing challenges such as nutrient management (Klopfenstein and Erickson, 2002) in the meat production chain. Environmental regulations in developed countries have addressed the need to reduce the excretion of certain compounds, especially nitrogenous (N) and phosphorus (P) compounds, due to soil, water and atmosphere pollution by N.

True protein is the nutrient with the highest unit cost in beef cattle diets, and its unbalanced inclusion in the diet results in increased production costs as well as increased excretion of nitrogen, mainly in urine, but also in the feces (Cavalcante et al., 2005). Phosphorus is the mineral that most contributes to environmental pollution and is considered a major polluter of water in many countries (Tamminga, 1992; Valk et al., 2000). Thus, the reduction of nitrogen and phosphorus losses is an environmental, social and economic concern.

Ruminant production systems are considered a major source of nitrogen and phosphorus excretion to the environment (Neeteson, 2000; Schroder et al., 2003). Intensified production increases the excretion of contaminants in manure. According to Tamminga (1992), the diet management was done with minimal or no concern about the nitrogen excretion in feces and urine. Nowadays, the environmental impact of animal feeding operations is a growing concern (Cole et al., 2006; Staerfl et al., 2012; Patra and Lalhriatipuii, 2016).

Rational control of nitrogen and phosphorus inputs (e.g., fertilizers remain and animal manure) is the main way to reduce environmental problems in agriculture. Cole (2003) proposed the use of precision feeding, defined as the feeding management of cattle in a way that does not reduce their performance, but rather decreases the nutrient concentration in the diet and thus also reduces the nutrient excretion in the environment. A tool for the use of this management would be the adequate formulation of diets to meet the nutritional requirements of cattle, reducing the excretion of polluting compounds without decreasing animal performance.

Reducing nitrogen and phosphorus excretion can result in less environmental impact and greater economic gain for the production system by reducing the use of nitrogen and phosphorus sources.

The development of control strategies is a complex issue, but an extremely important one. Proper sizing of animal facilities, avoiding surface runoff or infiltration into groundwater is essential. In addition, the management and composting of manure in intensive systems is a great opportunity to generate bio-fertilizers and/or bio-energy that minimize the environmental impact of beef cattle activity and can generate additional gains to the production system.

Thus, our objective was to develop equations for the prediction of nitrogen and phosphorus excretion by beef cattle under tropical conditions.

EVALUATION OF EQUATIONS PROPOSED BY NASEM (2016)

The NASEM (2016) incorporated information regarding the environmental impact of livestock farming. Prior to generating new equations for nitrogen and phosphorus excretion, prediction equations of nitrogen and phosphorus excreted (Geisert et al., 2010; Waldrip et al., 2013; Dong et al., 2014) as proposed by NASEM (2016), were tested for appropriateness for these databases. The tested equations are presented below.

Urinary N (g/d) = - 21.18 + 0.56 × NI
[Waldrip et al., 2013]

Fecal N (g/d) = 24.28 + 0.15 × NI
[Waldrip et al., 2013]

Urinary N (g/d) = - 14.12 + 0.51 × NI
[Dong et al., 2014]

Fecal N (g/d) = 15.82 + 0.20 × NI
[Dong et al., 2014]

Urinary N (g/d) = 2.39 + 0.55 × NI – 3.36 × DMI
[NASEM, 2016]

Total P (g/d) = 0.82 + 0.57 × P intake
[Geisert et al., 2010]

where NI is nitrogen intake (g/d); DMI is dry matter intake (kg/d) and P intake is phosphorus intake (g/d).

The equations proposed by the NASEM (2016) were tested using the BR-CORTE (2016) database. For nitrogen excretion, we used 751 individual data (Table 13.3) and for phosphorus excretion we used 178 individual data (Tables 13.8 and 13.10).

The equations for nitrogen excretion (Waldrip et al., 2013; Dong et al., 2014) use nitrogen intake as an independent variable. The NASEM (2016) proposed an equation for predicting urinary N excreted using the nitrogen intake and dry matter intake as independent variables. The equations cited by the NASEM (2016) system do not correctly estimated excretion of nitrogen ($P < 0.05$; Table 13.1). The equation showed from low to high systematic bias (4 to 38%). The lack of accuracy to estimate the excretion of N can be explained by the small number of young animals, with lower nitrogen intake, in the database used to generate the equations and due to genetic factors.

The proposed equation for P excretion (Geisert et al., 2010) did not correctly estimate P excretion for the BR-CORTE data ($P < 0.05$; Table 13.1); however, a high CCC value was obtained. The lack of accuracy in estimating the excretion of P can be explained by genetic factors, as the animals used by Geisert et al. (2010) differ from Zebu and crossbred animals used under tropical conditions.

Thus, it is necessary to develop equations consistent with the environmental and genetic conditions in Brazil. Therefore, the BR-CORTE (2016) generated new equations, based on a more robust database and with a greater number of observations to estimate nitrogen and phosphorus excretion by beef cattle under tropical conditions. These estimates are of critical importance for beef cattle production systems under such conditions as they help with environmental issues and can identify management practices to reduce excretions.

Table 13.1 - Regression analysis, concordance correlation coefficient (CCC), bias correction (Cb) and mean square error of prediction (MSEP) decomposition between the predicted and observed values of nitrogen and phosphorus excretion

Item	Waldrip et al. (2013)		Dong et al. (2014)		NASEM (2016)	Geisert et al. (2010)
	Fecal N	Urinary N	Fecal N	Urinary N	Urinary N	Total P
Regression analysis[1]	-	-	-	-	-	-
r^2	0.71	0.53	0.71	0.53	0.50	0.60
H_0: a = 0 and b = 1	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
CCC	0.59	0.72	0.71	0.72	0.69	0.76
Cb	0.70	0.98	0.84	0.99	0.97	0.99
MSEP	274	654	219	576	521	3.63
Mean bias (%)	0.28 (0.11)	6.40 (0.98)	1.39 (0.64)	10.3 (1.80)	24.0 (4.60)	0.07 (2.04)
Systematic bias (%)	106 (38.5)	199 (30.5)	48.9 (22.4)	118 (20.4)	19.4 (3.71)	0.13 (3.68)
Random errors (%)	168 (61.4)	448 (68.5)	168 (77.0)	448 (77.8)	478 (91.7)	3.43 (94.3)

[1] Linear regression between predicted and observed values using nitrogen and phosphorus excretion equations.

NITROGEN

Metabolism of nitrogen in animal and environment

Most protein sources have high digestibility for ruminants, often above 90% of true digestibility. Roughages and energy concentrates have lower digestibility. The indigestible protein is excreted in the feces, while the digested protein is converted into amino acids that can be used for animal tissue synthesis or oxidized for the production of ATP with consequent production of urea in the liver, partially filtered in the kidneys and excreted in the urine. Part of the urea can be recycled back into the gastrointestinal tract and assimilated by microorganisms. However, a portion of the nitrogen in microorganisms is excreted in the feces as a residue of microbial nitrogenous compounds (Satter et al., 2002).

Most of the nitrogen consumed by beef cattle is excreted in the feces and urine, and the loss of N through hair/scurf is of minor relevance. In manure, nitrogen is mainly present in the form of ammonia or organic nitrogen. These compounds are derived from undigested feedstuff in the gastrointestinal tract, indigestible microbial crude protein, endogenous nitrogen, urea and ammonia.

It is known that the efficiency of nitrogen assimilation by animals is low; this results in high levels of nitrogen excretion (Steinfeld et al., 2006). The nitrogen retention in animal product ranges from 5 to 20% of the total consumed. According to Hutchings et al. (1996), nitrogen use efficiency of beef cattle is approximately 10%. Detmann et al. (2014) using a database of animal on pasture under tropical condition found an average of 11.6% for the apparent nitrogen use efficiency. The average of nitrogen excretion, for this database, was 70%, analyzing 466 individual data, thus, on average 30% of N was retained, and this retention was higher than the average found in literature. Some causes of low nitrogen retention can be related to grazing systems with low quality forage (low N supply) or feedlot diets excess nitrogen, due to overestimation of animal requirements or use of requirement systems inconsistent to the climate conditions and animals (genetic groups).

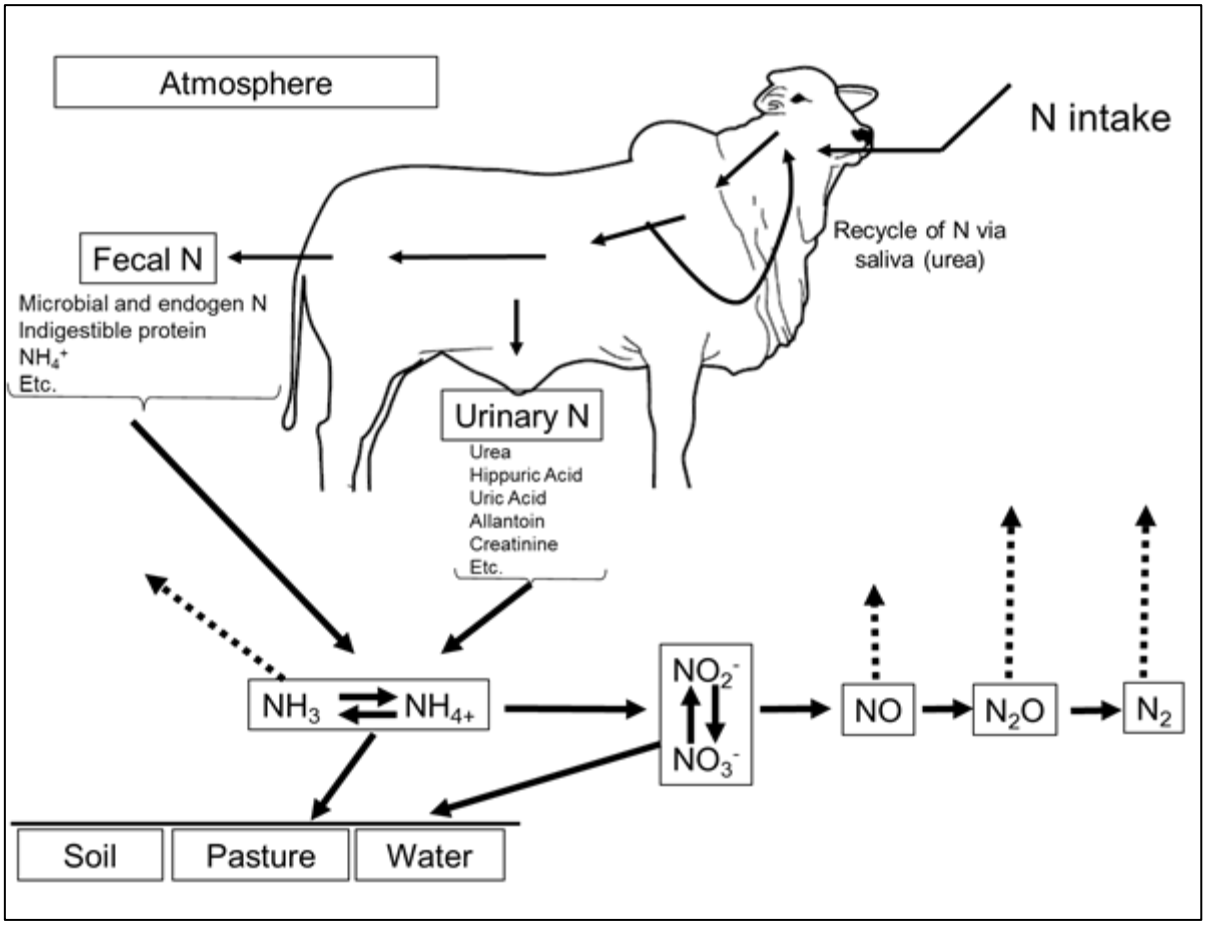
According to Menezes et al. (2016), nitrogen metabolism is affected by the different levels of crude protein in the diet, and urinary and fecal N excretion increases linearly with protein intake. If protein contents in the diet are higher than the animal nutritional requirements, it results in an increase of N excretion, mainly via urine. Therefore, reducing nitrogen excretion by meeting the nutritional requirements of animals, without decreasing performance, has great potential to reduce environmental impact of beef cattle production and increase economic return to producers.

The environmental concern about nitrogen is related to three main routes of this nutrient: losses as ammonia volatilization to the atmosphere, nitrate leaching in soil and groundwater, and nitrification and denitrification that result in nitrous oxide emission in the atmosphere (Scheme 13.1). According to De Klein and Eckard (2008),

nitrification and denitrification are the two major soil microbial processes that result in losses of nitrogen in the form of nitric oxide (NO) and nitrous oxide (N_2O).

Nitrification is an aerobic process where ammonium (NH_4^+) is oxidized to nitrite (NO_2^-), which is in turn oxidized to nitrate (NO_3^-), yielding N_2O as a by-product. This process is favored in well drained soils (appropriate aeration), high levels of NH_4^+ and elevated temperature. However, the proportion of N lost as N_2O through nitrification is minor. In contrast, denitrification is an anaerobic process where NO_3^- is reduced to N_2, being N_2O produced as the intermediate of the reaction. Denitrification is increased in wet soils, compacted soils, high temperatures, high concentration of NO_3^- and presence of reducing sources (C-labile) in soil. Thus, under tropical conditions, greater N_2O emissions from the denitrification are observed in the rainy season, being insignificant these emissions in the dry season (Lessa et al., 2014; Cardoso et al., 2019; Bretas et al., 2020).

In addition, the N losses due to the volatilization of NH_3 resulting from the deposition of urine are higher in the typical Brazilian summer, characterized by high temperatures and humidity.



Scheme 13.1. Summary of the nitrogen cycle.

According to IPCC (2019), the direct N_2O emissions from cattle excreta (without distinguishing between feces and urine) is 0.6 and 0.2 % of the total N present in excreta, respectively, for humid and dry climates. In indirect emissions, for each kg of excreta nitrogen deposited on the soil, 21% are volatilized and 24% leached. From the 21% volatilized, 1% is emitted in the form of N_2O, and from the 24% leached, 1.1% will be emitted as N_2O. However, these factors were produced in temperate conditions and may be inappropriate for the Brazilian climate and soil conditions. Furthermore, studies conducted in Brazil (Sordi et al., 2014; Lessa et al., 2014; Cardoso et al., 2017; Cardoso et al., 2019; Bretas et al., 2020) suggest that N_2O emission factors of excreta should be considered

separately, considering the type of excreta (feces or urine), to produce more accurate estimates of the environmental impact of livestock. These studies showed that the N_2O emission factor for feces is smaller than that emission from urine, and these emissions are minimal (or do not exist) in the dry season.

Lessa et al. (2014), using urine labelled with ^{15}N, evaluated the nitrogen lost through the deposition of urine in *Brachiaria brizantha* cv Marandu pasture in the tropical savannah region. They observed that 65% of N remained in the system, about 30% was lost as ammonia and the remaining 5% was emitted as N_2O or percolated. Additionally, the direct emission of N_2O considering dung and urine found by the authors (0.7% of the nitrogen excreta) was similar to the 0.6% adopted by IPCC (2019).

Sordi et al. (2014) evaluated the N_2O emissions in the dung and urine of cattle in a subtropical Brazilian pasture. The authors measured average direct N_2O emissions: 0.26% for urine and 0.15% for feces. They concluded that the value adopted by the IPCC (2019) is overestimated under Brazilian subtropical conditions. However, according to the authors, these results may be different depending on the animal's diet, excreted urine volume and microclimate conditions. Cardoso et al. (2019) reviewed 39 studies that measured the N_2O emission from dung and urine of cattle. The authors found an average emission factor of 0.63% for urine and 0.27% for dung.

Cardoso et al. (2018), evaluating the effect of the addition of different quantities of cattle urine and dung deposited in *Pangola* grass in southeastern Brazil on N_2O emissions, observed that the average emission was 0.18% for feces, regardless of the amount of manure applied (1.2, 1.8 or 2.4 kg). However, N_2O emissions decreased linearly with increasing in urine volume applied (1, 1.5 and 2 L). The authors attributed this decrease in emission factors with increased urine volume due to the greater flows of urine in the soil, carrying deeper the urea-N, and thus, reducing the availability of nitrogen for N_2O production.

Cardoso et al. (2017) identified that total N concentration of urine is the characteristic that most affects N_2O emissions. Bretas et al. (2020) also demonstrated the effect of N concentration in urine on N_2O emissions. The lower the concentration of N in the urine, the lower the N_2O emission. Therefore, strategies that reduce n excretion via urine are desirable for mitigating the emission of this gas.

The nitrogen in dung (mainly undigested dietary, microbial and endogenous proteins) differs substantially from the N in the urine (mainly urea, allantoin, hippuric acid, creatinine, ammonia and uric acid); the latter is more soluble and rapidly metabolized by microorganisms, which influences the rate of emission of each source (fecal or urinary N) as well as the severity of the environmental impact (Chizzotti et al., 2016). Thus, for a more precise estimate of the environmental impact of livestock, the prediction of urinary N excretion must be accounted separately from the fecal N excretion.

Data used to develop the equations using meta-analysis and cross-validation

The data used to estimate the parameters of the equations were collected from experiments with beef cattle (Nellore and crossbred), including information on all variables considered relevant to nitrogen excretion (feces and urine). The information collected for each observation included: body weight (BW), metabolic body weight ($BW^{0.75}$), percentage of crude protein in the diet (% CP), dry matter intake (DMI), total digestible nutrients intake (TDN) and nitrogen intake (NI).

The database included 751 observations from 18 theses and dissertations (Table 13.2), which investigated nitrogen intake and excretion, total digestible nutrients intake and body weight. Descriptive statistics (minimum, maximum, mean, and standard deviation) for all variables used in the development of prediction equations of nitrogen excretion is shown in Table 13.3.

Spearman's correlations were used to determine variables influencing nitrogen excretion via urine and feces in beef cattle. After this correlation, stepwise procedure was used to select the model variables. Then, a meta-analysis (St-Pierre, 2001), considering random effects from different studies was used to generate new prediction models. The meta-analysis was performed in order to examine the significance of the evaluated parameters. Several models and different variables were

tested; the choice of the best fitted models was based on Akaike's information criterion (AIC).

From the information collected for the selected variables (Table 13.3), we performed a meta-analysis to select the variables that significantly influence N excretion in feces and urine. The effects of independent variables were considered significant for a *P* value lower than 0.05.

Body weight, TDN and nitrogen intake significantly affected fecal N excretion. Dry matter intake and nitrogen intake significantly affected urinary N excretion.

Table 13.2 - Description of database used in the development of nitrogen excretion equations

Author	Year	n	Genetic group	Sex
Dias	1998	25	Crossbred	Bulls
Ladeira	1998	20	Nellore	Bulls
Cardoso	1999	25	Crossbred	Bulls
Tibo	1999	25	Crossbred	Bulls
Rennó	2003	64	Crossbred	Bulls
Dias	2005	12	Nellore	Heifers
Veras	2006	37	Nellore	Bulls, steers and heifers
Chizzotti	2007	29	Crossbred	Bulls
Marcondes	2007	18	Nellore	Bulls, steers and heifers
Marcondes	2010	27	Nellore and crossbred	Steers
Campos	2011	25	Nellore	Bulls
Cesario	2011	16	Crossbred	Bulls
Costa e Silva	2011	53	Nellore	Bulls
Rotta	2012	32	Crossbred	Bulls
Rufino	2014	40	Nellore	Bulls
Costa e Silva	2015	258	Nellore	Cows, bulls, steers and heifers
Louzada	2015	29	Nellore	Bulls and heifers
Menezes	2015	16	Nellore	Bulls

Table 13.3 - Descriptive statistics of the data used to fit the regression equations to estimate nitrogen excretion via urine and feces in beef cattle

Variables[1]	n	Mean	Standard deviation	Minimum	Maximum
BW, kg	751	312.73	123.23	34.94	671.78
DMI, kg/d	751	6.40	3.16	0.76	14.84
TDNI, kg/d	751	4.40	2.08	0.83	9.89
NI, g/d	751	134.84	65.70	24.53	328.00
Fecal N, g/d	751	43.97	23.96	6.36	167.35
Urinary N, g/d	466	47.68	30.93	4.83	178.61

[1] BW = body weight; DMI = dry matter intake; TDNI = total digestible nutrients intake; NI = nitrogen intake.

After evaluating the best models, we used the cross-validation method (leave-one-out) with the REG procedure of SAS to generate the parameters for nitrogen excretion prediction equations (Table 13.4).

The proposed equations for fecal and urinary N excretion are described below. However, for urinary N prediction, two equations were proposed, one based only on nitrogen intake and the other based on nitrogen and dry matter intake.

$$\text{Fecal N (g/d)} = 2.55 + 0.048 \times \text{BW} - 3.47 \times \text{TDNI} + 0.30 \times \text{NI}$$

$$\text{Urinary N (g/d)} = 3.26 + 3.68 \times \text{DMI} + 0.18 \times \text{NI}$$

$$\text{Urinary N (g/d)} = 3.82 + 0.34 \times \text{NI}$$

where: BW is body weight (kg); TDNI is total digestible nutrients intake (kg/d); NI is nitrogen intake (g/d); DMI is dry matter intake (kg/d);

The fixed effects solutions of the prediction equations for N excretion via urine and feces with their respective coefficients of determination (R^2) are shown in Table 13.4. In both equations, there was a positive relationship between nitrogen intake and excretion, corroborating with other studies (Cole, 2003; Marini e Van Amburgh, 2003; Menezes et al., 2016; Bougouin et al. 2022).

Predictions of N excretion proposed by Waldrip et al. (2013) and Dong et al. (2014), and used by NASEM (2016), also showed a positive correlation between nitrogen intake and excretion. These authors observed better fit of the prediction equations using the N intake than the percentage of crude protein in the diet, and the same behavior was observed in the present database.

Recently, Bougouin et al. (2022) performed a meta-analysis compiling data from several countries (including Brazil), containing individual data of beef cattle fed a wide variety of diets and observed that simple models using DMI showed better prediction of fecal N excretion whereas models based on N intake were more accurate for prediction of urinary and total N excretion. However, the authors observed that simple models, based only on DMI or N intake, have lower predictive performance when compared to complex models, which include DMI and concentrations of CP and NDF in the diet as predictive variables.

Table 13.4 - Solution of fixed effects of prediction equations based on significant variables with their respective coefficients of determination (R^2) for fecal and urinary nitrogen excretion

Item	Fecal N, g/d	Urinary N, g/d (Eq. 1)	Urinary N, g/d (Eq. 2)
Intercept	$2.55_{\pm 0.034}$	$3.26_{\pm 0.087}$	$3.82_{\pm 0.090}$
BW	$0.048_{\pm 0.0002}$	-	-
DMI	-	$3.68_{\pm 0.042}$	-
TDNI	$-3.47_{\pm 0.020}$	-	-
NI	$0.30_{\pm 0.0005}$	$0.18_{\pm 0.002}$	$0.34_{\pm 0.0008}$
R^2	0.585	0.545	0.530

[1] BW = body weight; DMI = dry matter intake; TDNI = total digestible nutrients intake; NI = nitrogen intake.

Adequacy of equations

After obtaining the urinary and fecal nitrogen excretion equations, we proceeded the validation using the Model Evaluation System software (MES; Tedeschi, 2006). There were used for the validation thirteen independent papers published between 2006 and 2015 in the journals: Brazilian Journal of Animal Science, Brazilian Journal of Veterinary and Animal Sciences and Semina. These data reported treatment average, totaling 45 averages for fecal N excretion and 50 averages for urinary N excretion (Table 13.5).

The prediction efficiency was evaluated by estimating the concordance correlation coefficient (CCC) and the mean square error of prediction, as proposed by Tedeschi (2006).

Table 13.5 - Descriptive statistics of the variables for validation of the proposed equations for nitrogen excretion

Variables[1]	n	Mean	Standard deviation	Minimum	Maximum
BW, kg	50	285.69	72.36	118.41	521.62
DMI, kg/d	50	5.55	1.41	2.80	8.37
TDNI, kg/d	50	3.59	0.85	1.20	5.14
NI, g/d	50	115.19	34.40	23.05	193.67
Fecal N, g/d	45	40.31	11.99	15.82	65.92
Urinary N, g/d	50	43.38	22.21	4.79	102.74

[1] BW = body weight; DMI = dry matter intake; TDNI = total digestible nutrients intake; NI = nitrogen intake.

The results of the validation of equations for predicting nitrogen excretion by beef cattle under tropical conditions are shown in Table 13.6. According to Mayer's test the intercept and the slope of the regression of observed and predicted values did not differ from zero and one ($P > 0.05$), respectively, suggesting that the estimates were accurate in predicting the N excretion by beef cattle.

The CCC indicates the accuracy and precision of the model. The equations proposed correctly estimated the fecal and urinary N excretion by beef cattle. In the decomposition of MSEP (Table 13.6), the majority of the errors are random, demonstrating that there is no over or underestimation of proposed equations.

A comparison of both equations proposed for urinary N excretion revealed that the equation based on nitrogen intake alone as independent variable (Equation 2) had greater accuracy and a lower mean square error of prediction (MSEP).

The similarity of predicted and observed nitrogen excretion is shown in Figure 13.1. The data are similarly disposed around the identical line (dotted line).

Table 13.6 - Regression analysis, concordance correlation coefficient (CCC), bias correction (Cb) and mean square error of prediction (MSEP) decomposition between the predicted and observed values of nitrogen excretion

Item	Prediction equation of nitrogen excretion		
	Fecal N	Urinary N (Eq. 1)	Urinary N (Eq. 2)
Regression analysis[1]	-	-	-
r^2	0.453	0.270	0.431
H_0: a = 0 and b = 1	0.131	0.902	0.526
CCC	0.64	0.40	0.55
Cb	0.95	0.77	0.83
MSEP	86.37	354.47	282.15
Mean bias (%)	4.98 (5.77)	0.51 (0.14)	0.005 (0.002)
Systematic bias (%)	2.80 (3.25)	0.99 (0.28)	7.44 (2.638)
Random errors (%)	78.59 (90.98)	352.97 (99.58)	274.705 (97.36)

[1]Linear regression between predicted and observed values by means of nitrogen excretion via urine and feces equations.

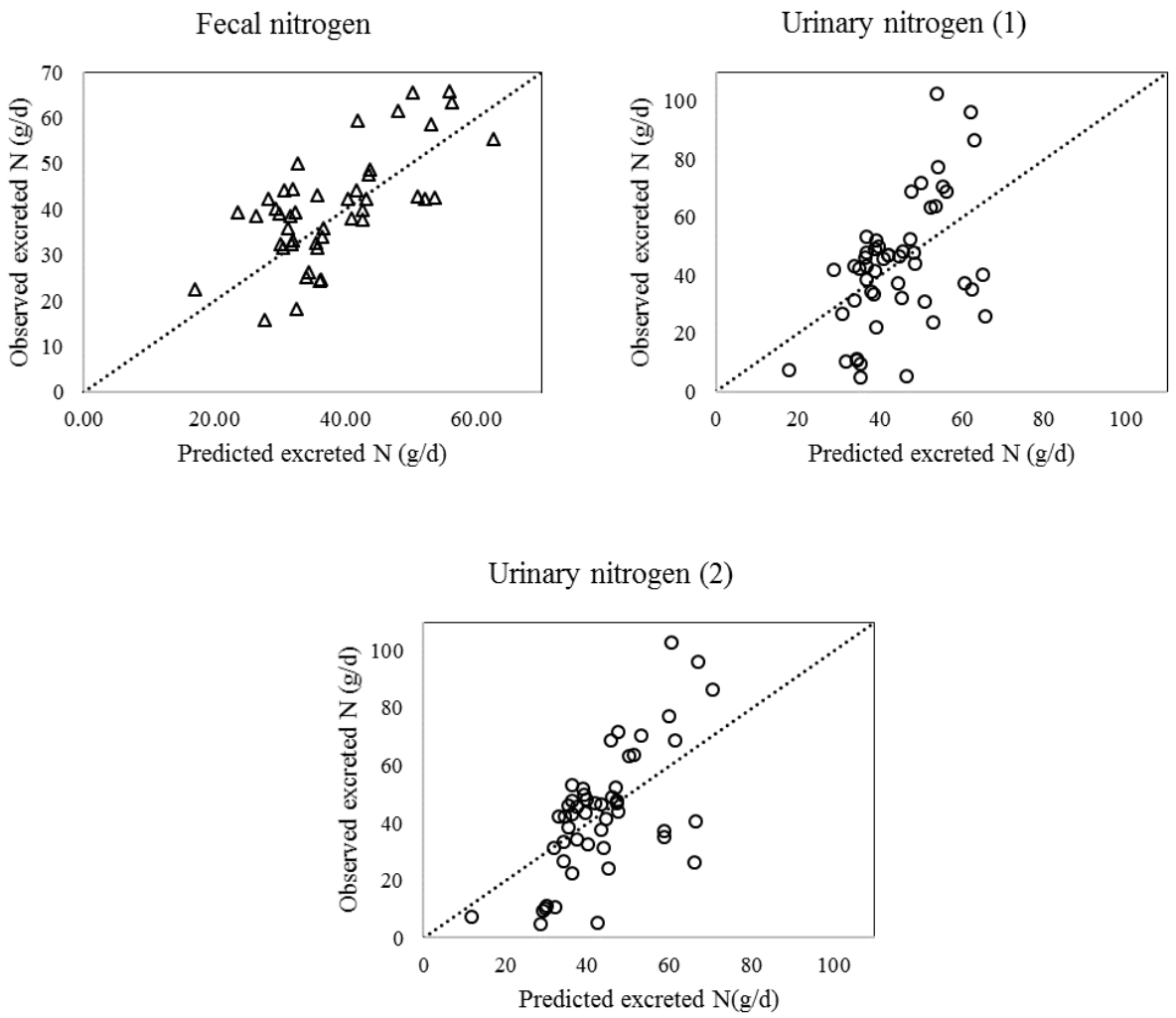


Figure 13.1 - Relationship between the observed values of fecal and urinary nitrogen excretion and those determined by the proposed equations. Predicted values are plotted on the X axis and the observed values are on the Y axis. The dotted line represents the ideal line (Y = X), intercept = 0 and slope = 1.

It is possible to meet the nutritional requirements of animals while reducing the crude protein in the finishing diet, which would also result in reduced intake of CP and N excreted to the environment (Cole et al., 2006). Thus nitrogen content in the diet can directly influence its excretion, explaining the use of this variable in the proposed equations. The excess of protein in the diet results in increased urinary urea excretion.

The optimization of microbial protein synthesis in the rumen can increase the efficiency of N use, which leads to decreased losses (Reynal and Broderick, 2005). The efficient growth of the microorganisms in the rumen and consequently optimization of microbial protein synthesis depends on the available energy (TDN; Dijkstra et al., 1998), justifying the use of TDN variable in fecal N excretion equation.

PHOSPHORUS

Metabolism of phosphorus in animal and environment

Phosphorus, despite being component of nucleic acids and having important structural role, is also involved in animal performance. Until recently, the recommendations of dietary P were conducted to ensure any deficit (safety margin), aiming maximum performance (Klopfenstein et al., 2002). But nowadays, environmental concerns began to be related to its excretion. With the increasing demand for environmental sustainability in all agricultural sectors, P

excess in soil is considered as dangerous for the environment as its scarcity (Pfeffer et al., 2005). Another important point of the P, is the fact that it is a non-renewable source and 90% of its demand is used for food production (Gunther, 2005). Steen (1998) has estimated that the global commercial P reserves will be exhausted from 50 to 100 years. Thus, the rational use of this mineral is essential.

Phosphorus goes into the rumen in two main ways: via saliva (recycling) and via diet (Scheme 13.2). The phosphorus recycling supplies partially the requirements of the rumen microorganisms, and it is responsible for 50% of the phosphorus that enters in the rumen (Kincaid and Rodehutscord, 2005). Sathler (2015), working with two levels of phosphorus in the diet of Nellore, observed net recycling of P to the rumen, ranging from 13.96 to 23.35 g of P/d in animals consuming between 5.51 to 13.73 g of P/d.

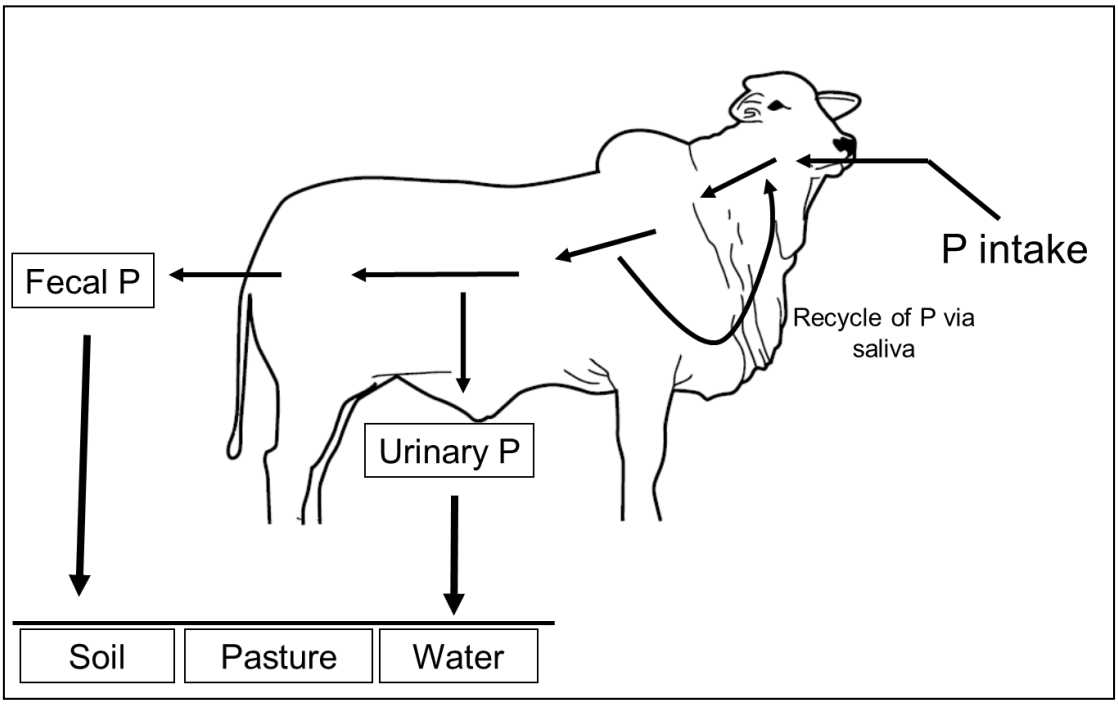
Most minerals are absorbed in the small intestine by specific transporters. The primary site for P absorption is the small intestine, with an average of 67.3% of the amount reaching this site, and the large intestine absorption of phosphorus is about 25.5% (Pfeffer et al., 2005; Sathler, 2015). The excess of phosphorus in the diet causes an increase in urinary excretion and in concentration in saliva which causes increase in phosphorus lost in feces (Underwood and Suttle, 1999). Phosphorus fecal excretion is a function of the intake (Geisert et al., 2010), showing a positive correlation.

Phosphorus fractions in feces are: the phosphorus contained in diets that have not been solubilized; phosphorus derived from microorganisms and endogenous losses, and phosphorus intake above the requirements of the animal (in ruminants, the major portion is excreted in feces).

The combination of phosphorus derived from microorganisms and endogenous sources in feces accounts for about half of total fecal phosphorus (Conrad, 1999), but this proportion varies depending on the amount of excess phosphorus in the diet. In the present database, urinary P represented only 9.6% of the total excreted. According to some studies, 90% of the total P excretion is via feces being only a marginal amount related to the urinary excretion (Braithwaite, 1985; Wylie et al., 1985; Martz et al., 1990; Khorasani and Armstrong, 1992; Bortolussi et al., 1996). Geisert et al. (2010), working with five different levels of P in the diets observed average of only 2.1 g/d of urinary P (10.8% of total phosphorus excreted). Phosphorus is excreted in the urine after the requirements of maintenance and production are met (Vitti et al., 2000; Geisert et al., 2010).

Various studies have used the NRC (1996) recommendations to make more accurate recommendations regarding the optimal level of phosphorus in the diet for beef cattle. Researches conducted at the University of Nebraska - USA by Erickson et al. (1999 and 2002), noted that varying the P levels in the diet from 0.14 to 0.40 for feedlot cattle, suggested that the recommendations of NRC (1996) were overestimated by 30%. This reduction of P in the diet has cost implications in diets and also environmental implications. Prados et al. (2015) concluded that the estimates of the BR-CORTE (Valadares Filho et al., 2010) and NRC (2000) were overestimated in, respectively, 14 and 43% for crossbred cattle. According to NASEM (2016), most of feed grains and by-products used in feedlot diets contain at least 0.25% P, and that it is not necessary supplemental phosphorus. However, in extensive systems, based on tropical pastures phosphorus supplementation is essential, but must be done with discretion to do not waste this noble and expensive element, by using sources with good P solubility.

Phosphorus excreted to the environment can undergo mineralization-immobilization, which involves sorption reactions in clays, oxides and hydroxides in soil and solubilization by microorganisms and plants. The phosphorus is hardly runoff because Brazilian soils have high levels of iron and aluminum oxides, and kaolinite group clays, and they are able to immobilizing the phosphorus by specific adsorption. However, in cases of compacted soils or high concentration of manure, the phosphorus can be washed away during rain, reaching water bodies, and contributing to a procedure known as eutrophication. Eutrophication is the accumulation of nutrients dissolved in water, which favors the growth of algae and cyanobacteria, obstructing the passage of light and causing fish death from lack of oxygen when the algae die and go into deterioration.



Scheme 13.2. Summary of the phosphorus cycle.

Data used to develop the equations using meta-analysis and cross-validation

The data used to estimate the parameters of the equations were collected from experiments with beef cattle (Nellore and crossbred), which included information on all variables considered relevant to phosphorus excretion. The information collected for each observation included: body weight (BW), dry matter intake (DMI), phosphorus intake (P intake) and excretion of phosphorus.

The database included 178 observations from eight theses and dissertations (Table 13.7). Data were randomly separated into: one database to development of equations (142 observations) and one database for validation (36 observations, 20% of each study). Descriptive statistics (minimum, maximum, average and standard deviation) of data for developing the equations is listed in Table 13.8.

The procedure for developing the equations was the same as previously presented for nitrogen.

Table 13.7 - Description of database used in the development of phosphorus excretion equations

Author	Year	n	Genetic group	Sex
Souza	2009	20	Nellore and crossbred	Heifers
Marcondes	2010	8	Nellore and crossbred	Steers
Gionbelli	2010	7	Nellore	Heifers
Prados	2012	17	Crossbred	Bulls
Zanetti	2013	17	Crossbred	Steers
Costa e Silva	2015	45	Nellore	Heifers and steers
Sathler	2015	25	Nellore	Bulls
Prados	2016	39	Nellore	Bulls

Using the variables presented in Table 13.8, the variables that significantly influenced phosphorus excretion were selected. The effects of independent variables were considered significant for a level of probability lower than 0.05. The model used for fecal

phosphorus excretion included the following terms: body weight and phosphorus intake. Due to the low contribution of the urinary P, urinary P excretion equation was not generated, but it was generated an equation accounting for the total P excretion.

Fecal P (g/d) = 1.47 – 0.0019 × BW + 0.48 × P intake

Total P (g/d) = 1.90 – 0.0030 × BW + 0.53 × P intake

where: BW is body weight (kg); P intake is phosphorus intake (g/d).

Table 13.8 - Descriptive statistics of the data used for phosphorus excretion estimation in beef cattle

Variables[1]	n	Mean	Standard deviation	Minimum	Maximum
BW, kg	142	265.80	70.69	125.00	423.00
P intake, g/d	142	11.69	4.66	3.34	22.60
Fecal P, g/d	142	6.59	2.78	1.71	17.55
Total P, g/d	142	7.30	2.97	1.92	18.77

[1] BW = body weight; P intake = phosphorus intake.

After the evaluation of models and variables to be included in the equations, we used the cross-validation method (leave-one-out) using the REG procedure in SAS to generate the parameters for the prediction equations of phosphorus excretion. The solution of the fixed effects of the prediction equations for P excretion and their respective coefficients of determination (R^2) is shown in Table 13.9.

Table 13.9 - Solution of fixed effects of prediction equations based on significant variables and coefficients of determination (R^2) for phosphorus excretion

Item	Fecal P	Total P
Intercept	$1.47_{\pm 0.043}$	$1.90_{\pm 0.044}$
BW	$-0.0019_{\pm 0.0002}$	$-0.003_{\pm 0.0002}$
P intake	$0.48_{\pm 0.0035}$	$0.53_{\pm 0.0036}$
R^2	0.607	0.630

[1] BW is body weight; P intake = phosphorus intake.

Adequacy of equations

After obtaining the phosphorus excretion equations, it was proceeded the validation. This was performed using the Model Evaluation System program (MES; Tedeschi, 2006). Thirty-six independent data from the total database were used for this validation of phosphorus predictions (Table 13.10), as previously mentioned.

Prediction efficiency was assessed by estimating the concordance correlation coefficient (CCC) and mean square error of prediction (MSEP), according to Tedeschi (2006).

Table 13.10 - Descriptive statistics of the variables for validation of the proposed equations for phosphorus excretion

Variables	n	Mean	Standard deviation	Minimum	Maximum
BW, kg	36	271.29	82.98	125.00	416.50
P intake, g/d	36	13.16	4.20	3.43	20.97
Fecal P, g/d	36	7.13	2.64	1.80	13.43
Total P, g/d	36	7.72	2.75	2.04	14.51

[1] BW = body weight; P intake = phosphorus intake.

Table 13.11 shows the result of the validation of equations for the prediction of phosphorus excretion by beef cattle under tropical conditions. Considering the Mayer's

test ($P > 0.05$), the equations are appropriate to estimate the fecal and total phosphorus excretion.

Considering the MSEP decomposition, it can be seen that most of the errors are random, showing that the proposed equations do not tend to over- or underestimation.

Table 13.11 - Regression analysis, concordance correlation coefficient (CCC), bias correction (Cb) and mean square error of prediction (MSEP) decomposition between the predicted and observed values of phosphorus excretion

Item	Prediction equation of phosphorus excretion	
	Fecal P	Total P
Regression analysis[1]	-	-
r^2	0.42	0.44
H_0: a = 0 and b = 1	0.74	0.50
CCC	0.61	0.63
Cb	0.95	0.95
MSEP	4.010	4.272
Mean bias (%)	0.03 (0.65)	0.11 (2.68)
Systematic bias (%)	0.04 (1.04)	0.06 (1.31)
Random errors (%)	3.94 (98.31)	4.10 (96.01)

[1]Linear regression between predicted and observed values by means of phosphorus excretion equations.

The similarity in estimated and observed phosphorus excretion values is shown in Figure 13.2. The values are similarly disposed around the identical line (dotted line).

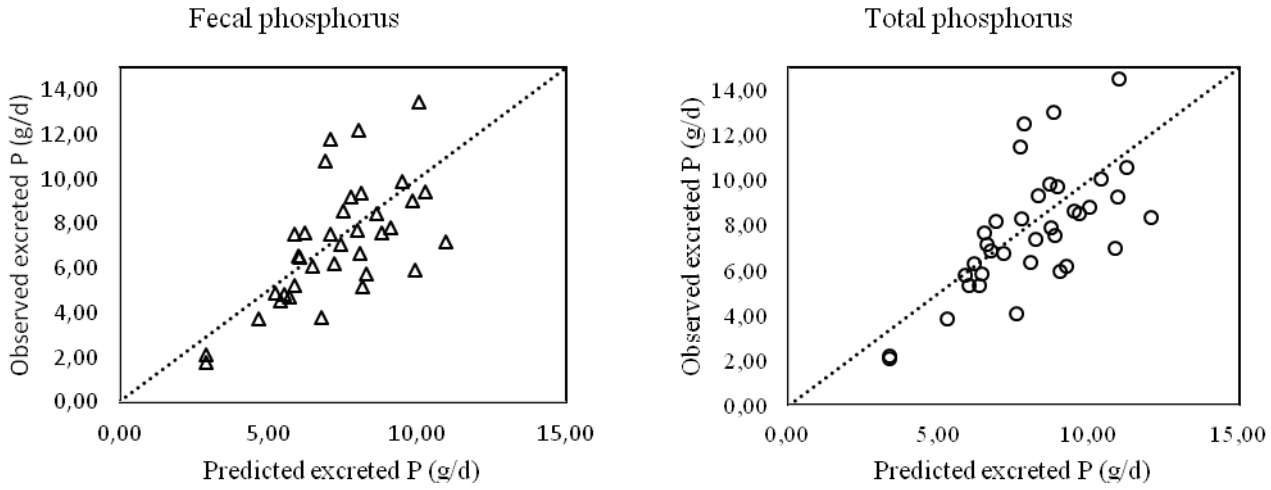


Figure 13.2 - Relationship between the observed values of phosphorus excretion and those determined by the proposed model. Predicted values are plotted on the X axis and the observed values are on the Y axis. The dotted line represents the ideal line (Y = X), intercept = 0 and slope = 1.

Both equations show positive correlation between phosphorus intake and excretion; corroborating with other authors (Prados et al., 2015; Prados, 2016) who observed that increasing the concentration of phosphorus in the diet results in increased fecal P excretion. Geisert et al. (2010) proposed an equation for the total P excretion, with a positive relationship between P intake and excretion.

FINAL CONSIDERATIONS

The prediction of nitrogen and phosphorus excretion is important for

modeling nutrient cycling in the beef cattle production system and for assessing the impact of changes in dietary formulation over the excretion of these nutrients to the environment. Reductions in phosphorus content and crude protein in the diet do not adversely affect performance and therefore represent important strategy to mitigate environmental impacts and improve productive efficiency in beef cattle.

The following equations are proposed to estimate the fecal and urinary excretion of nitrogen and phosphorus by beef cattle under tropical conditions:

$$\text{Fecal N (g/d)} = 2.55 + 0.048 \times \text{BW} - 3.47 \times \text{TDNI} + 0.30 \times \text{NI}$$

$$\text{Urinary N (g/d)} = 3.26 + 3.68 \times \text{DMI} + 0.18 \times \text{NI}$$

$$\text{Urinary N (g/d)} = 3.82 + 0.34 \times \text{NI}$$

$$\text{Fecal P (g/d)} = 1.47 - 0.0019 \times \text{BW} + 0.48 \times \text{P intake}$$

$$\text{Total P (g/d)} = 1.90 - 0.0030 \times \text{BW} + 0.53 \times \text{P intake}$$

where: BW is body weight (kg); TDNI is total digestible nutrients intake (kg/d); NI is nitrogen intake (g/d); DMI is dry matter intake (kg/d); P intake is phosphorus intake (g/d).

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14

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 x T + (RH/100) × (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 $T < 15$ºC $WI = 3.5 \times DMI$, for $T = 20$ºC $WI = 4.5 \times DMI$, for $T = 25$ºC $WI = 6.0 \times DMI$, for $T = 30$ºC $WI = 8.0 \times DMI$, for $T > 35$ºC
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: $Y = \beta0 + \beta1 \times X$, where Y is the observed value; β0 and β1 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: $\beta0 = 0$ and H0: $\beta1 = 1$ 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, ºC	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.

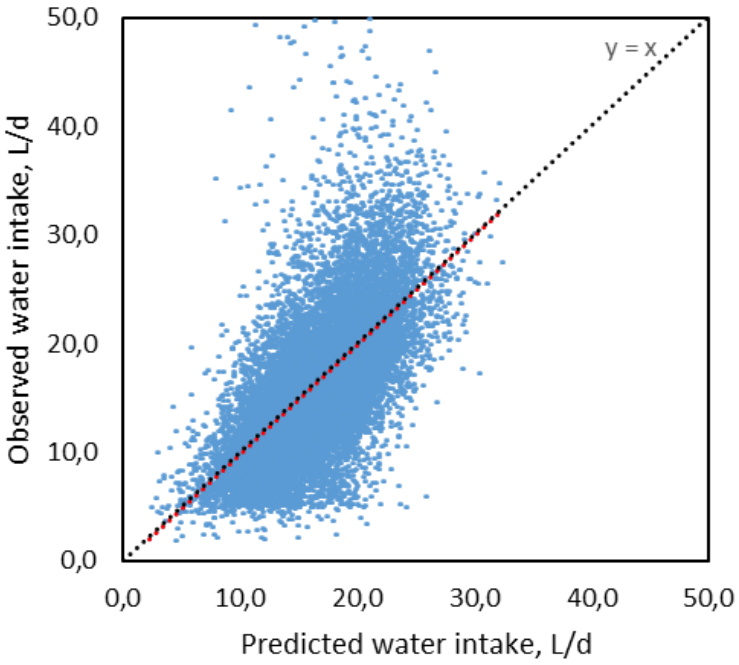


Figure 14.1 - Predicted (x-axis) and observed (y-axis) water intake. Values predicted using the equation **WI = 9.449 + 0.190 × MBW + 0.271 × T_{MAX} - 0.259 × RH + 0.489 × DMI** (Zanetti et al., 2019), where WI is the daily water intake (kg/d), MBW is the metabolic body weight ($kg^{0.75}$), T_{MAX} 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: $520^{0.75} = 108.89$
  - $WI = 9.449 + 0.190 \times MBW + 0.271 \times T_{MAX} – 0.259 \times RH + 0.489 \times DMI$
  - $WI = 9.449 + 0.190 \times 108.89 + 0.271 \times 25.7 – 0.259 \times 65.0 + 0.489 \times 10.62$
  - $WI = 9.449 + 20.69 + 6.96 – 16.84 + 5.19$
  - **WI = 25.46 L/d.**

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15

Vitamins for beef cattle

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INTRODUCTION

Vitamins are important metabolic catalysts used in livestock animal diets (Ball, 2006). As micronutrients, they are required in very small amounts in beef cattle diets. However, they are essential to meet the demands related to immunological processes (health), growth, and reproduction (McDowell, 2000). Moreover, vitamins are required for the metabolism of other nutrients, such as carbohydrates and proteins. Thus, vitamins must be present in diets in adequate amounts.

Vitamin supplementation, which is commonly incorporated into the mineral supplements, may contribute to a greater growth performance of beef cattle in intensive production systems, where the metabolic requirements may be increased. In addition, vitamins help to prevent diseases and to maintain animal health (Spears and Weiss, 2014).

Vitamins are mainly available in plant tissues as provitamins. In bovine tissues, they occur due their consumption or production by microorganisms in the digestive tract (Berchielli et al., 2006). Vitamins are classified according to their solubility in lipids and organic solvents as fat-soluble vitamins (A, D, E, and K), or in water as water-soluble vitamins (pantothenic acid, biotin, thiamine, niacin, riboflavin, and cyanocobalamin).

According to Acedo et al. (2018), only 69 articles studying vitamins A, D, and E for beef cattle were published in the Journal of Animal Science over the last 83 years. It represented only 0.16% of the total number of publications in this Journal. Moreover, the recommendations available in the literature regarding vitamin nutrition for beef cattle are mostly from studies developed between the 1960s and 1980s. Considering the genetic improvement and changes in energy and protein requirements over time, it may be necessary to adjust the current recommendations on vitamin supplementation for beef cattle. Thus, further studies on vitamin supplementation are still necessary.

Studies evaluating the effects of vitamin supplementation on beef cattle productive performance under Brazilian conditions are scarce. Over the last 27 years, only two articles were published in Brazil, evaluating vitamin supplementation for dairy cattle, in which the inclusion of individual vitamins was tested (Acedo et al., 2018). Hence, due the scarcity of data on vitamin supplementation for ruminants, the use of studies in non-ruminants and humans is inevitable. Therefore, the objective of this chapter was to discuss the main aspects regarding the supplementation of water and fat-soluble vitamins for beef cattle. Subsequently, two studies regarding the effects of vitamin supplementation on productive performance, physiology, and metabolism of feedlot cattle raised under Brazilian conditions are presented.

WATER-SOLUBLE VITAMINS

Water-soluble vitamins are mainly found in plant tissues. However, the ruminal microbiota can synthesize and provide water-soluble vitamins for ruminants. In addition, water-soluble vitamins are usually not stored in the animal body in large amounts and must be supplied daily. Nevertheless, water-soluble vitamin requirements have not been established for beef cattle. Failure to establish supplementation levels may be primary because adequate amounts of water-soluble vitamins are provided by ruminal bacterial synthesis in most dietary situations (NASEM, 2016). Furthermore, ruminants are able to produce their own vitamin C (NASEM, 2016).

Water-soluble vitamins, especially thiamine (vitamin B_1), niacin (vitamin B_3), and biotin (vitamin B_7) play relevant roles as coenzymes in the metabolism of carbohydrates, proteins, and lipids. They increase protein synthesis by ruminal

microorganisms (vitamin B_3); they are responsible for the enzymatic carboxylation of ketoacids in the tricarboxylic acid cycle (vitamin B_1), and play a very important role in glucose metabolism (vitamin B_7; NASEM, 2016). Besides, niacin acts on the hepatic conversion of ammonia to urea, as well as in the hepatic metabolism of ketones.

In general, B-complex vitamins have similar functional characteristics and act synergistically. The synthesis of B-complex vitamins in ruminants is influenced by the type of diet; however, considerable diet modifications can occur without causing any signs of deficiency (NASEM, 2016). The deficiency of B-complex vitamins in ruminants is usually limited to young animals that have not completed rumen development yet. Deficiency may also happen when vitamin antagonists are present in the rumen or when ruminal synthesis is limited by the absence of precursors. Next, a brief description of the main water-soluble vitamins for beef cattle will be presented. Additional information can be obtained from the studies listed in the references section at the end of this chapter.

Thiamine (Vitamin B_1)

Thiamine is widely distributed in plant and animal tissues. In animal tissues, it occurs as thiamine pyrophosphate (Ball, 2004), which contains a pyrimidine ring (2,5-dimethyl-6-aminopyrimidine) and a thiazole ring (4-methyl-5-hydroxy ethyl thiazole) linked by a methyl bridge (Aragón, 2018).

Deficiency of thiamine in ruminants is rare. However, it may cause weakness, retracted head, and cardiac arrhythmia, just like other water-soluble vitamins. Thus, water-soluble vitamins deficiencies can result in anorexia, diarrhea, and reduced animal growth (NASEM, 2016).

Thiamine plays a central role in the energy supply to the animal, especially in the metabolism of carbohydrates (Rodwell et al., 2015). Thiamine pyrophosphate is the coenzyme of three important enzyme complexes, which are involved in the main steps of decarboxylation in carbohydrate metabolism: pyruvate dehydrogenase (glycolysis), transketolase (pentose phosphate pathway), and α-ketoglutarate dehydrogenase (citric acid cycle pathways; Cunha et al., 2006). Therefore, the incorrect supply of thiamine may impair energy supply in all bovine tissues.

Although ruminants can usually synthesize vitamin B_1 in adequate amounts (Miller et al., 1986), there are reports about thiamine deficiency in sheep and cattle related to its increased degradation by thiaminase and decreased microbial thiamine synthesis due to the occurrence of ruminal acidosis (Brent, 1976; Pan et al., 2016). The production of thiamine analogues by thiaminase (thiaminase I, mainly) in grain-fed cattle can induce central nervous system disorders such as polioencephalomalacia (PEM), which is clinically a softening or degeneration of the gray matter of the brain (Brent et al., 1984).

In addition, some synthetic compounds (pyrithiamine and oxythiamine) are considered thiamine antagonists as they have a similar composition and act as inhibitors (competitive) of thiamine, interfering with different stages of animal metabolism (González and Silva, 2019).

Recent studies have demonstrated positive effects of thiamine supplementation on epithelial transport in the rumen and reduction of inflammation induced by high-grain diets in high producing dairy cows and finishing beef cattle (Karapinar et al., 2010; Pan et al., 2017; Aschenbach et al., 2019). In a study performed by Pan et al. (2016), thiamine supplementation for cattle fed high-grain diets improved ruminal pH and decreased ruminal lactate concentrations. In addition, the authors stated that thiamine supplementation was able to regulate the ruminal microbial population in cows with subacute rumen acidosis (SARA), by reducing the population of *Streptococcus bovis* and stimulating the growth of *Megasphaera elsdenii*.

In most cases, available studies have evaluated the supplementation of water-soluble vitamins combined as blends, composed mainly of thiamine (vitamin B_1) and/or niacin (vitamin B_3), and/or biotin (vitamin B_7; Zinn et al., 1987; Ebtehag et al., 2016; Aragón, 2018). Thus, the effects of water-soluble vitamin supplementation on the productive performance of ruminants will be discussed based on blends rather than individual supplementation in many sections of this chapter.

Improved average daily gain (ADG) and total body weight (BW) gain were observed for finishing buffaloes supplemented with vitamins B_3 and/or B_1 (Ebtehag et al., 2016). The authors of this study reported that animals supplemented with niacin (0.992 kg/d of ADG; total BW gain of 119 kg), thiamine (0.963 kg/d ADG; total BW gain of 115.6 kg), and both niacin and thiamine (1.01 kg/d ADG; total BW gain of 121.6 kg) showed greater ADG and total BW gain when compared to the control treatment (0.747 kg/d ADG; total BW gain of 89.6 kg). According to Aragón (2018), the improvements in the productive performance of animals supplemented with vitamins B_1 and/or B_3 may be related to their role on energy metabolism, resulting in a more efficient use of feed energy.

Riboflavin (Vitamin B_2)

Riboflavin, also known as vitamin B_2, exists in nature in three forms: free riboflavin and its coenzyme derivatives flavin mononucleotide (FMN) and flavin adenine dinucleotide (FAD). Riboflavin in its coenzyme form (FMN or FAD) is called flavoprotein and acts in intermediary metabolism, especially in oxidation-reduction reactions (McDowell, 2000). Vitamin B_2 is also required for the activation and metabolism of different B-complex vitamins, such as cyanocobalamin (vitamin B_{12}), folic acid (vitamin B_9) and pyridoxine (vitamin B_6; Wu et al., 2021). Additionally, riboflavin promotes the conversion of tryptophan to niacin and acts in the mobilization of iron (Ahmadian et al., 2021).

Zinn et al. (1987) observed that the synthesis and flow of riboflavin in the rumen are independent of the concentrate content in the diet fed to steers. However, Beaudet et al. (2016) suggested that ruminal synthesis of riboflavin was greater under dietary conditions that stimulate ruminal microbial growth (i.e., diets containing readily degradable carbohydrates sources and adequate supply of N). Nevertheless, there is a reasonable consensus that ruminal degradation of dietary riboflavin is almost complete (Zinn et al., 1987) and only approximately 1% of this vitamin could reach the small intestine and be absorbed (Santschi et al., 2005). Consequently, riboflavin supplementation in diets for adult ruminants would only be justified if technologies were used to protect it from ruminal degradation.

No daily requirements for riboflavin have been established for beef cattle, as ruminal microorganisms synthesize abundant amounts of this vitamin, representing approximately 1.5 times the estimated metabolic requirements of riboflavin (NASEM, 2016). Hence, riboflavin deficiencies are unlikely to occur in adult ruminants, and it has only been observed in young pre-ruminants (Casals and Calsamiglia, 2012). Zinn (1992) calculated, using data collected from pigs (NRC, 1979), that the requirements for feedlot cattle were 0.32 mg/kg $BW^{0.75}$. Recent evidence has shown that increasing levels of dietary riboflavin supplementation from 600 to 900 mg/d had no influence on dry matter (DM) intake but tended to increase ADG in bulls (Wu et al., 2021). Nonetheless, riboflavin supplementation should only be considered in animals under stress and with a low feed intake when the ruminal microbial population may be impaired (Zinn, 1992).

Niacin (Vitamin B_3)

Ruminants can be supplied with Niacin (vitamin B_3) from three sources: 1) dietary niacin; 2) conversion of tryptophan to niacin; and/or 3) synthesis of ruminal microorganism (NASEM, 2016). Niacin is part of the coenzymes NAD and NADP, being important in all the animal metabolism. Moreover, niacin is required for ammonia detoxification to urea and ketone metabolism in the liver in ruminants.

Niacin supplementation of niacin is usually not required due to its microbial synthesis in the rumen. However, studies have shown a variation in niacin concentration in the rumen according to the type of feed provided and roughage/concentrate ratio in the diet (forage: concentrate; Niehoff et al., 2009; Schwab *et al.,* 2006). However, it is unclear which diet component most influences the ruminal concentration of niacin. Nevertheless, of the total of niacin supplemented, only a small part reaches the duodenum (Niehoff et al., 2009), which may be due to ruminal degradation or absorption in the abomasum.

According to Zinn et al., (1987), ruminal starch degradation stimulates the synthesis of all B-complex vitamins. Results by Schwab et al. (2006) corroborate the previous findings of Zinn et al. (1987), who observed a positive correlation between non-fibrous carbohydrates (NFC) and starch concentrations in the diet, as well as their intake and ruminal degradation, and niacin synthesis in dairy cattle. However, no effect of diet forage (35 or 60% on a DM basis) or NFC (30 or 40% on a DM basis) ratio was observed on the production of water-soluble vitamins.

The effects of vitamin B_3 supplementation on the productive performance of beef cattle have been variable. Byers (1981) summarized 14 studies on the effects of vitamin B_3 supplementation for beef cattle in a meta-analysis. The authors concluded that niacin supplementation ranging from 50 to 250 mg/kg DM during diet adaptation (first 21 to 38 d) improved growth rate and feed efficiency of beef cattle by 9.7 and 10.9 %, respectively. Luo et al. (2019) evaluated the effects of vitamin B_3 supplementation at levels of 320, 480 and 640 mg/kg DM on the productive performance of finishing *Jinjiang* cattle. The results showed that cattle fed 640 mg/kg DM of supplemental niacin presented ADG 43.75% greater than those in the control group during the initial period (1 to 28 d). However, dietary doses of 480 and 640 mg/kg DM of supplemental niacin reduced feed efficiency by 26.07% and 31.61%, respectively, compared to the control group. According to Zinn et al. (1987), the absence of beneficial effects of vitamin B_3 supplementation at low doses (100-400 ppm) on the growth performance of cattle may be related to the degradation of this vitamin by the ruminal microbiota.

Nevertheless, previous research has suggested that dietary supplementation with niacin may improve rumen fermentation and microbial protein synthesis in beef cattle (Flachowsky, 1993; Girard, 1998). In addition, an increase in nutrient digestibility and productive performance was observed when vitamin B_3 was supplemented at a dose of 6g/cow/d and 1g/bull/d (Flachowsky, 1993).

Pantothenic acid (Vitamin B_5)

Pantothenic acid (vitamin B_5) is a component of two key enzymes in carbohydrate, lipid, and protein metabolism: coenzyme A (CoA) and the acyl group carrier protein (ACP; NASEM, 2016). This vitamin is composed of β-alanine and pantoic acid (Bässler et al., 2002) and it is found in almost all feed and living cells, associated with CoA, ACP, or as free pantothenic acid (Finlayson e Seeley, 1983; Ragaller et al., 2011).

The biological activity of vitamin B_5 is directly related to CoA and ACP. When associated with the CoA, vitamin B_5 is involved in energy-releasing reactions from carbohydrates, fatty acids, and amino acids, whereas it is involved in fatty acid biosynthesis when associated with ACP (Ball, 2006). In carbohydrate metabolism, acetyl-CoA provides acetyl groups for the tricarboxylic acid cycle. In addition, acetyl-CoA plays a role in the acetylation of amino sugars and choline to form mucopolysaccharides.

The quantification of vitamin B_5 in the rumen is complex since it is subjected to the processes of synthesis, degradation, and passage through the digestive tract, and probably absorption, simultaneously (Kon and Porter, 1954). Furthermore, variations in pantothenic acid concentrations in the rumen fluid of cattle fed concentrate diets tend to be greater than for those fed roughage diets (Hayes et al., 1966). Zinn et al. (1987) reported a negative apparent synthesis of B_5 vitamin (-13.5 mg/d) in growing male crossbred calves (116 kg) under transport stress fed a corn-based diet, indicating that there was not a net synthesis of B_5 vitamin. Authors stated that it may be related to the lower feed intake of growth when compared to older animals and to the characteristics of the diet, since the synthesis of vitamin B_5 varies according to the diet composition.

There are cases in the literature suggesting that vitamin B_5 is necessary for the proper growth of some ruminal bacteria, such as *Lactobacillus* sp., *Streptococcus bovis*, and *Megasphaera elsdenii* (Ford et al., 1958; Wolin et al., 1997). A beneficial influence on the *in vitro* protozoa count has also been reported (Völker et al., 2011). It is estimated that the amount of vitamin B_5 synthesized in the rumen is 20 to 30 times greater than the amount present in diets commonly offered to beef cattle (NASEM, 2016) and, because of that, nutritional requirements for vitamin B_5 have not been established yet.

About 80% of supplemental vitamin B_5 is degraded in the rumen (Zinn et al., 1987) and the use of its protected form (pantothenate) may be a viable alternative. According to Liu et al. (2018), increased ruminal concentrations of total volatile fatty acids (VFA), the degradability of neutral detergent fiber (NDF) and crude protein (CP), bacterial abundance, microbial enzyme activity, and microbial protein synthesis were observed when pantothenate was supplemented to Blonde d'Aquitaine × Simmental cattle. In a previous study, Li et al. (2017) observed better nutrient utilization and ADG for Blonde d'Aquitaine × Simmental calves supplemented with pantothenate.

Pyridoxine (Vitamin B_6)

Pyridoxine is also known as vitamin B_6 and represents a group of three compounds: pyridoxol, pyridoxal, and pyridoxamine. The latter two forms are predominantly found in animal products (McDowell, 2000). The vitamin activities of these three compounds are similar when offered to animals but are not equivalent when given to microorganisms (Morris, 2001). Pyridoxal phosphate and pyridoxamine phosphate are other chemical forms associated with this vitamin. Pyridoxal phosphate is a cofactor in over 60 enzymatic reactions associated with carbohydrate, protein, and lipid metabolisms (McCormick, 2006). However, it is best known for its important role in most reactions associated with amino acid metabolism (mainly methionine and tryptophan, Mohammed et al., 2004). Therefore, vitamin B_6 requirements should be established according to protein intake (Casals and Calsamiglia, 2012). This means that the use of higher levels of methionine and tryptophan in feedlots diets may increase the pyridoxine requirement in bovines.

Modifications in diet composition may affect the ruminal microbial population and probably the vitamin B_6 metabolism. Although not much is known about the factors that affect ruminal synthesis of this vitamin, it appears to be increased when high concentrate diets are fed (Schwab et al., 2006) and to be reduced in cattle fed high-forage diets (Castagnino et al., 2016). Recently, Clemmons et al. (2020) indicated that metabolism of the vitamin B_6 byproduct was higher in the rumen of more feed-efficient animals, and that this may have allowed a more efficient protein use and muscle gain.

Most published data show that pyridoxine is abundantly synthesized, and very low amounts are degraded in the rumen. Hence, the dietary supply of vitamin B_6 is sufficient to prevent deficiency symptoms and allow normal cattle growth and production. Zinn (1992), extrapolating data collected from studies with pigs, recommended the supply of 0.14 mg/kg $BW^{0.75}$ for feedlot cattle. However, vitamin B_6 requirements have not been set for beef cattle.

Biotin (Vitamin B_7)

Biotin is commonly known as vitamin B_7, vitamin H, or coenzyme R. This vitamin is present in nature in both protein-bound and free forms. Nevertheless, most of the ingredients used in feedlots contain biotin bound to the protein (covalent bonds), which hinders its digestion and bioavailability for the animal (Habeeb and Gad, 2019). Proteases in the digestive system degrade this bound form, releasing biocytin (vitamin linked to lysine; McDowell, 2000). The bound formed between lysine and biotin can only be broken under the action of a specific enzyme (biotinidase; McMahon, 2002), which is present in the pancreas, intestinal brush cells, and some bacterial species, releasing biotin in its free form to be absorbed (Santschi et al., 2005). Therefore, higher protein feed usually contains more biotin than feed with low protein concentrations (e.g., soybean meal = 0.30 mg/kg vs. barley = 0.08 mg/kg; Ammerman et al., 1995).

Biotin is a cofactor for many enzymes involved in many metabolic pathways. Biotin is required as a coenzyme in amino acid metabolism, cellular respiration, gluconeogenesis, and lipogenesis (McDowell, 2000). Besides, this vitamin is necessary for the normal functioning of the thyroid and adrenal glands and the reproductive and nervous systems (Habeeb and Gad, 2019). Specifically, biotin is a cofactor for four carboxylase enzymes: pyruvate carboxylase and propionyl-CoA- carboxylase, which are crucial for gluconeogenesis; acetyl-CoA-carboxylase, the first and rate-limiting step in

de novo fatty acid synthesis; and methylcrotonyl-CoA carboxylase (Weiss and Zimmerly, 2000). Moreover, biotin is necessary for many processes that contribute to the mechanical properties of the hoof and horn. These processes include keratinization, the formation of intracellular cementing substances, and the production of other lipids required to maintain epidermal permeability and integrity (Lischer et al., 1996; Mulling et al., 1999). It has been shown that biotin supplementation is recommended to improve the hardness of the hoof and horn in dairy cattle (Higuchi et al., 2003; Chen et al., 2012).

Although feeds commonly used in feedlots contain varying concentrations of biotin, the primary source of this vitamin for ruminants is the one synthesized by ruminal microorganisms (NRC, 2001; Enjalbert et al., 2008). Biotin is also required for some ruminal bacteria, especially cellulolytic bacteria for their growth (Baldwin and Allison, 1983). Furthermore, this vitamin is also needed for the ruminal microbiota to produce propionate because biotin is a cofactor in the microbial enzyme methylmalonyl-CoA-carboxytransferase, which catalyzes a step in the synthesis of propionic acid (Zempleni and Mock, 1999).

Ruminal bacteria synthesize large quantities of biotin depending on the energy availability (0.79 mg/kg of digested organic matter [DOM]; Briggs et al., 1964, cited by Casals and Calsamiglia, 2012). However, biotin synthesis may be reduced with high-energy diets. High-concentrate diets, usually fed in feedlots, can create an acidic rumen or change the site of starch fermentation. Thereby, the ruminal and intestinal flora may be altered and, in turn, affect the synthesis or degradation of microbial biotin. Thus, biotin supplementation may be required for ruminants fed high- concentrate diets.

Decreased biotin synthesis has been reported *in vitro* for diets containing more than 50% concentrate (Da Costa Gomez et al., 1998). In addition, Abel et al. (2001) observed that ruminal biotin synthesis decreased by 50% as the proportion of barley to hay increased from 50:50 to 83:17 in an *in vitro* continuous culture study, likely as a result of an imbalance among ruminal microorganisms species caused by pH decrease. Furthermore, the proportion and type of grain in the diet influenced the ruminal and intestinal apparent syntheses and absorption of biotin in duodenally cannulated beef steers (Miller et al., 1986).

However, Rosendo et al. (2004) suggested that the reduction of cellulolytic microbial growth caused by low ruminal pH (5.3) may decrease utilization rather than synthesis of ruminal biotin. Nonetheless, it has been reported that biotin is not extensively degraded in the rumen (NRC, 2001). Schwab and Shaver (2005) observed a significant increase in the concentration of biotin in the milk and plasma of dairy cattle, suggesting that this vitamin supplemented in an unprotected way against ruminal degradation was not completely degraded or used by ruminal microorganisms.

A meta-analysis using 9 studies indicated that supplementation with unprotected biotin positively affected milk yield in dairy cows (Chen et al., 2011), suggesting that biotin does not require ruminal protection. Nevertheless, a limited number of studies have been conducted evaluating biotin supplementation in beef cattle. De Silva et al. (2018) found that biotin supplementation (20 mg/d) to crossbred cattle did not alter their growth rates. Moreover, previous work indicated that dietary biotin largely escaped the rumen and supplementation at high levels with vitamins blend for feedlot cattle did not affect animal performance but tended to decrease morbidity (Zinn et al., 1987). Results from Campbell et al. (2000) indicated that biotin supplementation (10 mg/d) improved hoof health in Hereford cows. The combination of biotin synthesized by ruminal microorganisms and its supply in the basal diet seems to be sufficient to meet requirements of biotin for beef cattle.

The NASEM (2016) did not establish biotin daily requirements for beef cattle. Besides that, Zinn (1992) estimated the requirements of biotin for feedlot and/or finishing calves at 0.13 mg/kg of $BW^{0.75}$. In contrast, OVN (2016) recommends 10 to 20 mg/d for optimum hoof health and optimum meat marbling.

Choline (Vitamin B8)

Choline is often not considered a vitamin because, unlike classical vitamins, its

endogenous synthesis is possible. Therefore, it has been suggested that this compound may be an essential nutrient for ruminants, regardless of whether it is classified as a true vitamin (Pinotti et al., 2020). Accordingly, choline is required in relatively large amounts (grams and not in milligrams), usually more than other vitamins (NASEM, 2016).

Although a small amount of free choline may exist in some plant materials, phosphatidylcholine is the major natural form of choline in feed. Choline is essential for the synthesis of vital molecules in the body (e.g., phosphatidylcholine and acetylcholine); thus, it plays an essential role in energy, protein, and lipid metabolism (Berdanier, 2008). In addition, it is an important donor of methyl groups, contributing to the biosynthesis of other methylated compounds in animal metabolism (McDowell, 2006). Therefore, one of the advantages of supplementing choline is to increase the availability of methionine for protein synthesis, as biologically active methyl groups may also be obtained from this essential amino acid (NRC, 2001).

Choline requirements for beef cattle are not well established because of several reasons. For example, feed ingredients contain different concentrations of choline. The choline content in corn is approximately 80.04 mg/kg, while in soybean meal this concentration is 1686.54 mg/kg (Chen et al., 2019). Additionally, the combination of different levels and composition of protein, fat, and carbohydrates in the diet as well as the age, category, energy intake, and growth rate of animals have an influence on the lipotropic action of choline, and thus, the requirement of this vitamin (Mookerjea, 1971).

Furthermore, dietary choline is only available to adult cattle if it escapes ruminal degradation. One of the few reports available in the literature regarding the effects of unprotected choline supplementation for beef cattle observed no improvement in feedlot performance, carcass measurements, acidosis, or ruminal fermentation products in choline-steers supplemented with choline fed an all-concentrate diet (Morris, 2001). Dietary choline and synthetic supplements are rapidly and extensively degraded by the rumen microbiota (Baldi and Pinotti, 2006). Ruminal choline degradation values vary between 80 and 99%, depending on the source (Sharma and Erdman, 1989). Thus, even choline-rich feed can only contribute marginally to the post-ruminal supply of choline. Therefore, an effective method to increase choline availability to ruminants is to feed it in a way that is protected from ruminal degradation.

In this regard, rumen-protected choline, containing choline chloride covered by a protective layer of fatty acids, has received interest for research and production applications (Jayaprakash et al., 2016). Some studies have reported improvement in growth performance (Bindel et al., 2000; Pinotti et al., 2009) and carcass traits (Drouillard et al., 1998) in beef cattle supplemented with rumen-protected choline. Due to the limited number of available research and the inconsistency of the results, no practical recommendation for daily unprotected or rumen protected choline supplementation has been made in this chapter. However, it has been suggested that milk-fed calves should be supplemented of 0.26% choline in milk replacers (NASEM, 2016).

Folic acid (Vitamin B_9)

Folic acid, also known as vitamin B_9, folacin, or folate, is involved in the transfer of one-carbon units, playing a crucial role in the biosynthesis of purine and pyrimidines, synthesis of DNA, and amino acid metabolism (McDowell, 2000). Folic acid acts synergically with other vitamins, minerals, amino acids, and metabolites to maintain a functional one-carbon metabolic pool (e.g., choline, methionine, glycine, cobalt, and others; NASEM, 2016).

Ruminal microorganisms synthesize a great amount of folic acid, which depends on energy availability (NRC, 2001). Zinn (1992) estimated that folic acid synthesis in the rumen was 0.42 mg/kg of DOM. Thus, animals with functional rumen must have an adequate supply of folic acid (McDowell, 2000). Moreover, it is estimated that approximately 97% of dietary supplementary folic acid is degraded by ruminal microorganisms (Zinn et al., 1992; Wang et al., 2017) and only 3% of dietary folic acid could reach the small intestine to be absorbed (Santschi et al., 2005). Thus, folic acid supplementation in adult animals would only be justified with the use of

protection technology from ruminal degradation.

In this context, recent studies have found that rumen-protected folic acid supplementation to steers increased total ruminal VFA concentration, nutrient degradability, microbial protein synthesis, cellulolytic bacterial abundance, enzyme activity, ADG, and feed efficiency (Liu et al., 2020; Wang et al., 2016, 2017). Zinn (1992) extrapolating data collected from pigs (NRC, 1998), concluded that the requirements of folic acid were 0.75 mg/kg $BW^{0.75}$ for feedlot cattle. However, international nutrient requirements systems (e.g., NASEM, 2016; OVN, 2016) and this current publication have not established the requirements of vitamin B_9 for beef cattle.

Cobalamin (Vitamin B_{12})

Vitamin B_{12} is a generic name used to refer to a group of compounds that have vitamin B_{12} activity, such as cyano, hydroxy, methyl, or deoxyadenosylcobalamin. Cobalamin, the biologically active form of vitamin B_{12}, is involved on the metabolism of nucleic acids, protein, carbohydrates, and lipids (González-Montaña et al., 2020). Meeting vitamin B_{12} requirements is of a special interest in ruminants than in non-ruminant animals, as it is required for proper propionate metabolism. Methylmalonyl-CoA mutase is a vitamin B_{12}-dependent enzyme that is essential for the conversion of propionate to succinate, which by gluconeogenesis is later converted into glucose, influencing energy production in animals (Mansur, 2009; Rowley and Kendall, 2019).

Unlike other B vitamins, vitamin B_{12} is not present in plants and is only produced by bacteria if cobalt supply is adequate, which is usually used as an indicator of the B_{12} status in the animal organism (González-Montaña et al., 2020). The rumen microbiota can synthesize vitamin B_{12} if concentrations of free cobalt in the ruminal fluid are greater than 0.5 mg/mL (Underwood and Suttle, 2002). Thus, ruminants obtain the preformed vitamin B_{12} from their natural bacterial flora or by eating animal products.

Physiologically, the selective uptake of active vitamin B_{12} requires interaction between pre-carrier proteins, haptocorrin (HP), intrinsic factor (IF), transcobalamin (TC), and different receptors. Haptocorrin is part of many biological fluids, including gastric juice, and helps to break down vitamin B_{12} analogues. Gastric (humans) or pancreatic (dogs) IF selectively binds to B_{12} and enters intestinal cells via receptor-mediated endocytosis. Subsequently, the absorbed vitamin B_{12} is transmitted to the TC and delivered to the tissues via bloodstream. It is noted, therefore, that the complexity of the transport system allows efficiency in the absorption process of vitamin B_{12}. However, any failure at any point in this process can lead to the deficiency of this vitamin, which would lead to irreversible neurological damage, anemia, and even death (Fedosov, 2012; Kather *et al.,* 2020).

In a study comparing the pharmacokinetics of two forms of cobalamin (OHB12 and CNB12) associated with trace minerals in Holstein steers, Gonzalez-Rivas et al. (2021) found that animals that received the OHB12 form presented an increase of 11% in ADG when compared to those treated with CNB12 (1.17 and. 1.06 kg/d for steers receiving OHB12 and CNB12 forms of cobalamin, respectively). Furthermore, the authors stated that a single injection of OHB12 was effective in increasing the blood level of cobalamin in the first 24 hours and its liver storage, which was sustained for at least 28 days in a situation of deficiency. In contrast, supplementing cobalamin with the CNB12 form did not increase cobalamin in the liver (Gonzalez-Rivas et al., 2021).

FAT-SOLUBLE VITAMINS

Fat-soluble vitamins are found in association with the lipid constituents of plants and animals and are characterized by their long-term storage capacity in the animal organism (McDowell, 2000). Fat-soluble vitamins A, D, E, and K are absorbed concomitantly with the absorption of lipids and depend on the presence of bile and micelle formation in the gut (McDowell, 2000).

Fat soluble vitamins have several essential functions in the body of ruminants. For example, vitamin A is involved in the formation, regeneration, and protection of the ectoderm and mucous membranes (*Toledo et al.,* 2006). Vitamin E improves antibody formation and humoral immune system. It is also necessary for cell metabolism (cellular respiration and nucleic acid metabolism), cell division, and protein synthesis. Also, vitamin E acts as an antioxidant

compound for unsaturated fatty acids and vitamin A, contributing to improve meat quality (Leda *et al., 2018;* Toledo *et al.,* 2006).

On the other hand, vitamin D regulates calcium (Ca) and phosphorus (P) homeostasis, increasing intestinal uptake and bone resorption. In addition, it increases the activity of Ca-dependent proteolytic enzymes, which can lead to improved meat quality (Montgomery *et al.,* 2000; Toledo *et al.,* 2006). Vitamin K is required for the synthesis of several plasma clotting factors (factors II, VII, IX, and X) and may also participate in Ca homeostasis (Dores et al., 2001).

Vitamin A

Although all vitamins are equally important in maintaining ruminant life, vitamin A is the most relevant vitamin for beef cattle production, being essential for healthy growth and development (NRC, 2001). Vitamin A performs many functions in the animal's body, and the most important of which is associated with vision (vision pigment), embryo development, immunity, the maintenance of homeostasis, and maintenance of skeletal and epithelial tissue (Bendich, 1993; McDowell, 2006). Vitamin A and β-carotene are required to optimize the reproductive performance of Nellore cows (Gouvêa et al., 2018; Vasconcellos et al., 2018ab) and embryonic quality (Amaral et al., 2004). Furthermore, this vitamin has a positive role in the spermatogenesis of Nellore bulls (Silva et al., 2020).

Vitamin A is a family of molecules grouped under the name of retinol, which is nearly colorless, long-chain, and unsaturated compound. As a fat-soluble compound, normal processes of fat digestion, and absorption, and adequate dietary fat content are necessary to allow its absorption. The liver and adipose tissues are the local in the body where absorbed retinol can be stored. Several studies have confirmed that the liver (usually contains around 90% of total-body vitamin A) can store enough vitamin A to preserve animals from a deficiency caused by long periods of low vitamin A intake (McDowell, 2000).

The basic structure of vitamin A is all-trans retinol, which can originate several isomers. Nevertheless, the common forms of vitamin A supplementation used in commercial feeds are the all-trans retinyl acetate and all-trans retinyl palmitate. These are normally produced as hardened or cross-linked gelatin beadlets to improve stability. Thus, vitamin A requirements for ruminant nutrition are reported in either International Units (IU) or Retinol Equivalents (RE; NASEM, 2016). The definitions and relationships between IU and RE are shown in Table 15.1.

Table 15.1 - Definitions and relationships between International Units (IU) and Retinol Equivalents (RE) related to vitamin A

1 IU	0.3 μg of all-*trans* retinol
1 IU	0.344 μg of retinyl acetate
1 IU	0.55 μg of retinyl palmitate
400 IU	1 mg β-carotene
1 RE	1 μg of all-*trans* retinol, 2 μg of synthetic supplemented all-*trans* β-carotene, 6 μg of dietary all-*trans* β-carotene, or 12 μg of other dietary provitamin A carotenoids

*Adapted from NASEM (2016) and Casals and Calsamiglia (2012).

Retinol is not present in plant-based ingredients commonly used in ruminant diets, but its precursors (carotenes or carotenoids) occur in different forms. However, β-carotene activity is substantially higher than other carotenoids. β-carotene (or pro-vitamin A) is converted to vitamin A (retinol) by enzymes located in the intestinal mucosal cells. Besides, other carotenoids (e.g., α-carotene and cryptoxanthin) can also be converted to vitamin A. However, the efficiency of conversion of carotenoids to retinol appears to be lower in beef cattle than in non ruminants animals (Ullrey, 1972). The reduced conversion rate of carotene to retinol may be due to ruminal degradation of vitamin A (McDowell, 2000).

Ruminal degradation of vitamin A may be affected by the type of diet fed to beef cattle. Rode et al. (1990) reported that vitamin A

disappearance during *in vitro* ruminal fermentation increased from 20% to approximately 80% when donor steers were fed a high-concentrate diet in relation to those fed a high-forage diet. In this regard, new technologies have been commercially developed to protect vitamin A from ruminal degradation. In this case, commercial products are composed of vitamin A and other compounds, such as carbohydrates and antioxidants, aiming its stabilization (Alosilla et al., 2007).

Several factors can influence the carotenoid composition of a feedstuff, such as production conditions (e.g., temperature and humidity), maturity at harvest, and postharvest storage conditions and processing (Pickworth *et al.,* 2012). Retinol and carotenoids are highly sensitive to oxidation, exposure to UV light and the presence of acids, humidity, and microminerals (NRC, 2001). Prolonged storage in premixes containing trace minerals (particularly copper), elevated moisture, pelleting, extrusion processing, or the presence of rancid fats reduces the stability of vitamin A (Olson, 1991; Coelho, 2002).

Vitamin A deficiency in beef cattle raised in tropical conditions can occur during the winter, as forage mass availability and quality (e.g., low β-carotene concentration) are low. Vitamin A deficiency may also occur in high concentrate diets in feedlot systems, and when the feed ingredients have been exposed to sunlight and/or high temperatures or stored for a long period (Akhtar et al. 2011). Considering that fresh forage (e.g., pasture) has relatively higher concentrations of β-carotene than conserved forages (e.g., silage), the amount of supplemental vitamin A required when fresh forage is fed would be less. Although toxicity due to an excess of this vitamin in the diet is uncommon in ruminants due to its high rate of ruminal degradability, it also limits the amount of vitamin A available to the animal (Casals and Calsamiglia, 2012).

Some *in vivo* studies have documented that cattle fed 2,134 - 2,300 IU/kg DM of vitamin A supplement had greater gains and feed efficiency than those consuming approximately 6,274-11,000 IU/kg DM (Zinn et al., 1996). Furthermore, Gorocica-Buenfil et al. (2007bc; 2008) conducted three trials evaluating the supplementation of vitamin A at levels of 2,200 or 2,700 IU/kg DM for finishing beef cattle. Compared with the non-supplemented group, vitamin A-supplemented group improved gains in one trial (Gorocica-Buenfil et al., 2007b) and feed efficiency in the other two trials (Gorocica-Buenfil et al., 2007c; 2008). Bryant et al. (2010) evaluated the effects of vitamin A supplementation (0; 1,103; 2,205; 4,410; or 8,820 IU/kg DM) on the growth performance and carcass quality of steers fed a high-grain diet. The authors did not find differences in the final BW, feed efficiency, ADG, and daily DM intake (DMI) among treatments within each 28-days or the overall feedlot period. Thus, it was suggested that vitamin A supplementation for finishing cattle should be carefully evaluated.

According to these authors, typical feedlot diets (approximately 90% of concentrate in the total diet) have an average of 5,215 IU vitamin A/kg DM. The vitamin A requirement for finishing cattle fed with similar basal diets is ≤ 2,205 IU/kg DM (NASEM, 2016). Thus, diets with values above 2,205 IU/kg DM of vitamin A can overload the ability of the lower gastrointestinal tract to absorb other nutrients, not necessarily benefiting animal health and performance.

Recently, Wellmann et al. (2020) evaluated the supplementation of vitamin A at the estimated requirement (2,200 IU/kg DM) or 5 times the estimated requirement (11,000 IU/kg DM; NASEM 2016) for Nellore steers and did not observe differences across treatments for ADG, feed efficiency, hot carcass weight, rib eye area, or backfat thickness. Therefore, the current NASEM (2016) recommendations of 2,200 IU vitamin A/kg DM seem to be adequate for restoring the vitamin A status of feedlot steers.

Previous studies have suggested that vitamin A feeding strategy plays a crucial role in intramuscular fat deposition in beef cattle (Oka, 1996; Gorocica-Buenfil et al., 2007a; Bryant et al., 2010; Knutson et al., 2020; Peng et al., 2020). In contrast, a study showed that vitamin A restriction during the fattening period increased intramuscular fat in cattle's carcasses by adipocyte hypertrophy (Peng et al., 2021). Nonetheless, the general applicability of vitamin A restriction in beef

cattle production is still ambiguous and deserves further investigation.

Vitamin A requirements can be expressed as IU per kg of body weight (IU/kg BW), per head per day (IU/d), or per kg of diet DM (IU/kg DM). In this chapter, the requirements have been expressed as IU/kg DM when based on NASEM (2016) and as IU/d when based on OVN (2016) recommendations in Table 15.6.

Vitamin D

The main sources of vitamin D are cholecalciferol (vitamin D_3) and ergocalciferol (vitamin D_2). They are preformed sources of vitamin D and differ by the presence of an additional double bond and a methyl group in the plant sterol. Vitamin D_3 is known as the natural form found in animals and can be synthesized under the skin by the action of ultraviolet rays exclusively from 7-dehydrocholesterol (pro-vitamin D_3), which is derived from cholesterol or squalene molecules present in large amounts in the skin, intestinal wall, and other tissues. Vitamin D_2 is the vitamin D present in plants.

The synthesis of vitamin D_3 consists of several steps involving the photochemical modification of 7-dehydrocholesterol followed by non-enzymatic isomerization (Castro, 2011). Thus, the amount of cholecalciferol formed will depend on the frequency and intensity of the ultraviolet rays that reach the animal's skin. Hence, vitamin D requirements will depend on the degree of sunlight exposure. Consequently, the conversion of the provitamin form to active vitamin will be more intense in the tropics than in temperate and arctic zones, at high altitudes. Also, this conversion will be more intense in summer when compared to winter, and at noon when compared to the morning period.

Large amounts (approximately 70%) of vitamin D intake is degraded in the rumen (Ballet et al., 2000). In addition, ruminal degradation of vitamin D can generate metabolites with antivitamin D activity, which protect ruminants from vitamin D toxicity when it is ingested in excessive amounts (Ballet et al., 2000). The remaining vitamin D can be absorbed in the small intestine.

Vitamin D and its metabolites have functions other than acting on Ca metabolism and regulating bone mineralization. These well-known effects of vitamin D are related to biochemical changes that occur in the intestine, bone and kidneys. Vitamin D also has hormone-like functions. Like steroid hormones, 1,25–$(OH)_2D_3$ (Calcitriol) regulates gene expression through interaction with specific receptor proteins in the nucleus. Moreover, 1,25–$(OH)_2D_3$ synthesis is involved in the regulation of growth and differentiation of a variety of cell types, including hematopoietic and immune system cells (Lemire, 1992).

Steroid hormones, prolactin, growth hormone (GH), and insulin-like growth factor 1 (IGF-1) stimulate renal synthesis of 1,25-$(OH)_2D_3$ to regulate Ca absorption and meet higher Ca requirements during pregnancy, lactation, and growth in ruminants (Holick, 2007). When these hormones do not act efficiently, animals may present insufficient productive performance.

Young animals may have rickets caused by a decrease in the concentration of Ca, P or both, and a significant increase in acid phosphatase. In adult animals, vitamin D deficiency can lead to "milk fever" in lactating cows, mainly in multiparous ones. This is because older animals usually have a lower response to dietary Ca due to the decreased production of 1,25-$(OH)_2D_2$ and lower target tissue response to 1,25-$(OH)_2D_3$, which may result in metabolic problems. The NASEM (2016) still uses the NRC (1984) guidelines for vitamin D supplementation for beef cattle, which recommends a supplementation of 275 IU/kg DM or approximately 5.7 IU/kg BW.

Vitamin E

Vitamin E is mainly derived from compounds known as tocopherols, which are defined as fat-soluble biological antioxidants in animal tissues. Thus, this vitamin is important for the metabolism of essential fatty acids (Andriguetto and Perly, 1994). Moreover, it prevents the formation of peroxides resulting from *in vivo* oxidation of certain fatty acids (McDowell, 2000).

Among the different types of tocopherols, α-tocopherol is the most biologically active (100% of biological activity relative to vitamin E), being the predominant preformed vitamin E (McDowell, 2000) and the most used in commercial supplements (Scherf *et al.*, 1996). α-tocopherol is an excellent natural antioxidant that protects carotene and other oxidizable compounds in the feed and body (Buckley et al.,

1995), improving ADG (Pehrson *et al.,* 1991) and feed efficiency in beef cattle (Mir *et al.,* 2003).

The concentration of α-tocopherol (vitamin E) in the feed is variable. In forages, the concentration varies according to the vegetative stage of the plant, ranging from 80 to 200 IU/kg DM or from 80 to 200 mg of α-tocopherol acetate (1 UI is equivalent to 1mg of α-tocopheryl acetate; Insani et al., 2008; Acedo et al., 2018). In addition, concentrations of α-tocopherol decrease rapidly after the plant is harvested (Acedo et al., 2018). Therefore, silage and hay used in ruminant diets may contain from 20% to 80% less α-tocopherol than the plant before the conservation process. Concentrates contain reduced concentrations of vitamin E.

Vitamin E requirements can be met through exogenous dietary supplementation, which may improve animal performance. Requirements of vitamin E for ruminants can be expressed in IU, μmol, and α-tocopherol (mg/IU; NASEM, 2016). Definitions and relationships among units for expressing vitamin E are shown in Table 15.2.

Table 15.2 - Factors for converting international units (IU) of Vitamins E to α-tocopherol in milligrams (mg)[a]

Form of Vitamin E	USP Conversion Factors[b]		Molar Conversion Factors [c] μmol/IU	α-Tocopherol Conversion Factors[d] mg/IU
	IU/mg	mg/IU		
Synthetic Vitamin E and Esters				
DL-α-Tocopherol acetate	1.00	1.00	2.12	0.45
DL-α-Tocopherol succinate	0.89	1.12	2.12	0.45
DL-α-Tocopherol[e]	1.10	0.91	2.12	0.45
Natural Vitamin E and Esters				
DL-α-Tocopherol acetate	1.36	0.74	1.56	0.67
DL-α-Tocopherol succinate	1.21	0.83	1.56	0.67
DL-α-Tocopherol[e]	1.49	0.67	1.56	0.67

[a] Adapted from IOM (2000).
[b] Official United States Pharmacopeia (USP) conversions where 1 IU is defined as 1 mg of all-rac-a-tocopheryl acetate (USP, 1979, 1999).
[c] to convert mg to umol divide the mg by the molecular weight of the vitamin E compound (c-tocop eryl acetate=472; a-tocopheryl succinate = 530; a-tocopherol = 430) and multiply by 1,000. Because the amount of free and succinate compounds is adjusted for their different molecular weights relative to a-tocopheryl acetate, these forms have the same conversion factors as the corresponding tocopherol compound.
[d] to convert the umol of the vitamin E compound to mg of a-tocopherol, multiply the umol by the mc ecular weight of a-tocopherol (430) and divide by 1,000. The activities of the three synthetic a-tocopherol compounds have been divided by 2 because the 2 is ereoisomers contained in synthetic a-tocopherol are not maintained in the blood.
[e] DL-c-Tocopherol = all-rac-(racemic) a-tocopherol = synthetic vitamin E; all rac-a-tocopherol = RK R- RRS-, RSR-, RSS-, SSS-, SRS-, SSR-, and SRR a-tocopherol isomers.
F D-α-Tocopherol = RRR-a-tocopherol = natural vitamin E.

Roeber et al. (2001) evaluated the levels of α-tocopherol acetate in round steaks, T-bones steaks (loin and tenderloin), and ground beef from finishing cattle that were supplemented with 500 and 1000 IU/d of α-tocopherol acetate during commercial shelf display. Dietary supplementation of α-tocopherol acetate at 1000 IU/d ensured a better shelf life for sirloin steaks compared to supplementation at 500 IU/d. In addition, cuts classified as containing a high concentration of α-tocopherol presented greater shelf life (increase of 10.7 and 4.0 h for steaks and ground beef, respectively). Thus, these results suggested a relationship between the concentrations of α-tocopherol in the shelf life of ground beef and cuts. In contrast, Pereira (2002) did not observe effects of supplementation with α-tocopheryl acetate (1,000 mg/d) on the chemical and physicochemical characteristics of the meat of finishing Nellore steers. Nevertheless, shelf life was not determined in this study. According to Acedo et al. (2018), the beneficial effects of vitamin E supplementation on shelf life are related to the reduction of myoglobin oxidation and its conversion to metmyoglobin, responsible for giving the brown/dark red color to the meat; and the

reduction in lipid oxidation (antioxidant effect).

Secrist et al. (1997) carried out an extensive literature review about the effects of vitamin E supplementation on the productive performance of beef cattle. Authors summarized 21 studies and concluded that vitamin E supplementation improved weight gain rate and final body weight of feedlot cattle. Moreover, this study showed that vitamin E supplementation to beef cattle during the first days of feedlot (stressful period due to the transport and adaptation to a new environment) tended to improve feed efficiency. Furthermore, authors reported that vitamin E supplementation positively affected the immune system of cattle, increasing the immune response to diseases and pathogens, as well as to other disorders that arise at the beginning of the feedlot period. Consequently, these results suggested that vitamin E may usually be at a suboptimal level in feedlot diets, as its supplementation promoted a general improvement in growth performance of feedlot cattle (Secrist *et al.*, 1997). Therefore, when an adequate amount of vitamin E is not supplied in the diet formulation, animal performance may be impaired.

Vitamin K

Vitamin K is a generic term used to characterize a homologous group of fat-soluble vitamins, consisting of a 2-methyl-1,4-naphthoquinone, with various isomers that differ in nature and side-chain length, and have anti- hemorrhagic effects (NASEM, 2016). In addition, there are some cases in the literature that describe a relationship between vitamin K and some vitamin K-dependent proteins (proteins C, S, Z, and M), suggesting other functions in addition to its clotting action. Proteins C and S play an anticoagulant rather than a procoagulant role in normal hemostasis (Stenflo, 1999), and are also involved in the regulation of bone turnover (Binkley e Suttie, 1995). The functions of proteins M and Z are still unknown.

The forms of vitamin K can be grouped as: phylloquinone (K_1), menaquinones (K_2), and menadiones (K). Phylloquinone and menaquinones are natural forms of vitamin K. Phylloquinone is extracted from plants (chloroplasts) and presents a phytyl sidechain composed of four isoprene units. Menaquinone is synthesized by bacteria from compounds containing active vitamin K through fermentation. This vitamin K form presents double bonds that succeed each other periodically. The synthetic menadione (K) has an active nucleus (2-methyl-1,4-naphthoquinone) and does not have sidechain. It is usually used as a vitamin K supplement (Dôres et al., 2001).

Phylloquinone and menaquinone have similar biological activity in the blood clotting process. However, the activity of menadiones and their derivatives depends on the degree of stability of the synthetic product; and they are usually less effective than phylloquinone on antagonist substances (sulfaquinoxaline, dicumarol, warfarin, or actinomycin D; McDowell, 2000).

Vitamin K_2 is synthesized in large amounts by rumen bacteria (Berchielli et al., 2006). Thus, vitamin K requirements of ruminants are met by a combination of their intake and ruminal and intestinal microbial biosynthesis, which may involve intestinal microorganisms such as *Escherichia coli*. Moreover, ruminants can absorb considerable amounts of vitamin K synthesized in the rumen and small intestine through active transport (Mendonça Júnior *et al.*, 2010). According to McDowell (2000), males are more susceptible to vitamin K deficiency in the diet than female animals, apparently due to estrogen stimulation of phylloquinone absorption.

PRACTICAL EVALUATION OF VITAMINS SUPPLEMENTATION IN BEEF CATTLE DIETS

Two studies were carried out concurrently to evaluate the effects of vitamin supplementation on the metabolism (Study 1) and productive performance (Study 2) of beef cattle under Brazilian conditions. Therefore, feed intake, nutrient digestibility, and ruminal parameters of Nellore cattle fed diets containing different vitamin

supplements were evaluated in Study 1 (Silva et al., 2022). In study 2, the effects of different vitamin supplements on feed intake, ADG, and feed efficiency of Nellore young bulls were evaluated (Andrade, 2022).

In both studies, animals were fed a basal diet composed of 30% corn silage and 70% concentrate (DM basis) with a 2 × 2 factorial scheme. The factors consisted of two fat-soluble vitamin blend (A, D, and E) supplementation levels (ADE− or ADE+) and two B vitamin blend (biotin, niacin, and thiamine) supplementation levels (B-blend− or B-blend+). Thus, the treatments consisted of no vitamin supplementation (ADE− B-blend−), supplementation with a B vitamin blend (ADE− B-blend+), supplementation with a fat-soluble vitamin blend (ADE+ B-blend−), or supplementation with a combination of these two blends (ADE+ B-blend+). Blends were included in the concentrate and the levels of vitamins supplementations in the diet were: 3.3 mg/kg DM of biotin (D-biotin), 111.1 mg/kg DM of niacin (niacin), 28.9 mg/kg DM of thiamine (thiamine hydrochloride), 6666.7 IU/kg DM of vitamin A (retinyl acetate), 5111.1 IU/kg DM of vitamin D (13% D3-Cholecalciferol and 87% 25-Hydroxyvitamin D3 - Hy-D®), and 70 IU/kg DM of vitamin E (DL-alpha tocopherol acetate).

Study 1

In this study, four rumen-cannulated Nellore bulls (age = 8 ± 1.0 months; initial BW = 289 ± 11.2 kg) were used in a 4 × 4 Latin square design, with a 2 × 2 factorial scheme. The experiment lasted 100 d, with four periods of 25 d each. Each period consisted of 14 d for dietary adaptation, 5 d for feces and urine collection, 3 d for omasal and ruminal digesta collection, and 3 d for ruminal emptying. The main results are described below. More details can be obtained in Silva et al. (2022).

Dry matter and nutrient intake, as well as ruminal digestibility were not affected ($P \geq 0.072$) by any of the vitamin supplementation (Table 15.3). The apparent total-tract digestibility of DM, organic matter (OM), and neutral detergent fiber corrected for ash and protein (apNDF) were not influenced by the experimental diets ($P > 0.114$). However, an increase in starch total-tract digestibility was verified with ADE supplementation ($P = 0.031$).

Individual and total VFA concentrations (mol/100mol), as well as lactate concentrations were not affected ($P \geq 0.133$) by vitamin supplementations (Table 15.4). Bulls that consumed the combination of ADE and B-blend supplementation had lower ruminal NH_3-N concentrations ($P=0.008$). The B-blend vitamin supplementation decreased ruminal pH ($P = 0.003$). Besides that, serum 25-hydroxyvitamin D (25(OH)D) concentrations increased ($P <0.01$), with mean values of 38.7 and 31.5 (ng/mL), respectively, for diets with ADE and ADE+B-blend supplementation (Figure 15.1).

Table 15.3 - Dry matter and nutrient intake, ruminal, and apparent total-tract digestibility of Nellore bulls receiving diets with or without vitamin blend supplementation

Item	Experimental Diets[1]				SEM[2]	*P*-value		
	ADE$^-$		ADE$^+$			B-blend	ADE	B-blend × ADE
	B-blend$^-$	B-blend$^+$	B- blend$^-$	B-blend$^+$				
Intake (kg/d)								
Dry Matter	7.3	7.2	7.3	6.7	0.54	0.312	0.545	0.558
Organic Matter	7.1	6.9	7.0	6.5	0.53	0.326	0.539	0.570
apNDF[3]	1.5	1.5	1.5	1.4	0.12	0.301	0.630	0.765
Starch	3.7	3.6	3.6	3.3	0.29	0.331	0.465	0.549
Intake (g/kg BW)								
DM	22.1	21.2	21.9	20.0	0.94	0.175	0.448	0.578
Ruminal (g/kg)								
Dry Matter	418.8	401.7	398.9	433.4	27.23	0.577	0.705	0.132
Organic Matter	494.7	477.2	475.4	510.4	23.35	0.557	0.637	0.111
apNDF	313.2	301.4	278.4	364.6	27.12	0.149	0.549	0.071
Starch	842.0	852.4	841.1	862.3	16.26	0.273	0.744	0.694
Apparent total-tract (g/kg)								
Dry Matter	690.8	706.1	693.4	725.4	15.42	0.062	0.331	0.450
Organic Matter	707.6	720.5	707.4	742.2	15.04	0.056	0.327	0.322
apNDF	512.0	500.3	497.5	551.1	24.70	0.281	0.345	0.114
Starch	876.4	897.3	907.8	918.9	12.30	0.141	0.031	0.625

[a–b] mean values in the same line with different letters are statistically different. [1] ADE$^-$ = No vitamin ADE supplementation; ADE$^+$= diet with fat-soluble vitamin blend (ADE) supplementation, B-blend$^-$ = No B vitamin blend (biotin, niacin, and thiamine) supplementation, B-blend$^+$= diet with B vitamin blend (biotin, niacin, and thiamine) supplementation.[2]Standard error mean. [3]Neutral detergent fiber corrected for residual ash and protein.

Table 15.4 - Effects of vitamin supplementation on ruminal pH, NH_3-N, VFA and lactate concentrations in Nellore bulls

Item	Experimental Diets [1]				SEM[2]	*P*-value		
	ADE$^-$		ADE$^+$			B-blend	ADE	B-blend × ADE
	B-blend $^-$	B-blend $^+$	B-blend $^-$	B-blend $^+$				
Rumen pH	6.1	5.8	6.0	5.9	0.27	0.003	0.679	0.24
Rumen NH_3-N, mg/dL	11.8 [a]	9.3 [b]	9.7 [b]	10.0 [b]	1.38	0.058	0.205	0.008
Total VFA, mmol/L	94.7	97.8	92.9	88.8	6.75	0.907	0.215	0.396
Individual, mmol/100mmol								
Lactate	4.8	4.5	4.2	4.2	0.40	0.768	0.341	0.749
Acetate	63.6	63.2	64.5	66.5	1.50	0.485	0.106	0.318
Propionate	21.5	23.6	22.0	19.9	1.27	0.972	0.174	0.091
Butyrate	10.2	8.7	9.3	9.4	0.50	0.198	0.917	0.137
Ratio A:P	3.1	2.8	3.2	4.1	0.52	0.423	0.136	0.180

[a–b] mean values in the same line with different letters are statistically different.
[1]ADE$^-$ = No vitamin ADE supplementation; ADE$^+$= diet with fat-soluble vitamin blend (ADE) supplementation, B-blend$^-$ = No B vitamin blend (biotin, niacin, and thiamine) supplementation, B-blend$^+$= diet with B vitamin blend (biotin, niacin, and thiamine) supplementation. [2]Standard error mean.

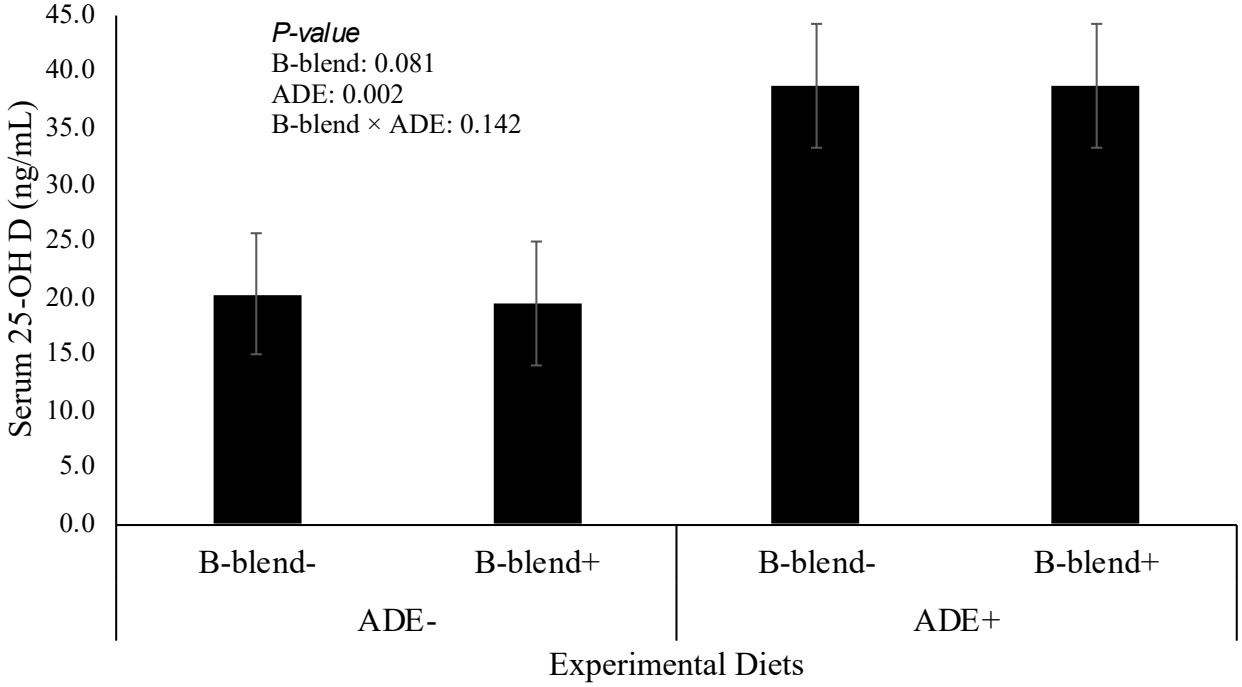


Figure 15.1 - Serum 25-hydroxyvitamin D [25(OH)D] concentrations in Nellore bulls fed diets with or without vitamin blend supplementation. ADE^- = No vitamin ADE supplementation; ADE^+= diet with fat-soluble vitamin blend (ADE) supplementation, B-$blend^-$ = No B vitamin blend (biotin, niacin, and thiamine) supplementation, B-$blend^+$= diet with B vitamin blend (biotin, niacin, and thiamine) supplementation.

Thus, this study showed that supplementing Nellore bulls with fat-soluble vitamin blend (ADE) in high concentrate-diets under Brazilian conditions increased starch total-tract digestibility.

Furthermore, supplementing Nellore bulls with a vitamin blend containing 25(OH)D_3 was a successful strategy for increasing circulating concentrations of 25(OH)D.

Study 2

In this study, 45 Nellore bulls (age = 8 ± 1.0 months; initial body weight = 261 ± 27.3 kg) were used. Five animals were slaughtered at the beginning of the experiment (REF) to determine the initial empty body weight (EBW) of the animals that remained in the experiment. The remaining 40 animals were randomly distributed into 4 groups of 10 animals each. The four treatments previously described were randomly assigned to each group. The experiment lasted 140 d. Dry matter ($P>0.05$) and OM (OMI) intakes were not influenced ($P>0.05$) by the experimental diets (Figure 15.2; A and B).

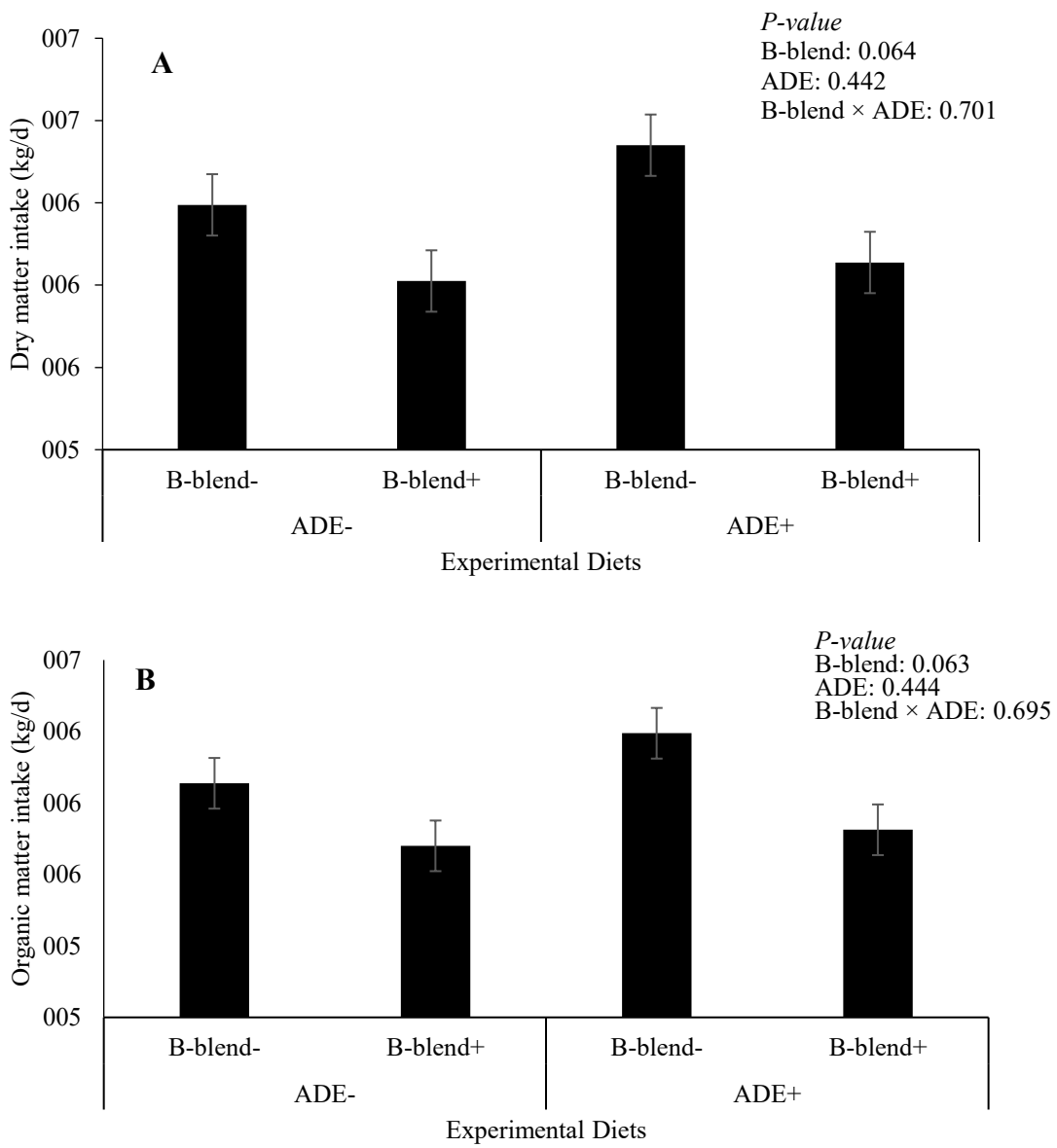


Figure 15.2 - Effect of fat- and/or water-soluble vitamins blends on intakes of dry matter (A) and organic matter (B) of young Nellore bulls. Treatments: ADE-/B-blend- = no vitamin supplementation; ADE-/ B-blend+ = supplemented with a water-soluble blend of vitamins biotin, niacin, and thiamine; ADE+/B-blend- = supplemented with a fat-soluble blend of vitamins A, D, and E; ADE+/B-blend+ = supplemented with both water and fat-soluble vitamin blends

No effects (P>0.05) of vitamin supplementation were observed on final body weight (fBW), final EBW (fEBW), ADG, empty body gain (EBG), hot carcass gain (HCG), cold carcass weight (CCW), hot carcass weight (HCW), backfat thickness (BFT), carcass length (CL), rib eye area (REA) and hot carcass yield (HCY; Table 15.5). Thus, no benefits were observed when supplementing water- (B-blend) and/or fat-soluble (ADE-blend) vitamins blends on DMI, OMI, productive performance, and carcass traits of young Nellore bulls receiving high grain diets under Brazilian feedlot.

Further research is needed regarding vitamin supplementation to feedlot diets. Thus, the committee of BR-CORTE current edition suggests the use of values recommended by NASEM (2016) and OVN (2016) for requirements of vitamins for beef cattle (Table 15.6.)

Table 15.5 - Effect of vitamin supplementation on animal performance and carcass traits of young Nellore bulls

Item[1]	Diets[2]					SEM[3]	P-value		
	REF	ADE-		ADE+			B-blend	ADE	B-blend × ADE
		B-blend-	B-blend+	B-blend-	B-blend+				
Number of animals	5	9	10	9	10	-	-	-	-
fBW (kg)	261	445	422	446	427	12.3	0.104	0.800	0.875
fEBW (kg)	234	408	386	410	390	11.7	0.089	0.811	0.962
ADG (kg/d)	-	1.25	1.14	1.26	1.19	0.054	0.120	0.608	0.693
EBG (kg/d)	-	1.19	1.08	1.20	1.12	0.050	0.075	0.624	0.834
HCG (kg/d)	-	0.77	0.72	0.75	0.74	0.032	0.268	0.946	0.594
CCW (kg)	-	258	244	259	247	8.1	0.131	0.823	0.882
HCW (kg)	155	268	256	266	258	7.9	0.211	0.995	0.824
BFT (mm)	-	7.16	6.58	6.33	6.34	0.768	0.717	0.502	0.711
CL (cm)	-	127	126	126	125	1.8	0.523	0.564	0.978
REA (cm^2)	55.9	75.8	73.2	77.1	75.8	2.44	0.449	0.441	0.792
HCY (%)	-	60.3	60.7	59.8	60.4	0.52	0.336	0.437	0.842

[1]fBW = Mean final body weight; fEBW = Final empty body weight; ADG = Average Daily Earnings; EBWG = Empty body weight gain; HDCG = Hot carcass gain; CCW = Cold carcass weight; HCW = Hot carcass weight; BFT = backfat thickness; CL = Carcass Length; REA = Loin eye area; HCY = Hot carcass yield.

[2]REF = reference group, reference animals were used to estimate the initial empty body weight, carcass, non-carcass and body composition of the other experimental animals. They were not included in the statistical analysis; (ADE-/B-blend-) = mineral supplementation without vitamins; (ADE-/B-blend+) = mineral supplementation with B vitamins (Thiamine = 28.9 mg/kg DM, Niacin = 111.1 mg/kg DM and Biotin = 3.3 mg/kg DM); (ADE+/B-blend-) = mineral supplementation with fat-soluble vitamins (A = 6,666.7 IU/Kg DM, D = 5,111.1 IU/Kg DM (13% D3 and 87% Hy-D®) and E = 70 IU/Kg DM); (ADE+/B-blend+) = mineral supplementation with B vitamins (Thiamine = 28.9 mg/kg DM, Niacin = 111.1 mg/kg DM and Biotin = 3.3 mg/kg DM) and fat-soluble vitamins (A = 6,666.7 IU/Kg DM, D = 5,111.1 IU/Kg DM (13% D3 and 87% Hy-D®) and E = 70 IU/Kg DM).

[3]The standard error of the mean for the treatments (ADE-/B-blend-) and (ADE+/B-blend+) are: [1]fBW = 13.0; fEBW = 12.3; ADG = 0.057; EBWG = 0.052; HDCG = 0.034; CCW = 8.5; HCW = 8.3; SFT = 0.809; CL = 1.8; REA = 2.57; HCY = 0.54.

TABLES OF VITAMIN REQUIREMENTS (NASEM, 2016 and OVN, 2016)

Table 15.6 - Requirement of fat-soluble and water-soluble vitamins for beef cattle according to NASEM (2016) and OVN (2016)

		Category/Phase					
Vitamins	Reference Table	[1]Calves, milk replacer (0-3 months)	Growing[2]	Fattening & finishing[2]	Pregnant Cows and Heifers[2]	Lactating Cows and Heifers[2]	Breeding bulls[2]
A[3]	OVN-DSM 2016 (IU/d)	20000-32000	25000-50000	40000-80000	40000-70000	40000-70000	50000-80000
	NASEM- 2016 (IU/ kg DM)	-	2200	2200	2800	3900	3900
B-carotene	OVN-DSM 2016 (mg/d)	100	-	-	300-500	300-500	-
D[3]	OVN-DSM 2016 (IU/d)	1400-1800	6000-90000	5000-70000	5000-10000	5000-10000	5000-10000
	NASEM- 2016 (IU/ kg DM)	-	275	275	-	-	-
E	OVN-DSM 2016 (mg/d)	100-150	200-300	500-2000[4]	300-500	300-500	300-500
	NASEM- 2016 (IU/ kg DM)	15-60	25-35[5]	25-35[5]	-	-	-
Tiamin	OVN-DSM 2016 (mg/d)	2.5-5	60-250[6]	60-250[6]	-	-	-
Biotin	OVN-DSM 2016(mg/d)	0.05-0.10	10-20[7]	10-20[7]	20	20	20

[1]Added per kg of powdered substitute; [2]Supplementary amount per animal per day; [3]Supplementary amount per animal per day; [4]Top level for longer color life, 100 to 120 days before slaughter; [5]400-500 IU/d for stressed calves newly received in confinement; [6]Higher level for cattle on high concentrate diets; [7]For optimal hoof health and meat marbling.

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Feed aditives for beef cattle

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INTRODUCTION

The enhancement in ruminant nutrition knowledge and the increased adoption of technologies by Brazilian farmers reveal knowledge gaps that need to be filled to provide the most accurate estimates of cattle nutrient requirements. In this context, the use of feed additives that alter ruminal fermentation in beef cattle diets are examples of these technologies.

According to surveys carried out on nutritional recommendations and management practices adopted in Brazilian feedlots, nearly 100% of the feedlots evaluated used some type of feed additive in the diets (Oliveira and Millen, 2014; Pinto and Millen, 2019; Silvestre and Millen, 2021). In addition, the latest survey (Silvestre and Millen, 2021) demonstrated that monensin (ionophore) was the primary feed additive used. Other feed additives commonly used in beef cattle diets include buffers, alkalizers, non-ionophore antibiotics, live yeast, exogenous enzymes, and plant extracts (e.g., essential and functional oils).

Feed additives are mainly used in beef cattle diets to beneficially alter rumen fermentation, prevent rumen acidosis, and improve nutrient utilization (Beauchemin et al., 2018). The effects of feed additives that alter ruminal fermentation (mainly ionophores) in beef cattle raised under temperate conditions have been extensively studied. It is well known that ionophores alter ruminal fermentation by limiting the growth of gram-positive bacteria and shift rumen fermentation towards more propionate and less acetate and butyrate (Bergen and Bates, 1984; NASEM, 2016; Beauchemin et al., 2018). In addition, reduced metabolic disorders incidence, methane production and rumen protein degradation are also effects of most feed additives (Beauchemin et al., 2018). Hence, the use of feed additives in ruminant diets may affect feed intake, ruminal parameters, and energy and protein metabolism, and, consequently, may influence cattle nutrient requirements and performance.

However, the effects of feed additives reported have not always been consistent. For example, reduced dry matter intake (DMI) and improved feed efficiency (FE), with either no effect or an increase in average daily gain (ADG), have been observed in feedlot cattle fed monensin (Raun et al., 1976; Maturana Filho et al., 2010; Melo et al., 2020), whereas some studies have not found significant effects on DMI and FE for cattle in either feedlot or pasture production systems (McGinn et al., 2004; Zawadzki et al., 2011; Maciel et al., 2019).

Furthermore, some recent studies have found the combination of a blend of essential oils (EO) with exogenous α-amylase in feedlot diets to increase feed intake and improve animal growth performance compared to monensin, without affecting FE (Gouvêa et al., 2019; Meschiatti et al., 2019). Nevertheless, in a study conducted by Toseti et al. (2020), including a blend of EO with exogenous α-amylase in feedlot diets improved animal growth performance compared to animals fed monensin, with no differences in DMI and FE. The variations among experimental conditions (i.e., dosage of feed additive; basal diet, experimental duration, sex, breed, age, among others) may impair the comparison of the effects of feed additives obtained in different studies. Thus, meta-analysis can be used to summarize effects of different feed additives across studies and to investigate factors explaining potential heterogeneity of response (Duffield et al., 2012).

However, authors are not aware of any meta-analytical study addressing the effects of feed additive on the productive performance and ruminal parameters of cattle raised under Brazilian conditions. In addition, the last edition of BR-CORTE (BR-CORTE, 2016) did not recommend any correction factor to estimate the nutrient requirements of cattle fed feed additives. Therefore, the committee of BR-CORTE current edition proposed a new chapter regarding the effects of feed additives on the productive performance and ruminal parameters of cattle raised under Brazilian conditions.

In this way, the first section of this chapter is composed by a review of the main feed additives currently available for cattle in Brazil. Subsequently, a meta-analysis regarding the effects of monensin and functional oils on the productive performance and ruminal parameters of feedlot cattle raised under Brazilian conditions is presented.

FEED ADDITIVES AVAILABLE IN BRAZIL

According to the Normative Nº. 13 of November 30, 2004 of the Ministry of Agriculture, Livestock and Supplying (MAPA), feed additives are defined as "products destinated to animal feeding such as substance, microorganisms, or formulated products, which are not commonly used as feed ingredients". Also, such products may or may not have nutritional value; and are usually used to improve the characteristics of products destinated to animal feeding or to animal products themselves, improve growth performance of healthy animals, meet animals' nutrient requirements, or have anticoccidial effect. However, although several feed additives have nutritional value, they are not fed to meet the ruminant nutrient requirements, instead, they are usually fed to alter ruminal or post-ruminal metabolism to improve nutrient utilization and animal productivity.

Many feed additives are available for use in the Brazilian beef industry (the list of feed additives allowed by the Brazilian legislation can be seen at https://www.gov.br/agricultura/pt-br/assuntos/insumos-agropecuarios/insumos-pecuarios/alimentacao-animal/aditivos), with many different formulations and commercial brands for each one. In practice, they can be classified into general categories, such as: ionophore antibiotics, non-ionophore antibiotics, probiotics, exogenous enzymes, buffers and alkalinizes, plant extracts, among others. Some feed additives such as ionophores have been extensively studied (at least under temperate conditions), while others lack robust evaluation. In this context, it can be hard for producers and consultants to balance all the information and decide on which feed additives to use. A brief description of the main feed additives used for beef cattle will be presented below.

Buffers and alkalizers

Ruminal acidosis is a major challenge when large amounts of readily fermentable starch are fed to cattle. Decreased DMI, animal performance, and FE (subacute acidosis), and in severe cases, animal death (acute acidosis) may occur if ruminal acidosis is not properly managed. An option to reduce the potential for acidosis is adding buffer agents, such as sodium ($NaHCO_3$) and potassium ($KHCO_3$) bicarbonate, and/or alkalizer agents, such as sodium (Na_2CO_3) and potassium carbonates (K_2CO_3) and magnesium oxide (MgO), to the diet. Magnesium ($MgCO_3$), calcium ($CaCO_3$), and calcium magnesium ($CaMg(CO_3)_2$) carbonates are other buffer and alkalizer agents used for preventing ruminal acidosis.

Technically, buffer and alkalizer agents are different. Buffer agents reduce the fluctuations in ruminal pH; meanwhile alkalizer agents increase the ruminal pH. Nevertheless, both agents have a direct effect on rumen fluid pH through chemical changes in the rumen as they neutralize acidity through H^+ sequestration and increase buffering capacity of ruminal fluid (Hernández et al., 2014). Moreover, some side effects of supplementing buffer or alkalizer agents may include improved DM and fiber digestibility (Peirce et al., 1983;

Stroud et al., 1985; Kovacik et al., 1986), acetate:propionate ratio (Okeke et al., 1983; Ghorbani et al., 1989; González et al., 2008), and cattle productive performance (Wise et al., 1965; Stroud et al., 1985; Zinn, 1991). Buffers and alkalizers are supposed to benefit ruminants that eat large amounts of readily fermentable carbohydrates. Therefore, they have been used in Brazilian feedlot diets to avoid or mitigate the occurrence of metabolic disorders (Millen et al., 2009).

Sodium bicarbonate is the most used buffer in ruminant diets. This feed additive is considered a true buffer as its pKa is close to the physiological pH of the rumen and it has excellent solubility in the rumen, besides being naturally the main buffer in saliva and ruminal fluid (Kohn and Dunlap, 1998). In addition, $NaHCO_3$ can elevate ruminal pH (Rogers and Davis, 1982; Ghorbani et al., 1989; Zinn, 1991) as it is a strong buffer (Kohn and Dunlap, 1998), and increase the dilution of ruminal contents, and, therefore, the flow of acids and fermentable carbohydrate from the rumen (Rogers and Davis, 1982; Okeke et al., 1983; Russell and Chow, 1993), although these responses are not detected in all studies (Kellaway et al., 1978; Zinn and Borques, 1993; Paton et al., 2006; Calsamiglia et al., 2012). Such increase in the rumen outflow may prevent severe decline in rumen pH, and consequently, be beneficial for feedlot cattle consuming high-concentrate diets.

Responses on growth performance to supplemental $NaHCO_3$ have been variable. Increase in DMI, ADG, and/or FE have been reported in cattle fed high concentrate diets containing $NaHCO_3$ at levels of 0.75% (Zinn, 1991), 1% (Thomas and Hall, 1984; Stroud et al., 1985; Brethour et al., 1986), and 3% of diet DM (Nicholson et al., 1963). Furthermore, experiments have shown similar growth performance responses by adding $NaHCO_3$ or monensin (0.75, 2.5, and 5% $NaHCO_3$ *vs.* 33 mg/kg monensin or 1.14 % $NaHCO_3$ *vs.* 34 mg/kg monensin) in finishing diets, with no further benefit when both were included together to the diet (Kargaard and Van Niekerk, 1980; Zinn and Borques, 1993; Oliveira et al., 2013).

In contrast, the addition of 0.75, 1.5, 2.25, and 5% (McKnight et al., 1979) or 1.0, 1.25, 2.5, and 5% $NaHCO_3$ (González et al., 2008) to high concentrate diets did not influence DMI, ADG, and FE or DMI and ruminal pH of Holstein steers and heifers, respectively. Similarly, the inclusion of 5.7% $NaHCO_3$ in all concentrate diets did not improve feed intake, ADG, or FE of Hereford steers (Nicholson et al., 1962). Furthermore, Thomas and Hall (1984) found that the inclusion of 1 and 1.25 % $NaHCO_3$ to roughage-based diets had no effect on ruminal pH, DMI, ADG, and FE of feedlot steers. Increased saliva production due to increased chewing and ruminating time, and consequently greater endogenous buffering capacity is expected when roughage-based diets are fed to cattle (Bailey, 1961; Maekawa et al., 2002). Such greater buffering capacity along with a reduced rate of volatile fatty acids (VFA) production, may reduce the effectiveness and requirements of dietary buffer supplementation.

In general, no effect on carcass traits has been observed when $NaHCO_3$ is supplemented in feedlot diets (Nicholson et al., 1962; McKnight et al., 1979; Kargaard and Van Niekerk, 1980); although small negative effects of $NaHCO_3$ inclusion at 0.75 and 1.2 % $NaHCO_3$ on carcass traits (retail yield, *Longissimus* muscle area, and fat thickness) have been described in some studies (Russell et al., 1980; Zinn, 1991; Zinn and Borques, 1993).

Nevertheless, there are many instances in the literature that describe only short-term effects of supplemented diets, where inclusion of 0.9, 1.1 and 1.2 % $NaHCO_3$ in high, moderate or low concentrate diets, respectively, enhanced growth performance of cattle during the first 28 days of feeding with no benefit for the entire feeding period (Russell et al., 1980; Worley et al., 1986; Lanna and Boin, 1990). These findings may corroborate the inconsistencies of the effects of $NaHCO_3$ supplementation on growth performance when the whole feeding period was considered.

Alkalizers may also contribute to the control of ruminal acidosis, with

magnesium oxide (MgO) being the most used. Magnesium oxide is a strong alkalinizer agent but has lower solubility in normal rumen pH range (Erdman et al., 1982; Schaefer et al., 1982; Erdman, 1988). The inclusion of MgO at levels of 0.4, 0.69 and 1.37% in moderate concentrate diets or 0.5, 0.69, and 1.05% in high concentrate diets have increased ruminal and/or fecal pH (Schaefer et al., 1982; Peirce et al., 1983; Christiansen and Webb, 1990), diet DM digestibility (Erdman et al., 1982; Peirce et al., 1983), acetate molar concentration (Emery et al., 1965), and acetate:propionate ratio (Teh et al., 1985) of beef and dairy cattle.

However, responses to MgO supplementation on productive performance of cattle in general were limited or variable. No effect of MgO supplementation at levels of 0.4, 0.8 and 1.37 % was observed on DMI (Erdman et al., 1982; Teh et al., 1985; Arambel et al., 1988), ADG (Schaefer et al., 1982), or milk production (Erdman et al., 1982; Arambel et al., 1988) of cattle. Furthermore, reduced DMI has been also reported in dairy cattle studies as a result of MgO supplementation (Thomas and Emery, 1969a; Erdman, 1988). Nevertheless, several studies have reported increased milk fat content when MgO was added to lactating cow diets (Emery et al., 1965; Thomas and Emery, 1969b; Erdman et al., 1982), with this effect being smaller as the fiber content of the diet increased (Erdman, 1988).

Because alkalizers act raising ruminal pH and buffers resisting to changes in pH, some studies were performed to evaluate the possibility of an additive or synergistic effect of combining $NaHCO_3$ and MgO. Some authors have reported increased DMI for both beef and dairy cattle with the combination of $NaHCO_3$ and MgO in the early period following the transition from a high forage to a high concentrate diet (Erdman et al., 1980; Peirce et al., 1983; Teh et al., 1985). Moreover, Erdman (1988) reviewed several publications and tested the interaction of $NaHCO_3$ and MgO on milk fat content and stated that their effect was additive and could be used for preventing the reduction in milk fat content. However, no apparent additive beneficial effect was observed on milk production with these two additives combined (Teh et al., 1985; Erdman, 1988; Cabrita et al., 2009).

It seems that the inclusion of buffers and/or alkalizers to diets containing high levels of fermentable carbohydrates have some benefits for cattle, at least at the beginning of feeding period or adaptation to high-concentrate diets. However, the cost-benefit ratio must be evaluated before use, since other feed additives that promote similar or even more consistent improvement in ruminal conditions and growth performance are also commercially available.

Ionophores

Ionophores are the primary feed additive used in finishing diets in Brazil (Oliveira and Millen, 2014; Pinto and Millen, 2019; Silvestre and Millen, 2021). These feed additives are a class of antimicrobial compounds, which do not include medically important drugs for humans. They are carboxylic polyester compounds, which are usually included in growing and finishing cattle diets to improve ruminal fermentation, allowing increased FE and decreased risk of acidosis and bloat (Bergen and Bates, 1984). More than 120 types of ionophores are known, mainly produced by bacteria of the genus *Streptomyces*. There are many ionophores currently licensed for use in animal nutrition in Brazil, such as: monensin, lasalocid, narasin, and salinomycin.

The mechanism of action is similar among the different ionophores compounds. They have the ability to interact with cations, usually sodium ions (Na^+), serving as a carrier by which these ions can be transported across the cell membrane of some ruminal microorganisms (Bergen and Bates, 1984). Nevertheless, it is noteworthy that some ionophores may have higher or similar affinity for other ions such as potassium (K^+) and calcium (Ca^{2+}) (Bergen and Bates, 1984; NASEM, 2016). This disruption in ionic gradients results in increased proton pump activity and, consequently, depletion of energy reserve (ATP), causing impaired cell division, and

probable death of the microorganism (Bergen and Bates, 1984; Russel and Strobel, 1989). In this context, ionophores selectively inhibit Gram-positive bacteria while preserving many Gram-negative bacteria, whose sensitivity is related to their different cell wall structure (Bergen and Bates, 1984; Russel and Strobel, 1989; NASEM, 2016). Gram-negative bacteria present an external membrane which is usually impermeable to ionophores (molecular size usually greater than 500 Daltons) and other macromolecules (Russel and Strobel, 1989). Thus, ionophores alter the profile of the microbial population in rumen and, thereby, the pattern of ruminal fermentation.

It is well known that ionophores alter ruminal fermentation by limiting the growth of Gram-positive bacteria and shift rumen fermentation towards more propionate (glucose precursor) and less acetate and butyrate (Bergen and Bates, 1984; NASEM, 2016; Beauchemin et al., 2018). Consequently, less H^+ is available for methane producer bacteria, leading to a reduced methane production (Nagaraja et al., 1997; NASEM, 2016). Thus, the reduced energy loss, through reduced methane production, and the increased input of glucose precursors for gluconeogenesis in the liver result in a greater energy supply to the animal (improve energy use efficiency). In addition, reduced metabolic disorders incidence (ruminal acidosis and bloat) and rumen protein degradation to ammonia (improve N use efficiency in the rumen) are also effects attributed to the use of ionophores (Bergen and Bates, 1984; Nagaraja et al., 1997; Beauchemin et al., 2018). Such effects are usually attributed to their anticoccidial effect and inhibition of ruminal lactate producers and obligate amino acid fermenting bacteria without inhibiting lactate users (Bergen and Bates, 1984; Beauchemin et al., 2018). Therefore, an enhanced productive performance would be expected from the improved retention of energy and N in the rumen fermentation. Nevertheless, the effects of feeding ionophores on animal performance seem to be dependent on animal, dose, and dietary factors (Tedeschi et al., 2003; Bretschneider et al., 2008; Duffield et al., 2012).

Monensin is the most widely studied and is also the most used ionophore in Brazil (Silvestre and Millen, 2021). Monensin generally depresses feed intake with a little or no effect on ADG. FE is improved when diets containing high levels of readily fermentable carbohydrates are fed to cattle (Maturana Filho et al., 2010; Duffield et al., 2012; Melo et al., 2020). In diets with greater forage content or in grazing systems, monensin does not decrease intake, and ADG is usually improved, resulting in improved FE (Bretschneider et al., 2008; Prado et al., 2010; Maciel et al., 2019; Gadberry et al., 2022a). Nonetheless, it is important to highlight that most of the research conducted to date with ionophores has focused on high concentrate diets; thus, information about the effects of these feed additives in cattle fed high-forage diets is still limited.

In fact, research data have shown a consistent improvement in FE of cattle raised in feedlot receiving monensin by improving or maintaining ADG and decreasing DMI. Goodrich et al (1984) summarized 228 trials in which monensin was added to feedlot cattle diets at 31.8 mg/kg DM, on average. These authors concluded that monensin increased ADG and FE by 1.6 and 6.5%, respectively, and decreased DMI by 6.4%. Moreover, carcass traits were not influenced by monensin. Subsequently, a meta-analysis of the impact of monensin on growing and finishing beef cattle was performed by Duffield et al. (2012). This study comprised data from 40 peer-reviewed articles and 24 trial reports. The average dose of monensin was 28.1 mg/kg DM. Authors stated that monensin improved both ADG and FE in approximately 2.5 and 6.4%, respectively, and decreased DMI by 3%. However, authors highlighted that the improvement in FE was influenced by the decade of the study, where the improvement of monensin in FE decreased from 8.1% in the 1970s to 2.3 to 3.5% in the 1990s to 2000s, respectively. Authors also pointed out that this reduced effect of monensin on FE may be associated with the increasing level of

concentrate (and energy content) in feedlot diets over the decades.

Bretschneider et al. (2008) summarized results from 48 references in a review regarding the effects of antibiotic growth promoters (AGP) in beef cattle receiving forage-based diets. Monensin and lasalocid were among the AGP compounds evaluated, whose doses averaged 70 and 68 mg/100 kg BW, respectively. Authors observed an increase of 12.1 and 10.3 % in ADG when monensin and lasalocid were used, respectively. However, no effect of monesin or lasalocid was observed on DMI. Likewise, FE was improved as a result of the improvement in ADG. In all reviews (Goodrich et al., 1984; Bretschneider et al., 2008; Duffield et al., 2012), the improvement in ADG of cattle receiving monensin decreased as the ADG of cattle fed the control diet (without monensin) increased. Nevertheless, Bretschneider et al. (2008) reported increased response to lasalocid with increasing ADG of cattle fed high forage diets.

Recently, Gadberry et al. (2022ab) performed two metanalytical studies regarding the effects of monensin supplementation on the performance of beef cows (21 experiments), developing replacement heifers (18 experiments), and growing cattle on high forage diets (38 experiments). Monensin supplementation at doses from 125 to 200 mg/d did not affect BW or body condition score (BCS) of beef cows. However, beef cows presented a reduction of 8% on forage intake and 18 d to first estrous, while the percentage of cows with estrous prior the breeding season increased by 19% and milk production increased by 5.4% when monensin was offered. These results suggested an increase in energy availability when monensin was fed to beef cows.

Furthermore, monensin increased ADG by 5%, FE by 14%, and percentage cycling before the breeding season by 15.9%; while decreasing DMI by 4.3%, and age at puberty by 8.9 d in replacement heifers (Gadberry et al., 2022b). In growing cattle, average improvement in ADG due to monensin supplementaion was of 11%, although this response was negatively affected by the duration of the feeding period (Gadberry et al., 2022a). Besides, monensin supplementation decreased the incidence of bloat by 20%.

Similar responses have been observed for other ionophores such as narasin and salinomycin. No change on DMI, increased ADG from 6.7 to 24.8% and improved FE from 5.8 to 25.1% were documented for cattle fed forage-based diets containing narasin at doses of 7.3, 13, 15.3, and 20 mg/kg DM (Silva, 2016; Polizel et al., 2017; Polizel et al., 2020; Limede et al., 2021). Furthermore, DMI has been reduced from 4 to 6% and FE was increased from 6 to 14.8% in cattle fed high concentrate diets at 11 to 50 mg/kg DM levels of supplementation of salinomycin (Wagner, 1984; Merchen and Berger, 1985; Zinn, 1986a). However, some studies have shown no change in DMI of feedlot cattle with the addition of 11 and 12.6 mg/kg DM of salinomycin (Zinn, 1986b; Neumann et al., 2016) or 10.6 mg/kg DM of narasin (Gobato et al., 2017). Nonetheless, it is noteworthy that narasin and salinomycin seem to be effective in improving FE at a smaller dosage than lasalocid and monensin (Bergen and Bates, 1984).

Several studies have evaluated the main effects of monensin and other feed additives on beef cattle growth performance raised in temperate climates (Goodrich et al., 1984; Bretschneider et al., 2008; Khiaosa-Ard and Zebeli, 2013), and general recommendations have been made to adjust the nutrient requirements of beef cattle fed feed additives by the North American System (NASEM, 2016). Based on a review of the literature, NASEM (2016) recommended: 1) 3% reduction in DMI when monensin is fed regardless of the diet composition with no decrease when lasalocid or laidlomycin are fed; and 2) 3.5% improvement in FE when both monensin and lasalocid are fed; and 3) improved metabolizable energy availability by 2.3% and 1.5% when monensin and lasalocid or laidlomycin are fed, respectively.

However, no recommendations on dietary energy or animal performance adjustments were proposed in the previous

edition of BR-CORTE (Valadares Filho et al., 2016) due to ionophores utilization in beef cattle diets. Unfortunately, there were only few data regarding the effects of ionophores from studies performed in Brazilian conditions to make any recommendation. In the current edition, the committee has performed a meta-analysis regarding the main effects of monensin on ruminal characteristics and productive performance of cattle raised in Brazilian conditions, which will be discussed further in this chapter.

Non-ionophores antibiotics

Like ionophores, non-ionophores antibiotics used as growth promoters, selectively modify microbial population in the rumen, resulting in changes in the proportions of VFA produced (towards more propionate and less acetate), reduced deamination of amino acids (increasing amino acids supply for the host animal), and inhibition of ruminal lactate producing bacteria; thus, improving FE, animal health, and productive performance (Nagaraja and Taylor, 1987; Nagaraja, 1995; Harfoot and Hazlewood, 2016). Virginiamycin and flavomycin are non-ionophores antibiotics available for use in animal diets in Brazil. However, the means by which specific compounds exert their antimicrobial effect differ.

Virginiamycin is produced during the fermentation of *Streptomyces virginiae*, and is an antibiotic of the streptogramin class. This antibiotic is composed of two main factors (M and S) that work synergistically (Boom and Dewart, 1974) and are able to bind specifically and irreversibly to ribosomal units (Cocito, 1979). Such binding inhibits protein synthesis, causing reduction in growth or even death of Gram-positive bacteria, mainly (Cocito, 1979). Flavomycin is a polypeptide antibiotic that inhibits the peptidoglycan formation, and therefore, cell wall formation in Gram-positive bacteria (Aarestrup et al., 1998). Virginiamycin can be used within the production system without withdrawal periods.

The benefits of including non-ionophores antibiotics in cattle diets are well documented. Molar proportions of propionate increased and acetate and butyrate decreased when virginiamycin is supplemented in forage and concentrate-based diets (Nagaraja et al., 1987; Harfoot and Hazlewood, 2016). Moreover, it is claimed to increase ADG and/or FE in growing and finishing cattle fed high forage or concentrate diets as well as to prevent liver abscesses in feedlot cattle (Fiems et al., 1992; Harfoot and Hazlewood, 2016; Tedeschi and Gorocica-Buenfil, 2018). Rogers et al. (1995) observed a linear improvement in ADG and FE and a decrease in the overall incidence and severity of liver abscesses in feedlot cattle as the supplemented dose of virginiamycin increased from 11 to 27.6 mg/kg DM. Authors stated that the effective dose range for virginiamycin in feedlot diets was 19.3 to 27.3 mg/kg DM to increase ADG, 13.2 to 19.3 mg/kg DM to improve FE, and 16.5 to 19.3 mg/kg DM to reduce the incidence of liver abscess.

Similarly, results from a meta-analytical study performed by Tedeschi and Gorocica-Buenfil (2018) demonstrated that liver abscesses incidence decreased linearly as virginiamycin dosage increased. Furthermore, these authors observed that virginiamycin was approximately 2.3 times more effective in improving ADG than monensin for the same dosage and feeding period (2.08 g/d per ppm compared to 0.92 g/d per ppm for monensin). Nonetheless, non-ionophores antibiotics had little or no effect on DMI and carcass traits (Lemos et al., 2016; Gorocica and Tedeschi, 2017; Castagnino et al., 2018).

Because of their similar selective effects on rumen microorganisms and complementary mechanism of action, several studies have hypothesized an additive feeding effect of ionophores and non-ionophores antibiotics for beef cattle. Recent studies performed under different conditions have shown improved productive performance (increase in ADG and FE) when virginiamycin and monensin were used in combination compared to monensin alone in high concentrate diets (Benatti et al., 2017; Heker et al., 2018; Neumann et al., 2020). Similarly, Nunez et al. (2013)

suggested that the combination of virginiamycin and salinomycin in high concentrate diets at doses of 15 and 13 mg/kg DM, respectively, improved the efficiency of dietary energy utilization efficiency when compared to cattle fed only salinomycin.

In contrast, Rigueiro et al. (2020), evaluating feedlot performance of Nellore bulls receiving different combinations of virginiamycin (25 mg/kg of DM) and monensin (30 mg/kg of DM) during the adaptation and finishing periods, observed an improvement in overall productive performance when bulls were fed the additive combination only during the adaptation period; with no benefits when the combination was supplemented during the finishing period or the entire feeding period (adaptation and finishing). The authors postulated that their results reflected the absence of the negative impact of monensin on DMI, since bulls were supplemented with ionophore for the shortest period. Furthermore, no evidence of benefits was found to support the supplementation of virginiamycin combined with monensin to cattle fed high forage diets (Maciel et al., 2019).

Concern about antimicrobial resistance has led to greater control over the use of antimicrobial agents in animal production. In this context, many countries have banned the use of antimicrobial agents as feed additives to improve animal performance, such as those in the European Union. In Brazil, the use of antimicrobial compounds and other growth promoters in animal production has been gradually restricted (Rabello et al., 2020). This has increased interest in alternative and more natural feed additives, such as yeast, essential and functional oils, and exogenous enzymes.

Yeasts

The increasing demand for natural products as an alternative to antibiotics, with potential to improve productive efficiency in ruminants, is increasing the interest in feed additives such as live cells, microorganisms, and/or their metabolites. In this regard, yeast (*Saccharomyces cerevisiae*) has been increasingly used in cattle diets to improve FE, productive performance and health. Nevertheless, studies evaluating the effects of yeast supplementation on the productive performance of beef cattle are recent.

Yeast (*Saccharomyces cerevisiae)* is usually supplied as dry preparations of live cells (live yeast) and, in some products, the cells are mixed with their growth medium (yeast culture). Products containing dead cells are also commercially available and, as they do not contain viable cells, they are used as a nutritional ingredient. Yeasts are composed by high quality proteins, carbohydrates, lipids, and B-complex vitamins, making them advantageous in relation to other feed additives. Moreover, commercially available products vary widely in the strain of *Saccharomyces cerevisiae* used, and in the number of yeast cells present.

In general, yeasts action has been related to the promotion of better ruminal conditions through: 1) removal of traces of oxygen, improving ruminal anaerobiosis; 2) competition with lactate-producing (e.g. *Streptococcus bovis and Lactobacillus*) bacteria for readily fermentable carbohydrates and, therefore, contribution to ruminal pH regulation; 3) stimulation of the growth of fiber digesting bacteria (e.g. *Fibrobacter succinogenes and Ruminococcus flavefaciens*) and growth of lactate-utilizing bacteria (e.g. *Megasphaera elsdenii*), which can be related to the probiotic effect of yeasts (Wallace and Newbold, 1992; Jouany and Morgavi, 2007; Chaucheyras-Durand et al., 2008).

Therefore, there are several instances in the literature that have related the supplementation of diets for growing and finishing cattle with yeast (*Saccharomyces cerevisiae*) to improve productive performance and health (Finck et al., 2014; Geng et al., 2016; Peng et al., 2020). Improved productive responses (DMI, ADG, final BW, and/or FE) attributed to yeast are usually related to increased ruminal pH and VFA concentrations, fiber digestion, and microbial protein flow from the rumen due to the inhibitory activity of rumen proteolytic bacteria (Jouany and

Morgavi, 2007; Chaucheyras-Durand et al., 2008; Amin and Mao, 2021). These effects may be particularly important when high grain diets are fed to cattle.

However, the effects of yeast supplementation are not reported as consistent in the literature. Some studies have shown no benefits of adding yeast to beef cattle diets on digestive parameters or growth performance (Adams et al., 1981; Edwards et al., 1990; Gattass et al., 2008). The discrepancies in responses of yeast supplementation seem to be dependent on different interaction factors, such as diet type, yeast strain, and dose.

The positive effects of adding yeast are more evident when diets with higher concentrate levels are fed, which may be associated with the ability of yeast to modulate ruminal pH. Carro et al. (1992) reported greater *in vitro* digestibility of DM and NDF when yeast was supplemented to high-concentrate diets, but no effect of yeast supplementation was observed with medium- and low-concentrate diets. Likewise, Desnoyers et al. (2009) performed a meta-analysis on the influence of yeast supplementation on ruminal parameters and performance of ruminants (beef and dairy cattle, goats, sheep, and buffaloes) and concluded that beneficial responses to DMI, ruminal pH, ruminal VFA and lactate concentrations, and milk yield were more pronounced in ruminants fed higher levels of concentrate in the diet.

Also, the effectiveness of yeast seems to be dependent on the relationship between the diet composition and the nutritional demands of the animal. The effectiveness of yeast on a low protein diet and high protein diet was investigated for dairy cows in early lactation and the results obtained revealed that yeast supplementation improved the milk yield of cows fed low protein diets, but had no effect on milk yield of cows fed high protein diets (Putnam et al., 1997).

Different strains and doses of yeast differ in their effectiveness in stimulating rumen fermentation and growth performance. The variability in the response to yeast supplementation regarding strain type may be related to differences in their metabolic activity and should be considered in the selection of yeasts for ruminants (Newbold et al., 1995; Jouany and Morgavi, 2007; Sartori et al., 2017). The effect of different dosages (0, 2×10^6; 4×10^6; and 6×10^6 CFU of the total dietary substrate) of yeast in different forage:concentrate ratio diets (80:20, 60:40, 40:60, and 20:80) on *in vitro* digestibility were investigated and the results revealed that the maximum DM and OM digestibility was achieved with the highest dose of yeast (Phesatcha et al., 2020). The inclusion of a higher dose of yeast (4 g/d) improved feed intake, ADG, and FE of calves, whereas the inclusion of a lower dose (1% dry yeast/kg DM) had no effect on calves' performance (Lesmeister et al., 2004). In a meta-analysis, Desnoyers et al. (2009) observed that ruminal pH, VFA concentration, organic matter digestibility and milk yield increased linearly with yeast dose supplemented to ruminants. Similarly, a linear increase in ADG was observed for beef heifers when yeast supplementation was increased from 5 to 20 g/d in the diet (Greene, 2002).

Essential and functional oils

This type of feed additives includes plant extracts that usually have an antimicrobial effect, causing changes in the fermentation profile. Most plant extracts have been associated with essential oils (EO). Essential oils are a diverse group of plant secondary metabolites obtained from volatile aromatic fractions of plants (e.g., thymol, carvacrol and eugenol), which have antimicrobial properties (Patra and Saxena, 2010). However, some plant oils cannot be classified as EO because they are not derived from aromatic portions. Instead, these oils are referred to as functional oils (FO) because they have functions beyond their nutritional value. Anarcardic and ricinoleic acids (main group of phenolic lipids) are examples of FO. Although they can be classified differently, a variety of positive health effects such as antitumor, antioxidant, gastroprotective, and antimicrobial properties have been attributed to these plant extracts (Dahham et al., 2015; Salehi et al., 2020). Thus, EO and FO are part of a natural alternative to improve animal health and productive performance, reducing the use of antimicrobials in livestock. As FO is a broader classification than EO, both types of

plant extracts have increasingly been described just as FO.

The antimicrobial effect of most EO and FO is believed to be similar to that of ionophores in which most Gram-positive bacteria are selectively inhibited (Calsamiglia et al., 2007; Watanabe et al., 2010). This selectiveness is also analogous to that of ionophores, as the hydrophobic nature of the oils allows their interaction with the bacterial membrane, resulting in altered ion transport and gradient (Calsamiglia et al., 2007; Watanabe et al., 2010). Nevertheless, it is noteworthy that these plant extracts may also be effective against some Gram-negative bacteria (although they are less sensitive than Gram-positive bacteria) and some compounds have other modes of action, acting in the cytoplasm or organelles of microbial cells (Burt, 2004; Benchaar and Greathead, 2011).

Thus, the main effects of these oils on ruminal fermentation can be expected to include a shift in the proportions of VFA towards less acetate and more propionate, and, thereby, decreased methane production in the rumen; decreased protein degradation; and improved nutrient utilization and FE. Many studies have been performed to evaluate the benefits of supplementing EO and FO as well as their components in ruminant diets. These studies have been using a wide range experimental procedures, compounds, doses, and diets; thus, results have been inconsistent.

Several *in vitro* studies have indicated the potential of EO and their components in the beneficial manipulation of rumen fermentation (McIntosh et al., 2003; Castillejos et al., 2005; Benchaar et al., 2008). An increase in total VFA concentration and/or propionate:acetate ratio, as well as a decrease in ammonia N concentration and methane production has been described when different EO and their components and doses were included in readily fermentable and medium and high-fiber diets/substrates (Cardozo et al., 2005; Busquet et al., 2006; Chaudhry and Khan, 2012). Nevertheless, positive results have been shown for substrate/diet, EO and/or their components or mixtures, dose applied, and pH dependent. For example, Busquet et al (2006) showed *in vitro* that propionate molar proportion increased and acetate molar proportion decreased when garlic oil was included in a 50:50 forage:concentrate diet at doses of 300 and 3000 mg/L but not at 3 or 30 mg/L. Moreover, other EO, such as ginger, cade, capsicum, and yucca oils had no effect on propionate or acetate molar proportions at all inclusion doses tested in the same study (3, 30, 300 and 3000 mg/L). In some cases, beneficial effects on VFA proportions, ruminal N metabolism, and *in vitro* methane were achieved only at high concentrations of some EO supplemented (Busquet et al., 2006; Benchaar et al., 2008; Benchaar and Greathead, 2011), which may also inhibit the process of ruminal fermentation (decreasing feed digestion and total VFA production) and are unlikely to be used in practice (*in vivo*). The effects can also be transient due to an adaptation of the microbiota to the EO (Benchaar et al., 2008).

Additive, antagonistic and synergistic effects have been suggested among different plant extracts and their components (Burt, 2004; Toroglu, 2007; Fandiño et al., 2020), which have resulted in a variety of commercial products combining different EO, FO, or their components currently available for ruminants in the market. Nonetheless, published studies on the effects of feeding EO and FO to beef cattle are limited when compared to the number of studies performed in dairy cattle.

Overall, results from feeding studies are inconsistent depending on the type of plant extract, source, diet, and doses evaluated. Nevertheless, there are some instances in the literature that describe potential benefits of feeding EO and FO to beef cattle. In a study, Yang et al. (2010) reported a linear increase in propionate molar proportion and a linear decrease in acetate:propionate ratio with increasing dose of EO (0, 400, 800, 1600 mg/d of eugenol) in the diet of growing beef cattle. Ornaghi et al. (2017) showed greater DMI, ADG, and final body and carcass weight in finishing feedlot cattle fed clove and cinnamon EO. Moreover, the authors also stated that responses for most of these variables increased linearly as the dose of EO increased from 3.5 to 7 g/d.

Similarly, greater ADG and FE were reported for feedlot Nellore heifers receiving protected EO blends (composed of eugenol, thymol, and vanillin plus clove EO or eugenol, thymol, and vanillin plus rosemary and clove

EO) (Souza et al., 2019). Moreover, Valero et al. (2014) documented improvement in growth performance (final weight, ADG, and FE) and carcass weight in feedlot bulls fed diets supplemented with FO (blend of castor oil acid and cashew nut shell liquid). These results may increase expectation regarding the use of EO and FO in beef cattle nutrition. In contrast, other studies have shown no effect on rumen fermentation parameters, growth performance, carcass traits or FE of cattle fed high, medium and low concentrate diets containing different commercial blends of EO and FO at different dosages (Beauchemin et al., 2006; Silva et al., 2019; Melo et al., 2020; Wang et al., 2020; Wilson et al., 2020).

In a meta-analytic study, Khiaosa-Ard and Zebeli (2013) investigated the effects of different EO and their compounds on ruminal fermentation, productive performance, and FE in ruminants (beef, dairy, and small ruminants). Although dose-dependent, the results indicated an overall improvement in ruminal fermentation (VFA production and individual VFA concentration) with EO supplementation in ruminants. Nevertheless, positive responses on VFA composition and methane production were more pronounced in beef cattle when compared to dairy cattle and small ruminants. The authors attributed the better response of beef cattle to a synergistic effect between EO and their low ruminal pH, since the reduction in ruminal pH is commonly observed in feedlot systems due to the high-grain diets used. No beneficial effects on ruminal protein degradation or productive performance and FE of dairy cattle were attributed to EO supplementation. The effects of EO supplementation on the productive performance of beef cattle and small ruminants were not evaluated due to the limited number of studies to date. Thus, it seems that manipulation of ruminal fermentation towards more energetically efficient routes is the most consistent benefit of utilizing EO in ruminants.

Despite the limited and inconsistent results reported so far on the productive performance of beef cattle, EO and FO are currently one of the best alternatives to the use of ionophores antibiotics. In this context, Torres et al. (2021) performed a meta-analysis evaluating the effects of different EO as an alternative to monensin in beef cattle diets. These authors reported that the replacement of monensin by EO had no influence on growth performance parameters, but positively affected dressing percentage, rib eye area, and subcutaneous fat thickness of beef cattle fed high grain diets. However, the authors also concluded that EO presented low effectiveness in preventing liver abscesses in these animals.

Likewise, Purevjav et al. (2013) evaluated the effects of FO (blend of castor oil acid and cashew nut shell liquid) with or without monensin on the growth performance and carcass traits of feedlot steers. The authors described improvement in carcass traits (dressing percentage, rib eye area, and prime grade classification) in cattle receiving only FO supplementation; however, they also presented a higher incidence of liver abscess, especially at the highest dose applied (500 mg/kg DM). Although further evaluation is still needed, published data suggest that there is still potential of replacing ionophores antibiotics by EO or FO in beef cattle diets.

For the authors, knowledge on the potential use of these plant extracts in beef cattle, particularly those raised under Brazilian conditions, is still very limited. Therefore, the committee carried out a meta-analysis on the main effects of FO on ruminal characteristics and productive performance of cattle raised in Brazilian production systems, which will be discussed later in this chapter.

Exogenous enzymes

Exogenous enzymes are another class of natural feed additives that have potential to replace growth promoters such as ionophore antibiotics. Enzyme additives are complex bacterial (e.g., *Bacillus*) or fungal (e.g., *Aspergillus, Trichoderma*) fermentation extracts with specific activities of enzymes such as amylases, xylanases, cellulases, and proteases. Enzymes are proteins that are ultimately digested or excreted by the animal, leaving no residues in meat or milk.

In ruminants, exogenous enzymes aid the microbial population of the rumen by performing part of the feed digestion, mainly. Thus, these compounds have potential to enhance the digestion of feed ingredients in the rumen and nutrient availability, and improve FE (Beauchemin et al., 2004; NASEM, 2016; Beauchemin et al., 2018). In addition, they can

be used to supplement the enzymes produced by young animals which, because of an immature digestive system, may have an inadequate enzyme production. The mode of action of the exogenous enzymes is not well understood. Nevertheless, the proposed mode of action of exogenous enzymes includes direct hydrolysis, stimulation of microbial population, synergism with microbial enzymes, and improved microbial adherence to feed particles (Beauchemin et al., 2004; Salem et al., 2013).

Most research in ruminants has examined the potential effects of exogenous fibrolytic enzymes (e.g., xylanase and cellulase) to improve fiber digestibility in the rumen (NASEM, 2016; Beauchemin et al., 2018), because increased fiber digestibility may increase the energy intake by the animal. Moreover, improved fiber digestibility in the rumen stimulates microbial growth, which usually increases the supply of metabolizable protein to the animal. As a result, higher productivity and FE may be achieved. Few studies have been conducted regarding other types of exogenous enzymes, such as amylases and proteases.

Research evaluated several enzymes products which were applied at various doses in different ways (e.g., sprayed on to forage, added to concentrate, etc.) to different types of diets fed to different types of animal (dairy cattle, beef cattle, and small ruminants) and categories (e.g., growing and finishing beef cattle, lactating dairy cows, etc.); thus, results have shown high variability. For example, increased digestibility (particularly fiber), productive performance (ADG, final BW, and/or FE), and/or carcass traits have been reported in some studies (Salem et al., 2013; Neumann et al., 2018; Lourenco et al., 2020) but not in others (ZoBell et al., 2000; Miller et al., 2008; Encinas et al., 2018) when exogenous fibrolytic enzymes were supplemented to high forage and high concentrate diets fed to growing and finishing cattle.

In a meta-analytical study, Tirado-González et al. (2018) evaluated the effects of using exogenous fibrolytic enzymes in ruminant diets with variable content of forage (grass or legume) on the productive performance of lactating dairy cow, growing beef cattle, and sheep. Research included data from 74 journal articles. Overall, results suggested that the inclusion of exogenous fibrolytic enzymes improve the productive performance of dairy and beef cattle, but responses were dependent on enzyme activity (cellulases, xylanases, or different mixtures of both) according to the diet composition (type of forage and forage to concentrate ratio). It is noteworthy that exogenous fibrolytic enzymes improved the productive performance of dairy cattle when they were supplemented in high forage diets, whereas increased productive responses in beef cattle were observed when exogenous fibrolytic enzymes were added to low forage diets. The effects of exogenous fibrolytic enzymes supplementation on the productive performance of sheep were inconsistent. It seems that responses to exogenous fibrolytic enzymes are greater when energy limits animal productivity, which is often the case of lactating dairy cows and growing beef cattle.

Although research has hypothesized that the digestion of starch and protein would not be limited within the rumen, some studies performed with supplementation of exogenous enzymes with amylolytic (Tricarico et al., 2007; DiLorenzo et al., 2011; de Oliveira et al., 2015) and proteolytic activities (Licitra et al., 1999; Vera et al., 2012; Amaro et al., 2021) have evaluated the potential of these exogenous enzymes to improve theproductive performance. Overall, the use of exogenous amylases and proteases seems to have potential to improve feed digestion and the productive performance of cattle, especially when added to high grain diets (Tricarico et al., 2007; Vera et al., 2012; Jolly-Breithaupt et al., 2019).

Furthermore, recent studies (Gouvêa et al., 2019; Meschiatti et al., 2019; Toseti et al., 2020) have suggested a positive synergistic effect on DMI and starch digestibility, and, consequently improved animal growth performance when EO and exogenous α-amylase were included in feedlot diets compared to other feed additives such as monensin.

The use of enzymes additives is expected to increase as the use of antibiotics in ruminant diets decreases. However, results from experiments with exogenous enzymes in ruminants are still inconsistent or limited.

Therefore, although much progress has been made in exogenous enzyme technology, it cannot be concluded at the moment that enzyme supplementation may be an effective way to enhance ruminant productivity.

3-nitrooxypropanol (3-NOP)

3-nitrooxypropanol (3-NOP; DSM Nutritional Products Ltd., Kaiseraugst, Switzerland), marketed as Bovaer® since 2021 in Brazil, is a ruminal CH_4 inhibitor through the inactivation of the enzyme methyl-coenzyme M reductase used by archaea (Duin et al., 2016). Feeding 3-NOP to cattle seems to have no adverse effects on animal or other ruminal microorganisms (Jayanegara et al., 2018; Honan et al., 2022). Moreover, residues of 3-NOP in milk and meat are minimal or inexistent (Thiel et al., 2019), with apparently low safety risks.

Results of CH_4 mitigation by 3-NOP have been promising. Vyas et al. (2016) reported that 200 mg/kg DM of 3-NOP supplementation reduced CH_4 production in backgrounding and finishing beef cattle by 37.6% and 84.3%, respectively, when compared to the control group. Similarly, Alemu et al. (2021) reported a decrease in CH_4 production of 25.7%, on average, in growing steers supplemented with increasing doses of 3-NOP (from 150 to 200 mg/kg of DM), whereas McGuinn et al. (2019), using the supplementation level of 125 mg/kg DM for finishing beef cattle, found a reduction of approximately 70% in CH_4 production. In a metanalysis, Hristov et al. (2022) demonstrated a consistent decrease of 28 to 32% in CH_4 emissions in dairy cows fed 3-NOP at doses ranging from 40 to 200 mg/kg DM, with no effect on DMI, milk production, body weight, or body weight change, and a slight increase in milk fat concentration (0,19%) and yield (90 g/d).

In fact, the effects of 3-NOP appear to depend on the dose, animal type, diet characteristics and feeding duration. In a metanalysis regarding the effects of 3-NOP on dairy and beef cattle, Dijkstra et al. (2018) concluded that CH_4 mitigation effect of this compound was dose-dependent and was less pronounced in beef (22% reduction) than in dairy (39% reduction) cattle. Furthermore, they concluded that increasing diet NDF content decreased the effectiveness of the additive. Therefore, in the same cattle category and dose applied, the mitigation effect of 3-NOP has been greater in higher concentrate diets.

A more recent metanalytical study reported that increasing the dose of 3-NOP linearly decreased CH_4 yield (g/kg DMI), regardless of animal type and feeding period, as well as the proportion of acetate and acetate to propionate ratio (A:P) in both dairy and beef cattle (Kim et al., 2020). Furthermore, authors also observed a trend for decreased DMI in beef but not in dairy cattle with increasing dose of 3-NOP, whereas increasing 3-NOP supplementation tended to decrease milk yield (kg/d) and increased milk fat (%) and protein (%). The effects of 3-NOP supplementation on ADG, BW or FE of beef cattle were not evaluated in the study.

In contrast, although CH_4 emissions decreased linearly, increasing 3-NOP supplementation had no effect on ruminants DMI (dairy cows, beef cattle, and sheep; Jayanegara et al., 2018). Moreover, the production performance of dairy and beef cattle was influenced by feeding 3-NOP in this study, except for FE and milk fat (%). Both FE and milk fat (%) were improved by 3-NOP supplementation, which may suggest greater energy availability as a result of reduced CH_4 emissions. There are instances in the literature that support these findings, in which improved milk fat and FE without change in milk yield and ADG were observed when feeding 3-NOP to dairy and beef cattle, respectively (Vyas et al., 2018; Hristov et al., 2022). However, reduction in DMI of beef cattle fed high forage diet has been often observed (Romero-Perez et al., 2014; Vyas et al., 2016; Vyas et al., 2018).

Other factors may affect the response to 3-NOP supplementation, such as the method used to measure CH_4 emissions (chambers, SF_6 tracer technique, and Greenfeed system) and interaction effects when 3-NOP was combined with other mitigation strategies. Results from Gruninger et al. (2022) showed that the combination of 3-NOP with canola oil in a high forage diet for beef cattle resulted in an additive reduction in CH_4 yield (g/kg DM; 3-NOP = -28%; canola oil = -24%; 3-NOP + canola oil = -52%).

3-NOP seems to be an effective strategy to mitigate CH_4 emissions from ruminants. However, results on animal performance (especially DMI) have been more variable. In addition, little is known regarding the effectiveness of 3-NOP for grazing animals and its long-term impacts. Furthermore, the authors are not aware of any published studies evaluating 3-NOP under Brazilian conditions. Thus, further information is still needed on the use of 3-NOP in a broad range of feeding systems and for longer durations.

METANALYSIS

The use of additive products to beef cattle diets could improve productive performance. However, the literature shows inconsistent results for most feed additives available. Furthermore, most research regarding the effects of feed additives supplementation to cattle was conducted under temperate conditions. In this context, since meta-analysis could summarize results of different studies, the committee of BR-CORTE current edition evaluated the effects of monensin and FO on the productive performance and ruminal parameters of cattle raised under Brazilian conditions through a meta-analytical method.

Database

A literature search and screening process was conducted using public data search engines, such as Google Scholar, Science direct, and Scielo, to create a dataset of feed additives manuscripts conducted in Brazil using the keywords: “feed additives, cattle, and Brazil”, “additive, cattle, and Brazil”, “monensin, cattle, and Brazil”, “essential oils, cattle, and Brazil” or “functional oils, cattle, and Brazil”. The same keywords were also searched in Portuguese. No date restrictions were used on the search; thus, the entire time feed additives in cattle studies conducted in Brazil have been available for research. In addition, Brazilian research and organizations were asked for unpublished and/or published data that might be used for this analysis. Experiments were treated individually even though they were published within the same study.

All unpublished data and peer-reviewed manuscripts were initially evaluated for acceptability by determining whether the research was conducted in Brazil and which feed additive was used. Articles investigating the effects of EO and FO as well as their specific bioactive compounds and blends were eligible for inclusion in the database in the category of FO, as FO is a more general term. Thus, hereafter, EO, FO, bioactive compounds, and their blends are referred to as FO. Initial screening of trial reports and manuscripts was conducted by two authors. Any rejections and inclusions were reviewed by one of the authors and confirmed by other two authors. Studies were required to be randomized trials (completely randomized, complete block, or factorial designs) performed under Brazilian conditions and to contain a control treatment to be eligible for analysis. Each treatment (control, monensin, and functional oils) required report of the number of animals/pens per treatment, mean for the treatment, and a measure of dispersion. As a result, a total of 22 peer-reviewed manuscripts and unpublished data were reached (Table 16.1). The complete list of experiments used in this metanalytic study can be found in Appendix 16.1. Data from different animal class (bulls, steers, heifers, and dry cows) from different genetic groups (*Bos taurus taurus*, *Bos taurus indicus*, or crossbred), raised in feedlot, were included. Other factors that could influence the outcomes of interest were included in the data extraction process, including physiological status (growing, finishing, or dry cow), treatment dose (mg/kg feed of DM), days on feed, forage:concentrate ratio, type of paper (peer-reviewed [J] or not [U]), and animal condition (cannulated or not).

Table 16.1 - Description of the experiments included in the database

Study	Source type: J = Journal U = unpublished	Treatment n	Animal class	Genetic group	Production system	Canullated Y = Yes N = No	Physiological status	Days on feed	Replicates per treatment	Feed additive: MON = monensin FO = functional oils	Doses tested (mg/kg DM)	Outcomes[1]
Chagas, L. J.	U	4	Bull	*Bos taurus indicus*	Feedlot	No	Finishing	124	10	MON, FO	MON = 30 FO = 300 and 500	DMI, BW, ADG, CW, G:F
Fonseca et al.	J	4	Bull	Crossbred	Feedlot	No	Growing	70	5	MON	22	DMI, ADG, G:F
Mogentale et al.	J	3	Cow	Crossbred	Feedlot	Yes	Dry cow	21	4	MON	26.5	DMI, ruminal pH, NH_3, VFA, acetate, propionate, butyrate, acetate:propionate ratio
Gomes et al.	J	4	Steer	*Bos taurus indicus*	Feedlot	No	Finishing	84	18	MON	30	DMI, BW, ADG
Maturana Filho et al.	J	3	Steer	*Bos taurus indicus*	Feedlot	No	Finishing	84	6	MON	30.8	DMI, BW, ADG, G:F
Pereira, M. C. S.	U	5	Bull	*Bos taurus indicus*	Feedlot	No	Finishing	70	12	MON	9, 18, 27, and 36	DMI, BW, ADG, CW, G:F
Prado et al.	J	4	Steer	*Bos taurus taurus*	Feedlot	Yes	Growing	21	4	MON	32.8	DMI, ruminal pH, NH_3, VFA, acetate, propionate, butyrate, acetate:propionate ratio
Ribeiro, F. G.	U	4	Heifer	*Bos taurus taurus*	Feedlot	No	Finishing	84	16	MON	13.3	DMI, BW, ADG, CW, G:F
Segabinazzi, L. R.	U	3	Cow	Crossbred	Feedlot	No	Dry cow	64	8	MON	24.2	DMI, BW, ADG, G:F
Sitta, C.	U	5	Bull	*Bos taurus indicus*	Feedlot	No	Finishing	102	22	MON	30	DMI, BW, ADG, G:F
Sitta, C.	U	5	Bull	*Bos taurus indicus*	Feedlot	No	Finishing	109	23	MON	30	BW, ADG, G:F
Zawadzki et al.	J	3	Bull	*Bos taurus indicus*	Feedlot	No	Finishing	84	11	MON	32.8	DMI, BW, ADG, CW, G:F
Souza, K. A.	U	5	Heifer	*Bos taurus indicus*	Feedlot	No	Finishing	73	8	FO	789, 640, 678, and 644	DMI, BW, ADG, CW, G:F

[1]DMI = dry matter intake; BW = body weight; ADG = average daily gain; CW = carcass weight; G:F = gain to feed ratio; NH = ruminal ammonia; VFA = volatile fatty acids.

Table 16.1 - Description of the experiments included in the database (continued)

Study	Source type: J = Journal U = unpublished	Treatment n	Animal class	Genetic group	Production system	Canullated Y = Yes N = No	Physiological status	Days on feed	Replicates per treatment	Feed additive: MON = monensin FO = functional oils	Doses tested (mg/kg DM)	Outcomes[1]
Zotti, C. A.	U	4	Steer	*Bos taurus indicus*	Feedlot	Yes	Finishing	21	6	MON, FO	MON = 30 and 40 FO = 400	DMI, ruminal pH, NH_3, VFA, acetate, propionate, butyrate, acetate:propionate ratio
Almeida et. al.	J	5	Steer	*Bos taurus indicus*	Feedlot	Yes	Finishing	21	5	MON, FO	MON = 30 FO = 500	DMI, acetate, propionate, butyrate, acetate:propionate ratio
Fugita et al.	J	4	Bull	Crossbred	Feedlot	No	Finishing	-	12	FO	485	DMI, BW, ADG, CW, G:F
Martinele et al.	J	4	Cow	Crossbred	Feedlot	Yes	Dry cow	21	4	MON	33	DMI, ruminal pH, NH_3, VFA, acetate, propionate, butyrate, acetate:propionate ratio
Melo et al.	J	4	Bull	*Bos taurus indicus*	Feedlot	No	Finishing	89	6	MON, FO	MON = 27 FO = 500	DMI, BW, ADG, CW, G:F
Perna Júnior et al.	J	3	Cow	*Bos taurus taurus*	Feedlot	Yes	Dry cow	30	6	MON	17.8	DMI, ruminal pH
Chagas, L. J.	U	4	Steer	*Bos taurus indicus*	Feedlot	Yes	Finishing	21	4	MON, FO	MON = 25 FO = 300	DMI, ruminal pH, NH_3, VFA, acetate, propionate, butyrate
Figueira, D.	U	5	Bull	*Bos taurus indicus*	Feedlot	No	Finishing	112	7	MON	20	DMI, BW, ADG, CW, G:F
Benatti, J. M. B.	U	4	Bull	*Bos taurus indicus*	Feedlot	No	Finishing	84	11	MON	7	DMI, BW, ADG, CW, G:F

[1]DMI = dry matter intake; BW = body weight; ADG = average daily gain; CW = carcass weight; G:F = gain to feed ratio; NH = ruminal ammonia; VFA = volatile fatty acids.

All response variables were not available in each feed additive and in all observations, leading to many missing data. Therefore, sub datasets for each feed additive tested were constructed according to each dependent variables: DMI, BW, ADG, FE (gain:feed ratio), carcass weight, ruminal pH, ruminal N-NH_3, total VFA, acetate (% of total VFA), propionate (% of total VFA), butyrate (% of total VFA), and acetate: propionate ratio. Moreover, due to the limited number of studies obtained and to avoid bias that may occur from differences regarding experimental conditions (genetic groups, animal class, mean BW, etc.) the analyzes of each variable within each feed additive were conducted on changes adjusted according to their corresponding control values (change = (value in feed additive treatment – control value)/ control value). This removed any interstudy bias effect (Ellis et al., 2012).

Statistical analysis

A meta-analysis was conducted through the MIXED procedure of SAS (version 9.4, Inst. Inc., Cary, NC, USA). A fixed effect model was first conducted for each parameter within each feed additive evaluated to estimate the effect size (ES), 95% confidence interval (CI), and statistical significance of effect size. Treatments differences relative to control were weighed by the inverse of variance (weighted mean differences; WMD).

Between-study heterogeneity was quantified using the I^2 statistic (Higgins et al., 2003), which describes the percentage of total variation across experiments that is due to heterogeneity rather than chance. Uncertainty intervals for I^2 were calculated. Negative values of I^2 were put to equal to 0 (Duffield et al., 2012; Torres et al., 2021). Consequently, I^2 lies between 0 and 1. A value greater than 0.5 was considered substantial heterogeneity (Duffield et al., 2012). If there was evidence of heterogeneity, a random effects model was used. A level of 0.05 was established as the critical level of probability for a type I error.

Results

The summary of the experiments used for this metanalytic study is provided in Table 16.1 and a descriptive statistic from the database used to evaluate the effects of monensin and FO is available in Table 16.2. The total number of cattle included in this study regarding the effects of monensin and FO on growth performance and ruminal fermentation parameters were: 448 and 153 for DMI; 353 and 118 for BW; 363 and 118 for ADG; 327 and 118 for FE (G:F ratio);196 and 118 for carcass weight; 70 and 20 for ruminal pH; 58 and 20 for ruminal N-NH_3; 73 and 35 for total VFA, acetate (% total VFA), propionate (% total VFA), and butyrate (% total VFA); and 65 and 27 for acetate:propionate ratio (A:P), respectively. The average dose of monensin tested was 24.3 mg/kg DM, with a range of 7 to 40 mg/kg DM, whereas the average dose of FO evaluated was 488 mg/kg DM, with a rage of 300 to 789 mg/kg DM. All studies utilized the Total Mixed Ration (TMR) system in the feeding operations, forage:concentrate ratio varied from 72.5:27.5 to 7.75:92.25 in monensin studies and from 50:50 to 12:88 in FO studies.

Table 16.2 - Descriptive statistics of database used to evaluate the effects of monensin and functional oils on growth performance and ruminal characteristics of cattle under Brazilian conditions

Item[1]	Studies	n	Mean	SD	Maximum	Minimum
Monensin						
Dry matter intake (kg)	20	448	10.5	2.80	18.0	6.10
Body weight (kg)	12	353	504	43.0	597	426
Average daily gain (kg/d)	13	363	1.33	0.187	1.58	0.87
Gain to feed ratio (G:F)	13	327	0.13	0.028	0.22	0.09
Hot carcass weight (kg)	7	196	283	34.0	341	223
Ruminal pH	6	70	6.21	0.324	6.75	5.74
Ruminal N-NH_3 (mg/dL)	5	58	11.6	5.54	20.5	6.72
Total VFA (mM)	6	73	109	15.2	142	81.0
Acetate (% total VFA)	6	73	60.1	9.08	71.7	46.4
Propionate (% total VFA)	6	73	27.6	5.09	37.3	19.9
Butyrate (% total VFA)	6	73	9.37	3.674	14.6	5.32
Acetate:propionate ratio	5	65	2.52	0.879	4.23	1.31
Functional oils						
Dry matter intake (kg)	7	153	8.24	1.699	10.3	5.07
Body weight (kg)	4	118	439	69.6	506	343
Average daily gain (kg/d)	4	118	1.17	0.357	1.76	0.47
Gain to feed ratio (G:F)	4	118	0.14	0.032	0.19	0.09
Hot carcass weight (kg)	4	118	238	40.1	282	186
Ruminal pH	2	20	5.87	0.128	6.06	5.79
Ruminal N-NH_3 (mg/dL)	2	20	13.9	6.97	20.3	7.32
Total VFA (mM)	3	35	124	20.0	147	101
Acetate (% total VFA)	3	35	56.9	8.86	69.1	45.6
Propionate (% total VFA)	3	35	29.0	5.84	37.3	23.0
Butyrate (% total VFA)	3	35	11.3	3.94	14.7	6.2
Acetate:propionate ratio (A:P)	2	27	1.85	0.632	2.59	1.27

[1]VFA = volatile fatty acids.

Monensin

The sumary of meta-analysis for each monensin supplementation outcome is presented in Table 16.3. There was between-study heterogeneity in the response of monensin on A:P (I^2 = 0.75; IC = 0, 0.87). According to Higgins et al. (2003), values of I^2 statistic above 0.5 denote high heterogeneity. Thus, the model for A:P was evaluated using a random effect of experiment. In this context, if the between-study variance was not considered in the model, this would inflate the residual variance. Consequently, increased residual variance would promote a greater type II error rate. That is, the error that occurs when accepting a null hypothesis that is actually false (false negative response).

Table 16.3 - Summary of effect size estimates of monensin on growth performance and ruminal characteristics outcomes in cattle raised under Brazilian conditions derived from meta-analysis

Outcomes[1]	Weighed mean difference for control (95% CI)[2]	% Change	Trials	n	I^2 (95% uncertainty interval)[3]	Effect size P-value
Dry matter intake (kg/d)	-0.45 (-0.58,-0.32)	-4.96	20	448	0 (0, 0.28)	<0.001
Body weight (kg)	-1.03 (-4.57, 2.52)	-0.22	12	353	0 (0, 0.01)	0.838
Average daily gain (kg/d)	-0.007 (-0.04, 0.03)	-0.58	13	363	0 (0, 0.01)	0.932
Gain to feed ratio (G:F)	0.0003 (-0.004,0.004)	0.93	13	327	0 (0, 0.05)	0.991
Carcass weight (kg)	-1.67 (-5.57, 2.23)	-0.69	7	196	0 (0, 0.01)	0.672
Ruminal pH	-0.06 (-0.08, -0.03)	-0.96	6	70	0 (0, 0.01)	0.001
Ruminal N-NH_3 (mg/dL)	0.26 (-0.10, 0.63)	-3.30	5	58	0 (0, 0.01)	0.322
Total VFA (mM)	-3.38 (-6.65, -0.10)	-2.99	6	73	0.06 (0, 0.43)	0.123
Acetate (% total VFA)	-3.07 (-3.96, -2.18)	-5.28	6	73	0 (0, 0.30)	<0.001
Propionate (% total VFA)	4.08 (3.17, 4.99)	22.2	6	73	0 (0, 0.27)	<0.001
Butyrate (% total VFA)	-0.13 (-0.62, 0.37)	-1.60	6	73	0.10 (0, 0.38)	0.860
Acetate:propionate ratio (A:P)	-0.33 (-0.64, -0.02)	-10.3	5	65	0.75 (0, 0.87)	0.062

[1]VFA = volatile fatty acids.
[2]Weighted mean difference of treatment relative to control, where the weights used were the inverse of the variance in the differences in means; CI = confidence interval.
[3]I^2 is a measure of variation beyond chance (Higgins et al., 2003).

Monensin supplementation decreased DMI (– 0.45 kg; % Change = -4.96; P < 0.001), ruminal pH (– 0.06; % Change = -0.96; P = 0.001), and acetate concentration (WMD = – 0.45; % Change = -0.96; P < 0.001). Propionate concentration was increased with the inclusion of monensin in diets (4.08; % Change = 22.2; P < 0.001). However, there was no effect of diet supplementation with monensin on BW, ADG, FE (gain:feed ratio), carcass weight, ruminal N-NH_3 concentration, total VFA, butyrate concentration, or A:P (P ≥ 0.062).

Functional oils

Results of the meta-analysis regarding the effects of including FO in cattle diets are described in Table 16.4. High between-study heterogeneity was observed when the effects of FO on ADG, ruminal pH, and A:P were evaluated in the present study (I^2 = 0.54 e IC = 0, 0.73 for ADG; I^2 = 0.53 e IC = 0, 0.53 for ruminal pH; and I^2 = 0.71 e IC = 0, 0.74 for A:P). Therefore, the models for ADG, ruminal pH, and A:P were evaluated using a random effect of experiment. As discussed in the previous section, if this between-study variance were not considered in the model, it would increase the probability of occurrence of type II error.

Feeding FO increased BW (12.9 kg; % Change = 3.75; P = 0.047) and hot carcass weight 7.21 kg; % Change = 3.80; P = 0.017) and decreased ruminal concentration of N-NH_3 (- 0.81 mg/dL; % Change = 4.40; P = 0.009) and total VFA (- 3.62 mM; % Change = - 3.01; P = 0.022). Nevertheless, no effects of FO supplementation were observed on DMI, ADG, FE (gain:feed), ruminal pH, A:P or concentrations of acetate, propionate, and butyrate in the rumen (P ≥ 0.157)

Table 16.4 - Summary of effect size estimates of functional oils on growth performance and ruminal characteristics outcomes in cattle raised under Brazilian conditions derived from meta-analysis

Outcomes[1]	Weighed mean difference for control (95% CI)[2]	% Change	Trials	n	I^2 (95% uncertainty interval)[3]	Effect size P-value
Dry matter intake (kg/d)	0.24 (-0.02, 0.50)	4.05	7	153	0.04 (0; 0.37)	0.157
Body weight (kg)	12.9 (3.05, 22.8)	3.75	4	118	0 (0; 0.01)	0.047
Average daily gain (kg/d)	0.09 (-0.05, 0.24)	12.5	4	118	0.54 (0; 0.73)	0.364
Gain to feed ratio (G:F)	0.0008 (-0.004, 0.006)	0.04	4	118	0 (0; 0.01)	0.941
Carcass weight (kg)	7.21 (2.76, 11.7)	3.80	4	118	0 (0; 0.01)	0.017
Ruminal pH	-0.02 (-0.59, 0.56)	-0.26	2	20	0.53 (0; 0.53)	0.944
Ruminal N-NH_3 (mg/dL)	-0.81 (-1.05, -0.57)	-4.40	2	20	0 (0; 0.01)	0.009
Total VFA (mM)	-3.62 (-5.81, -1.42)	-3.01	3	35	0 (0; 0.01)	0.022
Acetate (% total VFA)	-0.70 (-2.74, 1.34)	-14.6	3	35	0 (0; 0.01)	0.697
Propionate (% total VFA)	0.08 (0.36, 0.73)	1.10	3	35	0 (0; 0.01)	0.996
Butyrate (% total VFA)	0.04 (-0.92, 1.00)	-0.01	3	35	0 (0; 0.18)	0.994
Acetate:propionate ratio (A:P)	0.07 (-0.41, 0.56)	6.70	2	27	0.71 (0; 0.74)	0.832

[1]VFA = volatile fatty acids.
[2]Weighted mean difference of treatment relative to control, where the weights used were the inverse of the variance in the differences in means; CI = confidence interval.
[3]I^2 is a measure of variation beyond chance (Higgins et al., 2003).

Discussion

To the authors' knowledge, this is the first attempt to summarize studies evaluating the effects of monensin and FO in cattle diets that were conducted under Brazilian conditions. Although the limited number of studies in the database, the main results seem to corroborate previously published data regarding the effects of monensin or FO in cattle diets worldwide.

The main results obtained for the monensin analysis agreed with its main effects reported for feedlot cattle in the literature, which include altered ruminal fermentation towards more propionate and less acetate and decreased feed intake with little or no effect on ADG (Maturana Filho et al., 2010; Ellis et al., 2012; Melo et al., 2020). In the present study, cattle receiving monensin presented a decrease of approximately 5% in DMI and acetate concentration and an increase of 22% in propionate concentration. Likewise, Goodrich et al. (1984) and Duffield et al. (2012) concluded in two metanalytic studies that the inclusion of monensin at average doses of 31.8 and 28.1 mg/kg DM in beef cattle diets reduced DMI in 6.4 and 3%, respectively. Furthermore, similar ruminal fermentation responses to monensin were obtained by McGinn et al. (2004) and Tomkins et al. (2015). These authors described an increase in propionate concentrations of 18 and 23.7% and decreasing in acetate concentrations of 3.6 and 5% when monensin was added to high concentrate and high forage diets, respectively. Nevertheless, unlikely the results reported in Goodrich et al. (1984) and Duffield et al. (2012) meta-analyses, no effect of monensin was observed on ADG or FE in the current study.

As previously discussed, results on the effects of FO on the productive performance and rumen fermentation parameters of cattle varied due to many influential factors such as FO type, application rates and diet

composition. In fact, between-study heterogeneity was more pronounced in the FO outcomes when compared to monensin results in the current study. The greater between-study heterogeneity along with the limited number of studies in the database may have impaired obtaining significant differences even when large numerical changes due FO supplementation occurred, such as for ADG outcome (12% increase). Nevertheless, significant effects of FO supplementation observed herein agreed with previous findings in cattle.

Some studies have described improved ADG, final BW, and/or carcass weight when FO was included in beef cattle diets, which was usually associated to increased DMI and lack of effect on FE (Valero et al., 2014; Ornaghi et al., 2017; Silva et al., 2019). These positive effects of feeding FO partially corroborate with our findings, as FE (G:F) was not affected and an approximately 3.8% increase in body and carcass weight were observed for cattle fed FO. However, no significant effect of FO supplementation on DMI or ADG was observed in the current study.

Many studies available in the literature on FO supplementation in ruminants indicate that the total VFA concentration may remain unaltered rather than improving or even decreasing (Khorrami et al., 2015; Tomkins et al., 2015; Ghizzi et al., 2018), which is not consistent with the present findings. Nonetheless, the unchanged total VFA concentration due to FO may still be beneficial if ruminal N-NH_3 concentration decreases.

In the present study, inclusion of FO decreased ruminal N-NH_3 concentration by 4.4%, indicating that FO can be effective in reducing the loss of dietary protein due to less rumen degradation. Accordingly, some studies have associated the inclusion of FO in the diet with a reduction in ruminal protein and amino acid degradation (McIntosh et al., 2003; Cardozo et al., 2006; Bodas et al., 2012), resulting in reduced ruminal concentrations of ammonia and increased passage of protein to the small intestine.

As previously discussed, several studies have evaluated the effects of feed additives such as monensin and FO on the productivity of cattle raised in temperate climates (Goodrich et al., 1984; Duffield et al., 2012; Khiaosa-Ard and Zebeli, 2013), and general recommendations by the North American System (NASEM, 2016) have been made to adjust the nutrient requirements of beef cattle fed feed additives.

Our findings suggested that monensin and FO may positively affect ruminal metabolism and productive performance. The committee recommends reducing predicted DMI by 5% when monensin is included in feedlot diets. Although the inclusion of FO in cattle diets numerically increased DMI and ADG by approximately 4 and 12.5%, respectively, no adjustments are proposed by the current BR-CORTE committee, as these effects were not significant. Further research is needed to establish the effects of FO on DMI and ADG of cattle raised under Brazilian conditions.

It is noteworthy that the increase of about 22% in propionate and the reduction of approximately 5% in acetate concentrations promoted by monensin may have improved cattle energy utilization. Stoichiometrically, gas production (carbon dioxide and methane), and consequently, energy loss in rumen is usually reduced when fermentation is driven towards more propionate than acetate (Wolin et al., 1997). During the formation of propionate, no gas is generated but unlike acetate and butyrate, part of the excess hydrogen generated during their production is used to form propionate.

OTHER BRAZILIAN STUDIES WITH FEED ADDITIVES

Unfortunately, it was not possible to gather enough data to perform metanalytic studies regarding the use of other feed additives in Brazilian conditions. Nevertheless, a literature screening similar to that reported in the previous topic for monensin and FO was performed, and the data obtained are described in Table 16.5 (The list of studies is available in Appendix 16.2).

Table16.5 - Numerical mean difference for the control of different feed additives for dry matter intake (DMI), body weight (BW), average daily gain (ADG), gain to feed ratio (G:F), and carcass weight (CW)

Item	Study	DMI (kg/d)	BW (kg)	ADG (kg/d)	G:F	CW (kg)
Lasalocid	Cortada Neto, I. M.; Gonçalves, P. H.; Maturana Filho et al.	-0.08	-0.52	-0.01	0.003	4.00
Monensin + functional oils	Melo et al.; Chagas, L. J.	-1.15	0.00	0.00	0.02	0.00
Monensin + virginamycin	Fonseca et al.; Sitta, C.	-0.82	8.90	-0.08	0.004	-
Narasin	Gobato et al.	-	3.35	0.03	-	-
Salinomycin	Cortada Neto, I. M.; Ferreira et al.	-0.28	9.50	0.06	-	-
Salinomycin + virginamycin	Sitta, C.	-	-1.20	-0.01	-0.009	-
Virginamycin	Cortada Neto, I. M.; Fonseca et al.; Guimarães, K. L.; Sitta, C.; Ferreira et al.	-0.27	11.3	0.03	0.011	-
Yeast	Gomes et al.; Guimarães, K. L.; Sitta, C.; Fugita et al.; Benatti, J. M. B.	0.29	1.04	-0.002	-0.003	0.30
Yeast + monensin	Gomes et al.; Benatti, J. M. B.	-0.84	-6.05	-0.05	0.013	-7.00
Yeast + virginamycin	Guimarães, K. L.	-	14.1	0.13	-	-

In general, numerical reduction of 1.15, 0.83, and 0.85 kg/d in DMI were observed when monensin was utilized in association with FO, virginiamycin, and yeast, respectively. Moreover, a numerical increase in BW of 11.3, 8.90, and 14.1 kg when virginiamycin was included in cattle diets alone or in association with monensin or yeast, respectively.

The inclusion of virginiamycin combined with monensin numerically reduced ADG by 0.090 kg/d, whereas the association of virginimycin and yeast numerically increased ADG by 0.13 kg/d. Furthermore, addition of salinomycin in cattle diets numerically increased BW and ADG by 9.5 kg and 0.060 kg/d, respectively. Nevertheless, great numerical increase in G:F was only observed when monensin in association with FO or yeast was included in cattle diets. It seems that these preliminary results corroborate the discussion performed in the previous topics of this chapter. Nonetheless, more experimental results are needed to draw any conclusion regarding the effects of these feed additives in cattle diets.

PRACTICAL EVALUATION OF FEED ADDITIVES IN BRAZILIAN FEEDLOT DIETS

Two studies were concomitantly conducted to evaluate the effects of diets containing different feed additives on metabolism (Study 1) and growth performance (Study 2) of Nellore bulls raised under Brazilian conditions. Therefore, feed intake, nutrient digestibility, and rumen parameters of Nellore bulls fed diets containing different feed additives were evaluated in study 1 (Silva et al., 2021). In study 2, the effects of different feed additives supplementation on feed intake, ADG, and FE (G:F) were evaluated in finishing Nellore bulls (Pacheco, unpublished).

In both studies, bulls were fed a basal diet composed of 30% corn silage and 70% concentrate (DM basis). The treatments evaluated in both cases consisted of the addition of six feed additives (DM basis): 1.4% bicarbonate and magnesium oxide in a 3:1 ratio (BOX); 36 mg/kg DM lasalocid sodium (LAS); 30 mg/kg DM monensin sodium (MON); 25 mg/kg DM virginiamycin (VIR); 30 mg/kg DM monensin sodium plus 25 mg/kg DM virginiamycin (MV); and 3.15%

commercial mineral supplement containing D-limonene and exogenous α-amylase (EOA).

Study 1

In this study, six rumen-cannulated Nellore bulls (age = 8 ± 1.0 months; initial BW = 225 ± 13.2 kg) were distributed in a 6 × 6 Latin square design, with six treatments (different feed additives) and six periods. The experiment lasted 144 d, with six periods of 24 d. Each period consisted of 14 d for dietary adaptation, 3 d for total collection of feces and urine, and 7 d for omasal and ruminal digesta collection. The main results are described below (Figure 16.1 and Table 16.6). More details can be obtained in Silva et al. (2021).

Dry matter and other intakes (organic matter, starch, NDF and CP) were greater in bulls fed the BOX diet when compared to all other treatments (LAS, MON, VIR, MV, and EOA; Figure 16.1 A and B). It is noteworthy that improvement of DMI in bulls fed diets with BOX compared to those fed other diets was approximately 17.5%. There are instances in the literature that corroborate our finding in which greater feed intake was observed for beef cattle receiving diets containing BOX in relation to those fed no additive or other feed additives, such as MON (Adams et al., 1981; Peirce et al., 1983), since MON reduces DMI.

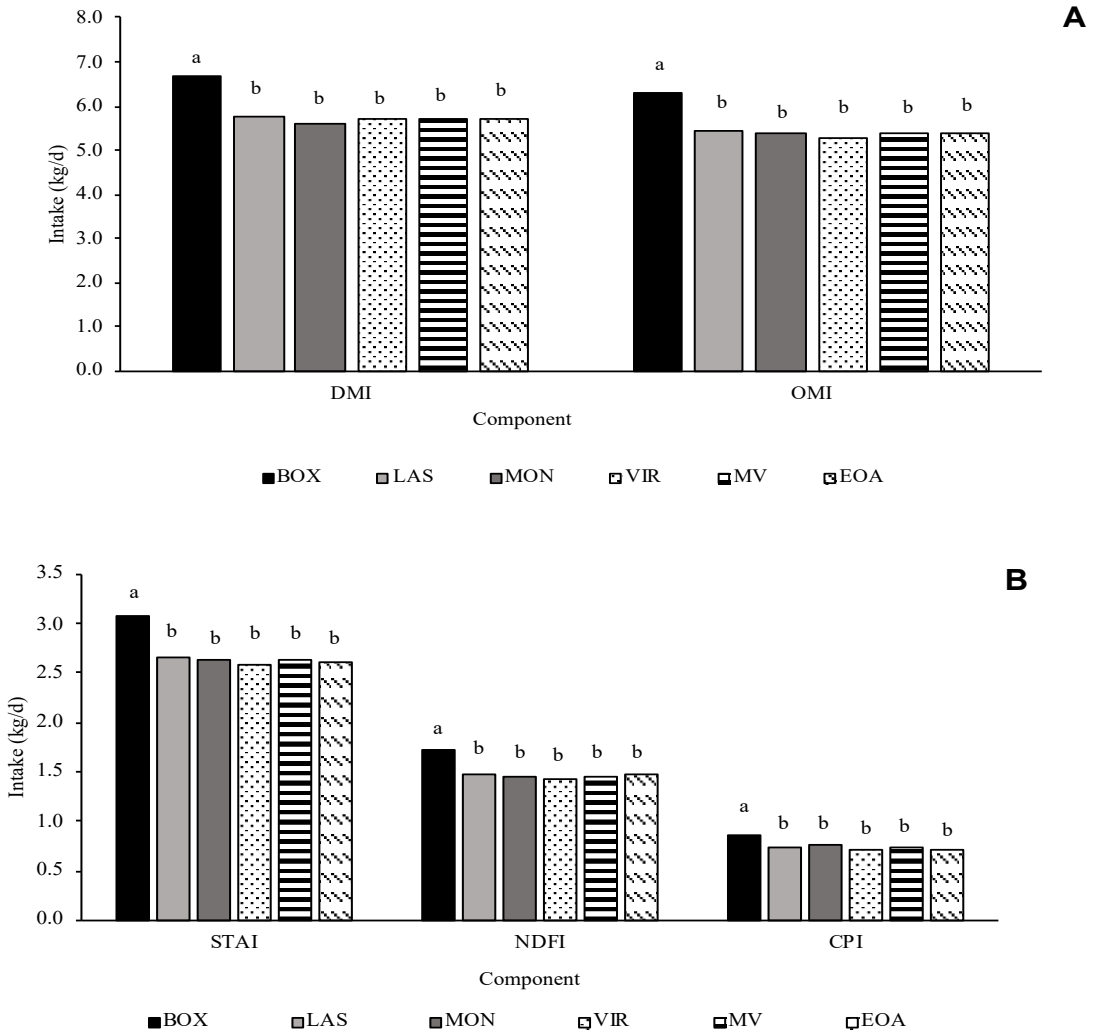


Figure 16.1 - Effect of different feed additives on dry matter intake (DMI; A), organic matter intake (OMI; A), starch intake(STAI; B), neutral detergent fiber intake (NDF; B), and crude protein intake (CPI; B) of Nellore bulls. Treatments were (DM basis): BOX = 1.4% bicarbonate and magnesium oxide in 3:1 ratio; LAS = 36 mg/kg DM lasalocid sodium; MON = 30 mg/kg DM monensin sodium; VIR = 25 mg/kg DM virginiamycin; MV = 30 mg/kg DM monensin sodium plus 25 mg/kg DM virginiamycin; and EOA = 3.15% commercial mineral supplement containing D-limonene and exogenous α-amylase [Adapted from Silva et al. (2021)].

In general, ruminal and intestinal digestibility of most nutrients were similar among all feed additives, except for starch rumen digestibility. Bulls fed EOA showed approximately 4.1% greater (trend; P = 0.09) ruminal digestibility of starch compared to those fed diets BOX, LAS, MON, VIR, or MV (Table 16.6).

Moreover, bulls fed EOA diet presented approximately 6.5 % greater (P < 0.05) total tract digestibility of DM compared to animals fed diets with BOX, LAS, MON, VIR, or MV. In agreement, the potential for exogenous α-amylase to improve ruminal starch digestibility has been reported in the literature (Nozière et al., 2014; Andreazzi et al., 2018).

Table 16.6 - Effects of different feed additives on starch digestibility, microbial efficiency, and rumen pH of Nellore bulls [Adapted from Silva et al. (2021)]

Item	Treatment[1]						SEM	P-value
	BOX	LAS	MON	VIR	MV	EOA		
Dry matter digestion (%)								
Rumen	50.2	48.4	81.4	50.2	50.0	52.3	2.53	0.897
Intestines	21.0	23.9	25.0	24.4	24.1	26.4	2.84	0.813
Total tract	71.2c	72.2bc	75.2b	74.5bc	73.4bc	78.7a	1.49	0.012
Starch digestion (%)								
Rumen	78.4	79.5	81.4	81.3	79.8	83.3	1.13	0.090
Intestines	10.7	9.13	8.11	8.59	9.39	8.72	1.187	0.717
Total tract	89.1	88.6	89.5	89.9	89.2	92.0	1.42	0.514
Microbial efficiency (g MCP/kg TDN)	125	125	121	127	125	124	5.2	0.978
Mean rumen pH	6.27	5.96	6.05	6.03	6.01	5.95	<0.001	0.634
Duration pH (min/d)								
pH > 5.6	1308	1089	1223	1161	1215	1129	139.4	0.887
5.6 < pH < 5.2	132	351	217	279	225	311	137.9	0.888
pH < 5.2	0.00	0.00	0.00	0.00	0.00	0.00	-	-

[1]Treatments were (DM basis): BOX = 1.4% bicarbonate and magnesium oxide in 3:1 ratio/ LAS = 36 mg/kg DM lasalocid sodium; MON = 30 mg/kg DM monensin sodium; VIR = 25 mg/kg DM virginiamycin; MV = 30 mg/kg DM monensin sodium plus 25 mg/kg DM virginiamycin; and EOA = 3.15% commercial mineral supplement containing D-limonene and exogenous α-amylase.

However, no effect of feed additive was observed (P > 0.05) on the intestinal or total tract digestibility of starch, microbial efficiency, or ruminal pH. Mean rumen pH varied between 6.0 and 6.3 for all diets. Moreover, the duration of pH between 5.6 and 5.2 was low and rumen pH values below 5.2 were absent, suggesting that all feed additives evaluated were efficient at controlling ruminal pH and preventing acute and/or subacute acidosis.

In summary, it seems that diets containing monensin, virginiamycin, monensin plus virginiamycin, and essential oils plus exogenous α-amylase reduced DM and nutrient intake of Nellore bulls compared to diets with the combination of sodium bicarbonate and magnesium oxide. Furthermore, the results of this study suggest that no major differences in digestive parameters seem to occur for the evaluated feed additives (BOX, LAS, MON, VIR, MV, and EOA). Nonetheless, this study results on rumen pH confirm that all the evaluated feed additives may be used in feedlot diets to minimize metabolic disorders, and consequently, the negative impacts on digestive parameters.

Study 2

Forty-two Nellore bulls (age = 8 ± 1.0 months; initial BW = 257 ± 26.3 kg) were randomly distributed in six groups with seven animals each and allocated in feedlot. The six treatments previously described for Study 1 were randomly distributed for each group. This study lasted 140 d, which was consisted of five sub-experimental periods of 28 d each: d 1-28 , d 29-56, d 57-84; d 85-112, and d 113-140. Main growth performance results are described below.

No differences ($P \geq 0.38$) were observed in overall (d 1 to 140) DMI, ADG, or G:F (Figure 16.2). However, feed additive affected ($P \leq 0.017$) DMI and ADG during the d 1-28 intermediate period evaluated. Bulls fed BOX had the greatest ($P < 0.05$) DMI (Figure 16.2; A), while bulls fed LAS had the lowest ($P < 0.05$) DMI; bulls fed MON, VIR, MV, and EOA had intermediate DMI and were not different ($P > 0.05$) from the other treatments. Average daily gain (Figure 16.2; B) on d 1-28 period was the greatest ($P < 0.05$) in bulls fed BOX and EOA comparing to animals fed LAS, VIR, and MV ($P < 0.05$). Bulls fed MON were intermediate and not different ($P > 0.05$) from the other treatments.

It is well documented in the literature that feeding MON to feedlot cattle decreases DMI (Maturana Filho et al., 2010; Duffield et al., 2012; Melo et al., 2020). In addition, there are instances in the literature that describe greater DMI for beef cattle fed BOX or EOA compared to those fed no additive or other feed additives, such as MON (Peirce et al., 1983; Gouvêa et al., 2019; Meschiatti et al., 2019). Also, no additional benefit of using the combination of monensin and virginiamycin (MV) to cattle diets have been reported recently (Fonseca et al., 2016; Lemos et al., 2016; Maciel et al., 2019).

Moreover, BOX and EOA diets resulted in the greatest ADG, whereas bulls fed LAS, VIR, and MV presented the lowest ADG during the d 1-28 period. Thus, the results suggest that adding BOX and EOA to feedlot diets may have some increase in feed intake, whereas LAS presented the lowest feed intake, at the begging of the feeding period to Nellore bulls.

CONSIDERATIONS ABOUT STUDIES 1 AND 2

In general, results from studies 1 and 2 suggested:

1 – All the evaluated feed additives were efficient in controlling ruminal pH and preventing acute and/or subacute acidosis; therefore, all feed additives are recommended for such purpose.

2 – In the long term (140 d of feedlot period), all tested feed additives presented similar effects on overall (d 1 to 140) DMI, ADG, or G:F.

3 – In the short term (first 28 d of feedlot period), animals fed BOX presented greater DMI in relation to those fed LAS.

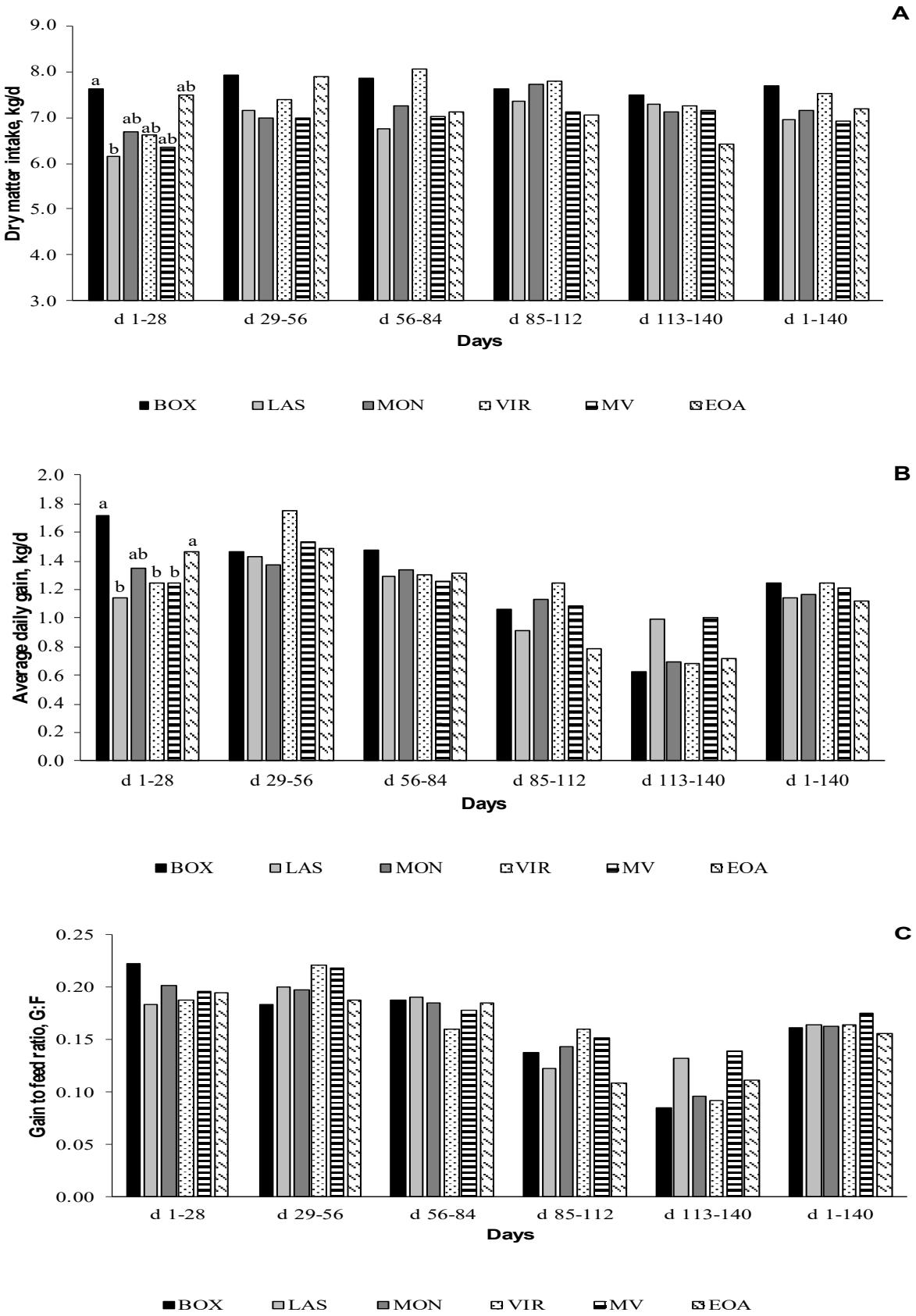


Figure 16.2 - Effect of different feed additives on dry matter intake (DMI; A), average daily gain (ADG; kg/d; B) and feed efficiency (gain to feed ratio; G:F; C) of finishing Nellore bulls. Treatments were (DM basis): BOX = 1.4% bicarbonate and magnesium oxide in 3:1 ratio/ LAS = 36 mg/kg DM lasalocid sodium; MON = 30 mg/kg DM monensin sodium; VIR = 25 mg/kg DM virginiamycin; MV = 30 mg/kg DM monensin sodium plus 25 mg/kg DM virginiamycin; and EOA = 3.15% commercial mineral supplement containing D-limonene and exogenous α-amylase.

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APPENDIX 16.1

List of studies utilized in the metanalytical study regarding the effects of monensin and functional oils on productive performance and ruminal parameters of cattle raised in Brazilian conditions:

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17

Tables of nutritional requirements for beef cattle

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INTRODUCTION

We will present examples of application of the equations proposed throughout the chapters of the current edition of BR-CORTE (BR-CORTE, 2023). Thus, Tables will be provided with the estimates of the nutritional requirements according to different categories (growing and finishing animals, lactating cows and lactating calves), production systems (feedlot and pasture), genetic groups (Zebu, crossbred beef and crossbred dairy cattle) and sex classes (bulls, steers and heifers).

To facilitate visualization and interpretation of the data, three different worksheets are shown for each example: the first shows the general energy and protein requirements, as well as dry matter (DMI) and water intake; the second the mineral requirements; and the third shows the amino acid requirements for gain.

In Tables 17.1 and 17.2 are presented the summaries with their numbering for each category, as well as the pages where they can be found.

Table 17.1 - Summary of the Tables with the nutritional requirements of growing and finishing beef cattle, split by production system, genetic group and sex

System	Genetic Group	Sex	Tables			Pages
			General	Minerals	Amino acids	
Feedlot	Zebu	Bulls	17.3a	17.3b	17.3c	427 - 429
		Steers	17.4a	17.4b	17.4c	430 - 432
		Heifers	17.5a	17.5b	17.5c	433 - 435
	Crossbred beef cattle	Bulls	17.6a	17.6b	17.6c	436 – 438
		Steers	17.7a	17.7b	17.7c	439 – 441
		Heifers	17.8a	17.8b	17.8c	442 – 444
	Crossbred dairy cattle	Bulls	17.9a	17.9b	17.9c	445 – 447
		Steers	17.10a	17.10b	17.10c	448 – 450
		Heifers	17.11a	17.11b	17.11c	451 – 453
Pasture	Zebu	Bulls	17.12a	17.12b	17.12c	454 - 456

Table 17.2 - Summary of the Tables with the estimated nutritional requirements of lactating beef cows and lactating calves

Category	Tables		Pages
	General	Minerals	
Primiparous Cows	17.13a	17.13b	459 – 460
Multiparous Cows	17.14a	17.14b	461 – 462
Calves - 100 e 150 kg BW	17.15a	17.15b	463 – 464
Calves - 200 e 250 kg BW	17.16a	17.16b	465 - 466

*BW = body weight;

In addition to the nutritional requirement Tables available in this chapter, an Excel® spreadsheet has also been developed to estimate the nutritional requirements of beef cattle, which is available for free download at the following address: https://www.brcorte.com.br. This worksheet allows the user to enter the specific information of the animal for which you want to formulate a diet (genetic group, sexual class, production system, etc.), for example a crossbred beef cattle, finished in feedlot, with 438kg of BW and 1.67kg of ADG, located in a region with 32.8°C maximum temperature and 72.4% humidity.

It is recommended that during the process of formulating diets, users should preferably use the actual information of the composition of the available feeds, whether obtained through conventional laboratory analysis or through technologies applied on the farm itself (NIR, for example). Despite providing greater accuracy in meeting the nutritional requirements of animals, the determination of feed composition is often not feasible, either by the delay in obtaining the results or by the high cost. An alternative is the use of tabulated values of feed composition, which are usually averages of several observations obtained in animal nutrition studies. In this context, the average composition of various foods used in ruminant feed in Brazilian conditions is available at as Brazilian Tables of Feed Composition for Ruminants (CQBAL 4.0), which can be accessed at the following address: https://www.cqbal.com.br .

It is worth noting that the formulated diet will hardly correspond exactly to what is being mixed and/or offered and effectively consumed by the animals, due to the need to make assumptions at the time of formulation (animal characteristics and feed composition, for example) and the variation in several other factors that affect the DMI and rumen environment (environmental conditions, feed management, etc.) Thus, the formulation of the diet is only one point of the animal feeding process, which needs to be constantly monitored and possibly adjusted in production systems.

EXAMPLES OF APPLICATION OF THE BR-CORTE (2023) RECOMMENDATIONS

Three examples of calculations of nutritional requirements for beef cattle are described as follows: the first for growing and finishing animals; the second for lactating beef cows; and the third for suckling beef calves.

Growing and finishing beef cattle

To calculate the nutritional requirements of growing and finishing cattle, a Zebu bull, with an average body weight of 520 kg and average daily gain of 1.4 kg/day, raised in a feedlot in a region with 25.7°C maximum temperature and 65.0% humidity, will be considered.

a) Dry matter intake

$$DMI = -2.1948 + 0.08338 \times BW^{0.75} + 3.9328 \times ADG - 0.9030 \times ADG^2$$
$$DMI = -2.1948 + 0.08338 \times 520^{0.75} + 3.9328 \times 1.4 - 0.9030 \times 1.4^2$$
$$DMI = 10.62 \text{ kg/day}$$

b) Energy requirements

Step 1: EBG calculation

$$EBG = 0.963 \times ADG^{1.0151} \rightarrow 0.963 \times 1.4^{1.0151} \rightarrow 1.355 \text{ kg/day}$$

Step 2: EQEBW calculation

$$SBW = 0.8915 \times BW^{1.0151} \rightarrow 0.8915 \times 520^{1.0151} \rightarrow 509.5 \text{ kg}$$
$$EBW = 0.8126 \times SBW^{1.0134} \rightarrow 0.8126 \times 509.5^{1.0134} \rightarrow 450.1 \text{ kg}$$
$$EQEBW = (EBW / 517) \times 517 \rightarrow (450.1 / 517) \times 517 \rightarrow 450.1 \text{ kg}$$

Step 3: MEg calculation

$$NEg = 0.061 \times EQEBW^{0.75} \times EBG^{1.035} \rightarrow 0.061 \times 450.1^{0.75} \times 1.355^{1.035} \rightarrow 8.16 \text{ Mcal/day}$$
$$REprot = 1.140 \times (NEg / EBG)^{-1.137} \rightarrow 1.140 \times (8.16 / 1.355)^{-1.137} \rightarrow 0.148$$
$$kg = 0.327 / (0.539 + REprot) \rightarrow 0.327 / [0.539 + 0.148] \rightarrow 0.476$$

MEg = NEg / *kg* → 8.16 / 0.476 →17.15 Mcal/day

Step 4: MEm calculation

NEm = $0.075 \times EBW^{0.75} \rightarrow 0.075 \times 450.1^{0.75} \rightarrow 7.33$ Mcal/day

km = (0.513 + 0.173 × *kg* + 0.100 × EBG) × 1 → [(0.513 + 0.173 × 0.476 + 0.100 × 1.355) × 1] → 0.73

MEm = NEm / *km* → 7.33 / 0.73 → 10.03 Mcal/day

Step 5: ME total and DE calculation

ME total= MEg + MEm → 17.15 + 10.03 → 27.18 Mcal/day

DE = [((ME total/ DMI) + 0.3032) / 0.9455] × DMI → [((27.18 / 10.62) + 0.3032) / 0.9455] × 10.62 → 32.15 Mcal/day

Step 6: TDN calculation

TDN = DE / 4.4 → 32.15 / 4.4 → 7.31 kg/day

Step 7: TDN % calculation

TDN (%) = TDN × 100/DMI = 7.31× 100/ 10.62 = 68.8%

c) Protein requirements

Step 1: MPm calculation

$MPm = 3.6 \times SBW^{0.75} = 3.6 \times 509.5^{0.75} = 386.1$ g/day

Step 2: MPg calculation

$NPg = 176.01 \times EBG - 0.381 \times EQEBW^{0.75} \times EBG^{1.035}$

$NPg = 176.01 \times 1.355 - 0.381 \times 450.1^{0.75} \times 1.355^{1.035}$

NPg = 187.5

k = 47.4%

MPg = NPg/*k* = 187.5/0.474 = 395.6 g/day

Step 3: MP total calculation

MP total = MPm + MPg = 386.1 + 395.6 = 781.7 g/day

Step 4: RDP calculation

$MCP = -53.07 + 304.9 \times CPI + 90.8 \times TDNI - 3.13 \times TDNI^2$

$MCP = -53.07 + 304.9 \times 1.135 + 90.8 \times 7.31 - 3.13 \times 7.31^2 = 789.3$ g/day

RDP = MCP = 789.3 g/day

Step 5: RUP calculation

RUP = [MP – (MCP × 0.64)]/0.80

RUP = [781.7 – (789.3 × 0.64)]/0.80 = 345.6 g/day

Step 6: Calculation da CP

CP = RDP + RUP = 789.3 + 345.6 = 1135 g/day

d) Calcium requirements

Maintenance: 11.7 × BW = 11.7 × 520 = 6084 mg = 6.08 g/day

Average daily gain: $EBG \times (147 \times EBW^{-0.50}) = 1.355 \times (147 \times 450.1^{-0.50}) = 9.39$ g/day

Total net requirements: Maintenance + Gain = 6.08 + 9.38 = 15.47 g/day

Dietary requirements = Total net requirements/retention coefficient = 15.46/0.568 = 27.24 g/day

e) Phosphorus requirements

Maintenance: 13.5 × BW = 13.5 × 520 = 7020 mg = 7.02 g/day

Average daily gain: 0.0 g/day

Total net requirements = Maintenance + Gain = 7.02 + 0 = 7.02 g/day

Dietary requirements = Total net requirements/retention coefficient = 7.02/0.678 = 10.35 g/day

Ca:P ratio = 27.24/10.35 = 2.63

f) Magnesium requirements

Maintenance: 5.9 × BW = 5.9 × 520 = 3068 mg = 3.07 g/day

Average daily gain: $EBG \times (0.3466 \times EBW^{0.0113}) = 1.355 \times (0.3466 \times 450.1^{0.0113}) = 0.50$ g/day

Total net requirements = Maintenance + Gain = 3.07 + 0.50 = 3.57 g/day

Dietary requirements= Total net requirements/retention coefficient = 3.57/0.355 = 10.06 g/day

g) Sodium requirements
Maintenance: 6.3 × BW = 6.3 × 520 = 3276 mg = 3.28 g/day
Average daily gain: EBG × (5.594 × $EBW^{-0.2998}$) = 1.355 × (5.594 × $450.1^{-0.2998}$) = 1.21 g/day
Total net requirements = Maintenance + Gain = 3.28 + 1.21 = 4.49 g/day
Dietary requirements = Total net requirements/retention coefficient = 4.49/0.371 = 12.10 g/day

h) Potassium requirements
Maintenance: 23.5 × BW = 23.5 × 520 = 12220 mg = 12.2 g/day
Average daily gain: EBG × (0.9463 × $EBW^{0.1216}$) = 1.355 × (0.9463 × $450.1^{0.1216}$) = 2.70 g/day
Total net requirements = Maintenance + Gain = 12.2 + 2.70 = 14.92 g/day
Dietary requirements = Total net requirements/retention coefficient = 14.92/0.484 = 30.82 g/day

i) Sulfur requirements
Maintenance: 10.4 × BW = 10.4 × 520 = 5408 mg = 5.41 g/day
Average daily gain: EBG × (0.03 × $EBW^{0.89}$) = 1.355 × (0.03 × $450.1^{0.89}$) = 9.34 g/day
Total net requirements = Maintenance + Gain = 5.41 + 9.34 = 14.75 g/day
Dietary requirements = Total net requirements/retention coefficient = 14.75/0.773 = 19.08 g/day

j) Copper requirements
Maintenance: 95.6 × BW = 95.6 × 520 = 49712 μg = 49.71 mg/day
Average daily gain: EBG × (1.25 × $EBW^{0.33}$) = 1.355 × (1.25 × $450.1^{0.33}$) = 12.72 mg/day
Total net requirements = Maintenance + Gain = 49.71 + 12.72 = 62.43 mg/day
Dietary requirements = Total net requirements/retention coefficient = 62.43/0.735 = 84.94 mg/day

k) Iron requirements
Maintenance: 2942 × BW = 2942 × 520 = 1529840 μg = 1530 mg/day
Average daily gain: EBG × (10.4 × $EBW^{0.24}$) = 1.355 × (10.4 × $450.1^{0.24}$) = 61.1 mg/day
Total net requirements = Maintenance + Gain = 1530 + 61.1 = 1591 mg/day
Dietary requirements = Total net requirements/retention coefficient = 1591/0.734 = 2167 mg/day

l) Manganese requirements
Maintenance: 184.9 × BW = 184.9 × 520 = 96148 μg = 96.15 mg/day
Average daily gain: EBG × (0.07 × $EBW^{0.80}$) = 1.355 × (0.07 × $450.1^{0.80}$) = 12.58 mg/day
Total net requirements = Maintenance + Gain = 96.15 + 12.58 = 108.73 mg/day
Dietary requirements = Total net requirements/retention coefficient = 108.73/0.439 = 247.67 mg/day

m) Selenium requirements
Maintenance: 3.72 × BW = 3.72 × 520 = 1934 μg = 1.93 mg/day
Average daily gain: EBG × (1.07 × $EBW^{-0.07}$) = 1.355 × (1.07 × $450.1^{-0.07}$) = 0.95 mg/day
Total net requirements = Maintenance + Gain = 1.93 + 0.95 = 2.88 mg/day
Dietary requirements = Total net requirements/retention coefficient = 2.88/0.487 = 5.91mg/day

n) Zinc requirements
Maintenance: 334.4 × BW = 334.4 × 520 = 173888 μg =173.89 mg/day
Average daily gain: EBG × (1.16 × $EBW^{0.86}$) = 1.355 × (1.16 × $450.1^{0.86}$) = 300.78 mg/day
Total net requirements = Maintenance + Gain = 173.89 + 300.78 = 474.67 mg/day
Dietary requirements = Total net requirements/retention coefficient = 474.58/0.668 = 710.58 mg/day

o) Cobalt requirements
Maintenance: 13.5 × BW = 13.5 × 520 = 7020 μg = 7.02 mg/day
Average daily gain: EBG × (0.045 × $EBW^{-0.023}$) = 1.355 × (0.045 × $450.1^{-0.023}$) = 0.05 mg/day
Total net requirements = Maintenance + Gain = 7.02 + 0.05= 7.07 mg/day
Dietary requirements = Total net requirements/retention coefficient = 7.07/0.868 = 8.15 mg/day

p) Chromium requirements

Maintenance: 22.9 × BW = 22.9 × 520 = 11908 μg =11.91 mg/day
Average daily gain: EBG × (0.23 × $EBW^{0.61}$) = 1.355 × (0.23 × $450.1^{0.61}$) = 12.95 mg/day
Total net requirements = Maintenance + Gain = 11.91 + 12.95 = 24.86 mg/day
Dietary requirements = Total net requirements/retention coefficient = 24.86/0.784 = 31.71 mg/day

q) Molybdenum requirements

Maintenance: 3.27 × BW = 3.27 × 520 = 1700 μg = 1.70 mg/day
Average daily gain: EBG × (0.0035 × $EBW^{0.4063}$) = 1.355 × (0.0035 × $450.1^{0.41}$) = 0.06 mg/day
Total net requirements = Maintenance + Gain = 1.70 + 0.06 = 1.76 mg/day
Dietary requirements = Total net requirements/ retention coefficient = 1.76/0.497 = 3.54 mg/day

r) Water intake

For the estimation of water intake. the maximum temperature (T_{MAX}) and the relative humidity (RH) equal to 25.7 ºC and 65.0%, respectively, were considered.

- I_{WATER} = 9.449 + 0.190 × $BW^{0.75}$ + 0.271 × T_{MAX} – 0.259 × RH + 0.489 × DMI
- I_{WATER} = 9.449 + 0.190 × $520^{0.75}$ + 0.271 × 25.7 – 0.259 × 65.0 + 0.489 × 10.62
- I_{WATER} = 25.5 L/day

s) Essential amino acid requirements

Metabolizable arginine requirements for gain = (($30.8 \times EBW^{-0.1631}$)/*k)* × EBG → (($30.8 \times 450.1^{-0.1631}$)/0.56) × 1.355 → 27.52 g/day
Metabolizable histidine requirements for gain: (($3.69 \times EBW^{0.0556}$)/*k)* × EBG → (($3.69 \times 450.1^{0.0556}$)/0.62) × 1.355 → 11.33 g/day
Metabolizable isoleucine requirements for gain: (($9.56 \times EBW^{-0.0631}$)/*k)* × EBG → (($9.56 \times 450.1^{-0.0631}$)/0.30) × 1.355 → 29.37 g/day
Metabolizable Leucine requirements for gain: (($21.5 \times EBW^{-0.0997}$)/*k)* × EBG → (($21.5 \times 450.1^{0.0997}$)/0.30) × 1.355 → 52.81 g/day
Metabolizable Lysine requirements for gain: (($15.9 \times EBW^{-0.0464}$)/*k)* × EBG → (($15.9 \times 450.1^{-0.0464}$)/0.37) × 1.355 → 43.86 g/day
Metabolizable Methionine requirements for gain: (($5.43 \times EBW^{-0.0803}$)/*k)* × EBG → (($5.43 \times 450.1^{-0.0803}$)/0.58) × 1.355 → 7.77 g/day
Metabolizable Phenylanine requirements for gain: (($8.98 \times EBW^{-0.0630}$)/*k)* × EBG → (($8.98 \times 450.1^{-0.0630}$)/0.31) × 1.355 → 26.71 g/day
Metabolizable Threonine requirements for gain: (($9.54 \times EBW^{-0.0651}$)/*k)* × EBG → (($9.54 \times 450.1^{-0.0651}$)/0.34) × 1.355 →25.54 g/day
Metabolizable Tryptophan requirements for gain: (($1.57 \times EBW^{-0.0302}$)/*k)* × EBG → (($1.57 \times 450.1^{-0.0302}$)/0.39) × 1.355 → 4.54 g/day
Metabolizable Valine requirements for gain: (($9.61 \times EBW^{-0.0249}$)/*k)* × EBG → (($9.61 \times 450.1^{-0.0249}$)/0.40) × 1.355 → 27.96 g/day

t) ***Non-essential amino acid requirements***

Metabolizable Alanine requirements for gain: (($34.2 \times EBW^{-0.1885}$)/*k)* × EBG → (($34.2 \times 450.1^{-0.1885}$)/0.35) × 1.355 → 41.86 g/day
Metabolizable Aspartate requirements for gain: (($23.4 \times EBW^{-0.1249}$)/*k)* × EBG → (($23.4 \times 450.1^{-0.1249}$)/0.26) × 1.355 → 56.86 g/day
Metabolizable Cystine requirements for gain: (($1.64 \times EBW^{0.0111}$)/*k)* × EBG → (($1.64 \times 450.1^{0.0111}$)/0.18) × 1.355 → 13.21 g/day
Metabolizable Glutamic acid requirements for gain: (($37.7 \times EBW^{-0.0942}$)/*k)* × EBG → (($37.7 \times 450.1^{-0.0942}$)/0.67) × 1.355 → 42.88 g/day
Metabolizable glycine requirements for gain: (($82.7 \times EBW^{-0.2709}$)/*k)* × EBG → (($82.7 \times 450.1^{-0.2709}$)/0.63) × 1.355 → 33.99 g/day

Metabolizable proline requirements for gain: $((47.7 \times EBW^{-0.2450})/k) \times EBG \rightarrow$
$((47.7 \times 450.1^{-0.2450})/0.43) \times 1.355 \rightarrow 33.65$ g/day
Metabolizable serine requirements for gain: $((16.0 \times EBW^{-0.1509})/k) \times EBG \rightarrow$
$((16.0 \times 450.1^{-0.1509})/0.31) \times 1.355 \rightarrow 27.82$ g/day
Metabolizable tyrosine requirements for gain: $((6.53 \times EBW^{-0.0526})/k) \times EBG \rightarrow$
$((6.53 \times 450.1^{-0.0526})/0.26) \times 1.355 \rightarrow 24.68$ g/day

Lactating beef cows

The following information will be considered for calculating the requirements of lactating beef cows: multiparous beef cow, 450 kg body weight, 10th week of lactation, with an average daily gain of 0.2 kg/day

a) Milk yield (MY)
$MY = 7.996 - 0.101 \times WL - 7.996 \times \exp^{(-1.447 \times WL)}$
$MY = 7.996 - 0.101 \times 10 - 7.996 \times \exp^{(-1.447 \times 10)}$
MY = 6.99 kg/day

b) Dry matter intake
$DMI = (6.535 - 7.558 \times \exp^{(-0.578 \times WL)} + 0.323 \times WL + 1.66 \times MY) * BW / 1000$
$DMI = (6.535 - 7.558 \times \exp^{(-0.578 \times 10)} + 0.323 \times 10 + 1.66 \times 6.99) * 450 / 1000$
DMI = 9.60 kg/day

c) Energy requirements
Step 1: EBG calculation
$EBG = 0.963 \times ADG^{1.0151} \rightarrow 0.963 \times 0.2^{1.0151} \rightarrow 0.188$ kg/day
Step 2: EBW calculation
$SBW = 0.8915 \times BW^{1.0151} \rightarrow 0.8915 \times 450^{1.0151} \rightarrow 439.9$ kg
$EBW = 0.8507 \times SBW^{1.0002} \rightarrow 0.8507 \times 439.9^{1.0002} \rightarrow 374.7$ kg
Step 3: Nem calculation
$NEm = 97.8 \times EBW^{0.75} \rightarrow 97.8 \times 374.7^{0.75} \rightarrow 8329.4$ kcal/day → 8.33 Mcal/day
Step 4: Mem calculation
$MEm = 135.0 \times EBW^{0.75} \rightarrow 135.0 \times 374.7^{0.75} \rightarrow 11497$ kcal/day → 11.5 Mcal/day
Step 5: Neg calculation
$NEg = 1.0076 \times EBW^{0.2389} \times EBG \rightarrow 1.0076 \times 374.7^{0.2389} \times 0.188 \rightarrow 0.78$ Mcal/day
Step 6: MEg calculation
$MEg = NEg/kg \rightarrow 0.78/0.44 \rightarrow 1.77$ Mcal/day
Step 7: EL_l calculation
$NE_l = 0.82$ Mcal/kg de Milk → 0.82 × 6.99 → 5.73 Mcal/day
Step 8: ME_l calculation
$ME_l = EL_l/k_l \rightarrow 5.73/0.72 \rightarrow 7.96$ Mcal/day
Step 9: Met calculation
$MEt = MEm + MEg + ME_l \rightarrow 11.5 + 1.77 + 7.96 \rightarrow 21.23$ Mcal/day
Step 10: DE calculation
$DE = (((MEt/DMI) + 0.3032)/0.9455) \times DMI \rightarrow (((21.23/9.6) + 0.3032)/0.9455) \times 9.6 \rightarrow$ 25.53 Mcal/day
Step 11: TDN calculation
$TDN = DE/4.4 \rightarrow 25.53/4.4 = 5.80$ kg/day
Step 12: % TDN calculation
$TDN (\%) = TDN \times 100/DMI \rightarrow 5.80 \times 100/9.6 \rightarrow 60.4\%$

d) Protein requirements

Step 1: MPm calculation

$MPm = 3.9 \times SBW^{0.75} \rightarrow 3.9 \times 439.9^{0.75} \rightarrow 374.6$ g/day

Step 2: MPg calculation

$NPg = 0.3764 \times EBW^{-0.1839} \times EBG \rightarrow 0.3764 \times 374.7^{-0.1839} \times 0.188 \rightarrow 0.0238$ kg/day $\rightarrow 23.8$ g/day

$MPg = NPg/k \rightarrow 23.8/0.474 \rightarrow 50.2$ g/day

Step 3: MP_l calculation

$MP_l = 50.5$ g/kg Milk $\rightarrow 50.5 \times 6.99 \rightarrow 353$ g/day

Step 4: MP total calculation

$MPt = MPm + MPg + PM_l \rightarrow 374.6 + 50.2 + 353 \rightarrow 778.8$ g/day

Step 5: RDP calculation

$MCP = -53.07 + 304.89 \times CPI + 90.79 \times TDNI - 3.13 \times TDNI^2 \rightarrow -53.07 + 304.89 \times 1.115 + 90.79 \times 5.8 - 3.13 \times 5.8^2 \rightarrow 708.2$ g/day

$RDP = MCP = 708.2$ g/day

Step 6: RUP calculation

$RUP = (MPt - (MCP \times 0.64))/0.80 \rightarrow (778.8 - (708.2 \times 0.64))/0.80 \rightarrow 406.9$ g/day

Step 7: CP calculation

$CP = RDP + RUP \rightarrow 708.2 + 406.9 \rightarrow 1115$ g/day

Step 8: % CP calculation

$CP\ (\%) = CP \times 100/DMI \rightarrow 1.115/9.6 \times 100 \rightarrow 11.6\%$

e) Calcium requirements

Maintenance = $11.7 \times 450/1000 = 5.27$ g/day

Gain = $EBG \times (147 \times EBW^{-0.50}) = 0.188 \times (147 \times 374.7^{-0.50}) = 1.42$ g/day

Lactation = 1.1 g/kg Milk = $1.1 \times 6.99 = 7.68$ g/day

Dietary requirements= (Net Requirements for Maintenance + Gain + lactation) / retention coefficient = (5.27 + 1.42 + 7.68) / 0.568 = 25.3 g/day

f) Phosphorus requirements

Maintenance = $13.5 \times 450/1000 = 6.08$ g/day

Gain = $EBG \times (54.4 \times EBW^{-0.4484}) = 0.188 \times (54.4 \times 374.7^{-0.4484}) = 0.71$ g/day

Lactation = 0.77 g/kg Milk = $0.77 \times 6.99 = 5.38$ g/day

Dietary requirements= (Net Requirements for Maintenance + Gain + lactation) / retention coefficient = (6.08 + 0.72 + 5.38) / 0.678 = 17.95 g/day

Relação Ca:P = 25.3/17.96 = 1.41

g) Magnesium requirements

Maintenance = $5.9 \times 450/1000 = 2.66$ g/day

Gain = $EBG \times (1.4 \times EBW^{-0.3227}) = 0.188 \times (1.4 \times 374.7^{-0.3227}) = 0.039$ g/day

Lactation = 0.07 g/kg Milk = $0.07 \times 6.99 = 0.49$ g/day

Dietary requirements= (Net Requirements for Maintenance + Gain + lactation) / retention coefficient = (2.66 + 0.039 + 0.49) / 0.355 = 8.97 g/day

h) Sodium requirements

Maintenance = $6.3 \times 450/1000 = 2.84$ g/day

Gain = $EBG \times (1.4 \times EBW^{-0.0575}) = 0.188 \times (1.4 \times 374.7^{-0.0575}) = 0.186$ g/day

Lactation = 0.2 g/kg Milk = $0.2 \times 6.99 = 1.39$ g/day

Dietary requirements= (Net Requirements for Maintenance + Gain + lactation) / retention coefficient = (2.84 + 0.186 + 1.39) / 0.371 = 11.9 g/day

i) Potassium requirements

Maintenance = $23.5 \times 450/1000 = 10.58$ g/day

Gain = $EBG \times (3.1 \times EBW^{-0.2142}) = 0.188 \times (3.1 \times 374.7^{-0.2142}) = 0.164$ g/day

Lactation = 0.7 g/kg Milk = $0.7 \times 6.99 = 4.89$ g/day

Dietary requirements= (Net Requirements for Maintenance + Gain + lactation) / retention coefficient = (10.58 + 0.164 + 4.89) / 0.484 = 32.3 g/day

j) Sulfur requirements

Maintenance = 10.4 × 450/1000 = 4.68 g/day
Gain = EBG × (0.03 × $EBW^{0.89}$) = 0.188 × (0.03 × $374.7^{0.89}$) = 1.10 g/day
Lactation = 0.3 g/kg Milk = 0.3 × 6.99 = 2.10 g/day
Dietary requirements= (Net Requirements for Maintenance + Gain + lactation) / retention coefficient = (4.68 + 1.11 + 2.09) / 0.773 = 10.2 g/day

k) Cobalt requirements

Maintenance = 13.5 × 450/1000 = 6.08 mg/day
Gain = EBG × (0.045 × $EBW^{-0.023}$) = 0.188 × (0.045 × $374.7^{-0.023}$) = 0.007 mg/day
Lactation = 0.23 mg/kg Milk = 0.23 × 6.99 = 1.608 mg/day
Dietary requirements= (Net Requirements for Maintenance + Gain + lactation) / retention coefficient = (6.08 + 0.007 + 1.608) / 0.868 = 8.86 mg/day

l) Copper requirements

Maintenance = 95.6 × 450/1000 = 43.02 mg/day
Gain = EBG × (1.25 × $EBW^{0.33}$) = 0.188 × (1.25 × $374.7^{0.33}$) = 1.66 mg/day
Lactation = 1.99 mg/kg Milk = 1.99 × 6.99 = 13.9 mg/day
Dietary requirements= (Net Requirements for Maintenance + Gain + lactation) / retention coefficient = (43.02 + 1.66 + 13.9) / 0.735 = 79.7 mg/day

m) Chromium requirements

Maintenance = 22.9 × 450/1000 = 10.31 mg/day
Gain = EBG × (0.23 × $EBW^{0.61}$) = 0.188 × (0.23 × $374.7^{0.61}$) = 1.61 mg/day
Lactation = 3.2 mg/kg Milk = 3.2 × 6.99 = 22.37 mg/day
Dietary requirements= (Net Requirements for Maintenance + Gain + lactation) / retention coefficient = (10.31 + 1.61 + 22.37) / 0.784 = 43.7 mg/day

n) Iron requirements

Maintenance = 2942 × 450/1000 = 1324 mg/day
Gain = EBG × (10.4 × $EBW^{0.24}$) = 0.188 × (10.4 × $374.7^{0.24}$) = 8.1 mg/day
Lactation = 29.9 mg/kg Milk = 29.9 × 6.99 = 208.9 mg/day
Dietary requirements= (Net Requirements for Maintenance + Gain + lactation) / retention coefficient = (1324 + 8.1 + 208.9) / 0.734 = 2099 mg/day

o) Manganese requirements

Maintenance = 184.9 × 450/1000 = 83.21 mg/day
Gain = EBG × (0.07 × $EBW^{0.80}$) = 0.188 × (0.07 × $374.7^{0.80}$) = 1.50 mg/day
Lactation = 1.41 mg/kg Milk = 1.41 × 6.99 = 9.85 mg/day
Dietary requirements= (Net Requirements for Maintenance + Gain + lactation) / retention coefficient = (83.21 + 1.50 + 9.85) / 0.439 = 215.4 mg/day

p) Zinc requirements

Maintenance = 334.4 × 450/1000 = 150.5 mg/day
Gain = EBG × (1.16 × $EBW^{0.86}$) = 0.188 × (1.16 × $374.7^{0.86}$) = 35.64 mg/day
Lactation = 35.4 mg/kg Milk = 35.4 × 6.99 = 247.44 mg/day

Dietary requirements= (Net Requirements for Maintenance + Gain + lactation) / retention coefficient = (150.5 + 35.64 + 247.44) / 0.668 = 649 mg/day

Suckling beef calves

The following informations were considered for calculating the requirements of lactating calves of 150 kg body weight at 10 weeks of age, with an average daily gain of 0.8 kg/day.

a) Dry matter intake

DMI Milk = MY × % MS Milk = 6.99 × 0.139 = 0.97 kg/day
DMI solids = 0.353 – 0.532 × DMI Milk + 0.01065 × BW + 0.3497 × ADG
DMI solids = 0.353 – 0.532 × 0.97 + 0.01065 × 150 + 0.3497 × 0.80 = 1.71 kg/day
DMI total = DMI solid + DMI Milk = 1.71 + 0.97 = 2.68 kg/day
DMI Milk% = (DMI Milk / DMI total) × 100 = (0.97 / 2.68) × 100 = 36.19%
DMI solids% = (DMI solids / DMI total) × 100 = (1.71 / 2.68) × 100 = 63.81%
SBW = BW
EBW = 0.962 × SBW = 0.962 × 150 = 144.3 kg
EBG = 0.958 × ADG = 0.958 × 0.80 = 0.77 kg/day

b) Energy requirements

$NEm = 70.3 \times EBW^{0.75} = 70.3 \times 144.3^{0.75} = 2.93$ Mcal/day
$MEm = 118.6 \times EBW^{0.75} = 118.6 \times 144.3^{0.75} = 4.94$ Mcal/day
$NEg = 0.0932 \times EBW^{0.75} \times EBG^{0.9157} = 0.0932 \times 144.3^{0.75} \times 0.77^{0.9157} = 3.04$ Mcal/day
kg = (DMI Milk% × 0.69 + DMI solids% × 0.57)/100 = 36.19 × 0.69 + 63.81 × 0.57 = 0.613
MEg = NEg/kg = 3.04/0.613 = 4.96 Mcal/day
MEt = MEm + MEg = 4.94 + 4.96 = 9.90 Mcal/day
DE = MEt/0.96 = 9.90/0.96 = 10.31 Mcal/day
TDN = DE/4.4 = 10.31/4.4 = 2.34 kg/day
TDN % = (TDN / DMI total) × 100 = (2.34 / 2.68) × 100 = 87.26%

c) Protein requirements

$MPm = 3.9 \times SBW^{0.75} = 3.9 \times 150^{0.75} = 167.2$ g/day
$NPg = 0.1397 \times EBW^{0.0351} \times EBG = 0.1397 \times 144.3^{0.0351} \times 0.77 = 0.1275$ kg/day= 127.5 g/day
$k = 84.665 – 0.1179 \times EQEBW = 84.665 – 0.1179 \times 144.3 = 67.7\%$
MPg = NPg/k = 127.5/0.677 = 188.4 g/day
MPt = MPm + MPg = 167.2 + 188.4 = 355.6 g/day
CPI Milk = MY × 0.0356 = 6.99 × 0.0356 = 0.249 kg
TDNI Milk = MY × 0.18 = 6.99 × 0.18 = 1.258 kg
$MCP = -53.07 + 304.9 \times (CPI – CPI\ Milk) + 90.8 \times (TDNI – TDNI\ Milk) – 3.13 \times (TDNI – TDNI\ Milk)^2$
$MCP = -53.07 + 304.9 \times (0.466 – 0.249) + 90.8 \times (2.34 – 1.258) – 3.13 \times (2.34 – 1.258)^2 = 107.7$ g/day
RDP = MCP = 107.7 g/day
RUP = (MPt – (RDP × 0.64)) / 0.80 = (355.6 – (107.7 × 0.64))/0.80 = 358.3 g/day
CP = RDP + RUP = 107.7 + 358.3 = 466 g/day
CP % = (CP / DMItotal) × 100 = (0.466 / 2.68) × 100 = 17.38%

d) Minerals requirements

Calcium

- Net Requirements for Maintenance: 11.7 × 150/1000 = 1.76 g/day
- Net Requirements for Gain = $EBG \times (54.8 \times EBW^{-0.3981}) = 0.77 \times (54.8 \times 144^{-0.3981}) = 5.83$ g/day
- Dietary requirements= (Net Requirements for Maintenance + Gain) / retention coefficient = (1.76 + 5.83) / 0.568 = 13.4 g/day

Phosphorus

- Net Requirements for Maintenance: 13.5 × 150/1000 = 2.03 g/day
- Net Requirements for Gain = $EBG \times (8.6 \times EBW^{-0.0371}) = 0.77 \times (8.6 \times 144^{-0.0371}) = 5.51$ g/day

- Dietary requirements= (Net Requirements for Maintenance + Gain) / retention coefficient = (2.03 + 5.51) / 0.678 = 11.1 g/day
- Relação Ca:P = 13.4/11.1 = 1.20

Magnesium
- Net Requirements for Maintenance: 5.9 × 150/1000 = 0.89 g/day
- Net Requirements for Gain = EBG × (0.4 × $EBW^{-0.0173}$) = 0.77 × (0.4 × $144^{-0.0173}$) = 0.24 g/day
- Dietary requirements= (Net Requirements for Maintenance + Gain) / retention coefficient = (0.89 + 0.24) / 0.355 = 3.18 g/day

Sodium
- Net Requirements for Maintenance: 6.3 × 150/1000 = 0.95 g/day
- Net Requirements for Gain = EBG × (1.2 × $EBW^{-0.0209}$) = 0.77 × (1.2 × $144^{-0.0209}$) = 0.83 g/day
- Dietary requirements= (Net Requirements for Maintenance + Gain) / retention coefficient = (0.95 + 0.83) / 0.371 = 4.79 g/day

Potassium
- Net Requirements for Maintenance: 23.5 × 150/1000 = 3.53 g/day
- Net Requirements for Gain = EBG × (1.5 × $EBW^{-0.0636}$) = 0.77 × (1.5 × $144^{-0.0636}$) = 0.84 g/day
- Dietary requirements= (Net Requirements for Maintenance + Gain) / retention coefficient = (3.53 + 0.84) / 0.484 = 9.03 g/day

TABLES FOR GROWING AND FINISHING BEEF CATTLE

Tables 17.3 to 17. 12 present the daily nutritional requirements for growing and finishing beef cattle. The values used for generating the data in these tables included average body weight from 210 to 630 kg and average daily gain from 0.3 to 1.8 kg/day. The nutritional requirement values can be directly used for formulating diets according to the performance levels presented.

It is important to note that the values of amino acid requirements for weight gain of light animals, with body weights of 210 and 270 kg, are not presented in the Tables. This is because the database used to generate the equations did not include these specific weights. Therefore, the use of the models based on these Tables for light animals should not be recommended.

In addition, it is important to note that metabolizable amino acid requirements for maintenance are not included in the amino acid requirement tables. The amino acid requirements for maintenance will be a focus for updates in the next editions of BR-CORTE.

It is emphasized that there is a thesis (Silva et al.,2002. Net amino acid requirements for weight gain of bulls Nellore. *Revista Brasileira de Zootecnia*, 31, 765-775.) published with data on the requirements of metabolizable essential amino acids for maintenance obtained with Nellore cattle.

However, we present in Table 17.12d, the net amino acid requirements calculated using the amino acid composition values of endogenous protein (NRC, 2021: p.79) multiplied by the net protein requirements for maintenance (BR-CORTE, 2023). Considering the difficulty in obtaining data on the utilization efficiency of metabolizable amino acids for maintenance, BR-CORTE (2023) did not calculate the requirements of metabolizable amino acids for maintenance.

Therefore, the committee decided to expect for new information on zebu before making its recommendation on the nutritional requirements of metabolizable amino acids for maintenance.

Table 17.3a - Nutritional requirements of **ZEBU** beef cattle, **BULLS** in **FEEDLOT** system

Average BW kg	ADG kg	DMI kg	Intake of water[1], L		Energy			Protein					
			Summer	Winter	ME, Mcal	TDN, kg	TDN, %	RDP, g	RUP, g	CP, g	CP,%	RDP, % CP	RUP, % CP
210	0.3	3.5	9.0	10.8	8.2	2.2	63.5	249	130	380	10.8	65.6	34.4
	0.8	5.0	9.8	11.5	11.6	3.1	63.3	370	183	553	11.1	66.9	33.1
	1.3	6.0	10.3	12.0	15.1	4.1	68.0	486	240	727	12.1	66.9	33.1
	1.8	6.6	10.5	12.3	18.8	5.0	76.1	596	303	900	13.7	66.3	33.7
270	0.3	4.5	11.7	13.4	9.7	2.7	59.5	303	146	449	10.1	67.4	32.6
	0.8	5.9	12.4	14.1	13.5	3.7	61.9	431	204	635	10.7	67.9	32.1
	1.3	6.9	12.9	14.6	17.4	4.7	67.6	555	267	822	11.8	67.5	32.5
	1.8	7.5	13.2	14.9	21.5	5.7	76.1	671	337	1008	13.4	66.6	33.4
330	0.3	5.4	14.2	15.9	11.1	3.1	57.0	353	163	516	9.6	68.3	31.7
	0.8	6.8	14.9	16.6	15.2	4.2	60.9	490	230	719	10.5	68.1	31.9
	1.3	7.8	15.4	17.1	19.6	5.3	67.3	620	302	922	11.8	67.3	32.7
	1.8	8.4	15.7	17.4	24.1	6.4	76.1	743	382	1125	13.4	66.1	33.9
390	0.3	6.2	16.6	18.3	12.4	3.4	55.4	399	179	578	9.3	69.0	31.0
	0.8	7.7	17.3	19.0	17.0	4.6	60.3	542	250	793	10.3	68.4	31.6
	1.3	8.7	17.8	19.5	21.7	5.9	67.2	678	329	1007	11.6	67.3	32.7
	1.8	9.3	18.1	19.8	26.6	7.1	76.2	804	416	1220	13.2	65.9	34.1
450	0.3	7.1	18.9	20.6	13.7	3.8	54.2	439	189	628	8.9	70.0	30.0
	0.8	8.5	19.6	21.3	18.6	5.1	59.8	584	255	839	9.8	69.6	30.4
	1.3	9.5	20.1	21.8	23.7	6.4	67.1	719	329	1048	11.0	68.6	31.4
	1.8	10.1	20.4	22.1	29.0	7.7	76.4	844	412	1256	12.4	67.2	32.8
510	0.3	7.9	21.1	22.8	15.0	4.2	53.2	478	198	677	8.6	70.7	29.3
	0.8	9.3	21.8	23.5	20.2	5.5	59.4	623	260	883	9.5	70.6	29.4
	1.3	10.3	22.3	24.0	25.7	6.9	67.1	758	330	1088	10.5	69.6	30.4
	1.8	10.9	22.6	24.3	31.4	8.3	76.5	880	411	1291	11.8	68.2	31.8
570	0.3	8.6	23.2	25.0	16.2	4.5	52.5	515	209	724	8.4	71.1	28.9
	0.8	10.1	24.0	25.7	21.8	6.0	59.1	660	266	926	9.2	71.3	28.7
	1.3	11.1	24.4	26.2	27.6	7.5	67.1	793	333	1126	10.1	70.4	29.6
	1.8	11.7	24.7	26.5	33.7	9.0	76.6	913	411	1324	11.3	68.9	31.1
630	0.3	9.4	25.3	27.1	17.4	4.9	51.9	550	219	769	8.2	71.5	28.5
	0.8	10.9	26.0	27.8	23.3	6.4	58.9	695	273	967	8.9	71.8	28.2
	1.3	11.9	26.5	28.3	29.5	8.0	67.1	826	337	1163	9.8	71.0	29.0
	1.8	12.4	26.8	28.6	36.0	9.6	76.8	942	414	1356	10.9	69.5	30.5

*BW = body weight; ADG = average daily gain; DMI = dry matter intake; ME = metabolizable energy; TDN = total digestible nutrients; CP = crude protein; RDP = rumen degradable protein; RUP = rumen undegradable protein. [1]Winter = 22°C of maximum temperature and 65% of relative humidity; Summer = 29°C of maximum temperature and 79% of relative humidity.

Table 17.3b - Minerals requirements for **ZEBU** beef cattle, **BULLS** in a **FEEDLOT** system

Average BW kg	ADG kg	Macrominerals, g							Microminerals, mg							
		Ca	P	Ca:P	Mg	Na	K	S	Cu	Co	Cr	Fe	Mn	Mo	Se	Zn
210	0.3	9.84	6.69	1.47	3.78	4.47	11.24	3.93	29.98	3.28	8.09	855.64	91.29	1.40	2.04	147.39
	0.8	19.26	10.96	1.76	4.28	6.02	13.01	5.81	34.52	3.30	11.43	879.40	96.15	1.43	2.78	219.52
	1.3	28.77	15.28	1.88	4.79	7.58	14.81	7.71	39.11	3.32	14.81	903.40	101.05	1.46	3.53	292.38
	1.8	38.34	19.63	1.95	5.30	9.15	16.61	9.63	43.73	3.35	18.20	927.55	105.99	1.48	4.28	365.67
270	0.3	10.41	7.66	1.36	4.78	5.42	14.18	5.02	38.02	4.21	10.18	1097.02	117.22	1.80	2.49	187.95
	0.8	18.68	11.55	1.62	5.28	6.85	16.02	7.39	42.97	4.23	14.09	1122.30	123.19	1.83	3.22	278.03
	1.3	27.04	15.49	1.75	5.79	8.30	17.87	9.79	47.97	4.26	18.04	1147.84	129.22	1.86	3.95	369.04
	1.8	35.45	19.45	1.82	6.30	9.75	19.73	12.19	53.00	4.28	22.01	1173.54	135.29	1.89	4.69	460.58
330	0.3	11.17	8.69	1.29	5.78	6.39	17.12	6.11	46.03	5.15	12.24	1338.27	143.12	2.19	2.94	228.24
	0.8	18.63	12.31	1.51	6.28	7.74	19.00	8.96	51.33	5.17	16.67	1364.83	150.16	2.23	3.66	335.82
	1.3	26.17	15.96	1.64	6.79	9.10	20.90	11.83	56.68	5.19	21.15	1391.67	157.27	2.26	4.38	444.51
	1.8	33.75	19.63	1.72	7.30	10.46	22.81	14.73	62.06	5.21	25.66	1418.66	164.43	2.30	5.11	553.84
390	0.3	12.05	9.76	1.23	6.78	7.37	20.06	7.19	54.01	6.08	14.28	1579.41	169.00	2.59	3.39	268.32
	0.8	18.89	13.16	1.44	7.28	8.65	21.98	10.51	59.62	6.10	19.20	1607.09	177.08	2.62	4.10	393.04
	1.3	25.81	16.59	1.56	7.79	9.94	23.92	13.86	65.28	6.12	24.18	1635.06	185.24	2.66	4.82	519.03
	1.8	32.77	20.05	1.63	8.31	11.24	25.87	17.23	70.98	6.14	29.19	1663.20	193.45	2.70	5.54	645.77
450	0.3	13.00	10.85	1.20	7.78	8.36	22.99	8.27	61.98	7.01	16.30	1820.48	194.86	2.98	3.85	308.22
	0.8	19.36	14.07	1.38	8.28	9.58	24.95	12.05	67.87	7.03	21.69	1849.16	203.95	3.02	4.55	449.77
	1.3	25.79	17.33	1.49	8.79	10.82	26.92	15.88	73.81	7.06	27.13	1878.14	213.13	3.06	5.26	592.76
	1.8	32.25	20.61	1.57	9.31	12.06	28.91	19.72	79.79	7.08	32.61	1907.28	222.37	3.10	5.97	736.61
510	0.3	14.00	11.96	1.17	8.77	9.35	25.93	9.35	69.93	7.94	18.31	2061.50	220.71	3.38	4.30	347.97
	0.8	19.97	15.04	1.33	9.28	10.53	27.91	13.59	76.08	7.97	24.14	2091.08	230.78	3.42	5.00	506.09
	1.3	25.99	18.15	1.43	9.79	11.71	29.92	17.88	82.28	7.99	30.03	2120.96	240.96	3.46	5.70	665.83
	1.8	32.05	21.27	1.51	10.31	12.91	31.93	22.19	88.52	8.01	35.95	2151.02	251.20	3.51	6.40	826.52
570	0.3	11.74	11.35	1.03	9.77	10.35	28.86	10.42	77.88	8.88	20.31	2302.48	246.55	3.78	4.76	387.58
	0.8	11.74	11.35	1.03	10.28	11.48	30.87	15.12	84.25	8.90	26.56	2332.88	257.59	3.82	5.45	562.06
	1.3	11.74	11.35	1.03	10.79	12.63	32.90	19.86	90.70	8.92	32.88	2363.59	268.74	3.86	6.14	738.32
	1.8	11.74	11.35	1.03	11.30	13.78	34.95	24.64	97.18	8.94	39.23	2394.49	279.96	3.91	6.84	915.63
630	0.3	12.98	12.54	1.03	10.77	11.34	31.78	11.49	85.81	9.81	22.30	2543.41	272.37	4.17	5.21	427.09
	0.8	12.98	12.54	1.03	11.28	12.45	33.82	16.64	92.41	9.83	28.96	2574.58	284.36	4.22	5.90	617.71
	1.3	12.98	12.54	1.03	11.79	13.56	35.88	21.84	99.07	9.85	35.68	2606.06	296.47	4.26	6.59	810.29
	1.8	12.98	12.54	1.03	12.30	14.68	37.95	27.07	105.78	9.88	42.44	2637.73	308.66	4.31	7.28	1004.01

*BW = body weight; ADG = average daily gain; Ca = calcium; P = phosphorus; Ca:P = ratio calcium/phosphorus; Mg = magnesium; Na = sodium; K = potassium; S = sulfur; Cu = copper; Co = cobalt; Cr = chromium; Fe = iron; Mn = manganese; Mo = molybdenum; Se = selenium; Zn = zinc.

Table 17.3c - Metabolizable amino acids requirements for **ZEBU** beef cattle, **BULLS** in a **FEEDLOT** system

Average BW kg	ADG kg	Essentials, g										Non-Essentials, g							
		Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val	Ala	Asp	Cys	Glu	Gly	Pro	Ser	Tyr
330	0.3	6.22	2.31	6.33	11.58	9.38	1.69	5.76	5.51	0.96	5.92	9.57	12.62	8.08	9.38	8.08	7.90	6.25	5.30
	0.8	16.83	6.25	17.14	31.35	25.40	4.57	15.59	14.92	2.61	16.03	25.90	34.16	21.86	25.39	21.86	21.38	16.92	14.33
	1.3	27.54	10.24	28.06	51.33	41.57	7.48	25.52	24.43	4.27	26.24	42.40	55.91	35.79	41.57	35.79	35.00	27.69	23.46
	1.8	38.33	14.24	39.04	71.42	57.84	10.41	35.51	33.99	5.94	36.51	59.00	77.80	49.79	57.84	49.79	48.70	38.53	32.64
390	0.3	6.05	2.33	6.26	11.39	9.31	1.67	5.70	5.45	0.96	5.90	9.27	12.35	7.71	9.23	7.71	7.57	6.09	5.25
	0.8	16.36	6.31	16.95	30.82	25.19	4.51	15.42	14.76	2.59	15.96	25.08	33.43	20.87	24.99	20.87	20.50	16.48	14.20
	1.3	26.78	10.33	27.75	50.45	41.24	7.38	25.24	24.15	4.24	26.13	41.05	54.73	34.16	40.90	34.16	33.56	26.98	23.25
	1.8	37.27	14.38	38.62	70.20	57.39	10.27	35.12	33.61	5.91	36.35	57.12	76.15	47.53	56.91	47.53	46.69	37.54	32.35
450	0.3	5.90	2.35	6.21	11.22	9.25	1.65	5.65	5.40	0.95	5.88	9.01	12.13	7.41	9.10	7.41	7.31	5.96	5.21
	0.8	15.97	6.37	16.80	30.37	25.02	4.45	15.28	14.61	2.58	15.90	24.39	32.82	20.05	24.64	20.05	19.77	16.12	14.09
	1.3	26.15	10.42	27.50	49.72	40.96	7.29	25.01	23.92	4.23	26.03	39.93	53.73	32.82	40.34	32.82	32.37	26.39	23.07
	1.8	36.38	14.50	38.26	69.18	56.99	10.15	34.80	33.29	5.88	36.22	55.56	74.76	45.67	56.13	45.67	45.04	36.72	32.10
510	0.3	5.78	2.37	6.16	11.08	9.19	1.63	5.60	5.35	0.95	5.86	8.80	11.93	7.15	8.99	7.15	7.08	5.84	5.17
	0.8	15.64	6.41	16.66	29.98	24.87	4.41	15.16	14.49	2.57	15.85	23.81	32.30	19.36	24.34	19.36	19.16	15.81	14.00
	1.3	25.60	10.49	27.27	49.08	40.72	7.22	24.81	23.72	4.21	25.95	38.97	52.87	31.70	39.85	31.70	31.36	25.88	22.92
	1.8	35.63	14.60	37.95	68.30	56.66	10.04	34.52	33.01	5.86	36.10	54.23	73.57	44.11	55.45	44.11	43.64	36.01	31.89
570	0.3	5.67	2.38	6.11	10.95	9.14	1.61	5.56	5.32	0.95	5.84	8.61	11.76	6.94	8.90	6.94	6.88	5.74	5.14
	0.8	15.35	6.45	16.54	29.64	24.74	4.37	15.05	14.39	2.56	15.81	23.30	31.84	18.77	24.08	18.77	18.63	15.54	13.91
	1.3	25.13	10.56	27.08	48.53	40.50	7.15	24.63	23.55	4.20	25.87	38.14	52.12	30.73	39.42	30.73	30.50	25.44	22.78
	1.8	34.97	14.70	37.68	67.52	56.36	9.95	34.27	32.77	5.84	36.00	53.07	72.52	42.76	54.86	42.76	42.43	35.39	31.69
630	0.3	5.58	2.40	6.07	10.84	9.10	1.60	5.52	5.28	0.94	5.83	8.44	11.61	6.75	8.81	6.75	6.71	5.65	5.11
	0.8	15.10	6.49	16.43	29.34	24.62	4.33	14.95	14.29	2.55	15.77	22.85	31.43	18.26	23.85	18.26	18.17	15.30	13.84
	1.3	24.71	10.62	26.90	48.03	40.31	7.09	24.47	23.39	4.18	25.81	37.41	51.46	29.89	39.04	29.89	29.74	25.05	22.65
	1.8	34.39	14.78	37.43	66.83	56.09	9.87	34.05	32.55	5.82	35.91	52.05	71.60	41.58	54.33	41.58	41.38	34.85	31.52

*BW = body weight; ADG = average daily gain; Arg = Arginine; His = histidine; Ile = isoleucine; Leu = leucine; Lys = lysine; Met = methionine; Phe = phenylanine; Thr = threonine; Trp = tryptophan; Val = valine; Ala = alanine; Asp = aspartic acid; Cys = cystine; Glu = glutamic acid; Gly = glycine; Pro = proline; Ser = serine; Tyr = tyrosine.

Table 17.4a - Nutritional requirements of **ZEBU** beef cattle, **STEERS** in **FEEDLOT** system

Average BW kg	ADG kg	DMI kg	Intake of water[1], L		Energy			Protein					
			Summer	Winter	ME, Mcal	TDN, kg	TDN, %	RDP, g	RUP, g	CP, g	CP,%	RDP, % CP	RUP, % CP
210	0.3	3.5	9.0	10.8	8.3	2.2	64.0	252	132	385	11.0	65.6	34.4
	0.8	5.0	9.8	11.5	12.0	3.2	65.1	381	186	566	11.4	67.2	32.8
	1.3	6.0	10.3	12.0	15.8	4.2	70.7	503	245	748	12.5	67.3	32.7
	1.8	6.6	10.5	12.3	19.8	5.2	79.8	619	310	929	14.2	66.7	33.3
270	0.3	4.5	11.7	13.4	9.9	2.7	60.4	308	149	457	10.3	67.4	32.6
	0.8	5.9	12.4	14.1	14.0	3.8	64.2	448	211	658	11.1	68.0	32.0
	1.3	6.9	12.9	14.6	18.4	4.9	70.9	580	279	859	12.4	67.5	32.5
	1.8	7.5	13.2	14.9	22.9	6.0	80.5	704	355	1059	14.1	66.5	33.5
330	0.3	5.4	14.2	15.9	11.4	3.1	58.3	362	169	531	9.9	68.2	31.8
	0.8	6.8	14.9	16.6	16.0	4.3	63.6	514	245	759	11.1	67.7	32.3
	1.3	7.8	15.4	17.1	20.9	5.6	71.2	657	329	986	12.6	66.7	33.3
	1.8	8.4	15.7	17.4	25.9	6.8	81.2	791	421	1212	14.4	65.3	34.7
390	0.3	6.2	16.6	18.3	12.8	3.5	56.9	405	171	576	9.3	70.3	29.7
	0.8	7.7	17.3	19.0	17.9	4.9	63.3	554	231	786	10.2	70.6	29.4
	1.3	8.7	17.8	19.5	23.3	6.2	71.5	694	300	995	11.4	69.8	30.2
	1.8	9.3	18.1	19.8	28.8	7.6	81.9	822	379	1202	13.0	68.4	31.6
450	0.3	7.1	18.9	20.6	14.3	3.9	55.9	447	179	626	8.9	71.4	28.6
	0.8	8.5	19.6	21.3	19.8	5.4	63.1	598	233	831	9.7	72.0	28.0
	1.3	9.5	20.1	21.8	25.6	6.9	71.8	737	296	1034	10.8	71.3	28.7
	1.8	10.1	20.4	22.1	31.6	8.3	82.5	863	372	1234	12.2	69.9	30.1
510	0.3	7.9	21.1	22.8	15.6	4.3	55.2	487	187	674	8.6	72.3	27.7
	0.8	9.3	21.8	23.5	21.6	5.9	63.0	639	235	874	9.4	73.1	26.9
	1.3	10.3	22.3	24.0	27.9	7.5	72.2	777	294	1071	10.4	72.5	27.5
	1.8	10.9	22.6	24.3	34.4	9.1	83.1	898	367	1265	11.6	71.0	29.0
570	0.3	8.6	23.2	25.0	17.0	4.7	54.6	525	195	721	8.4	72.9	27.1
	0.8	10.1	24.0	25.7	23.4	6.4	63.0	677	238	915	9.1	74.0	26.0
	1.3	11.1	24.4	26.2	30.1	8.1	72.5	813	294	1107	10.0	73.4	26.6
	1.8	11.7	24.7	26.5	37.1	9.8	83.6	930	365	1295	11.1	71.8	28.2
630	0.3	9.4	25.3	27.1	18.3	5.1	54.2	562	205	766	8.2	73.3	26.7
	0.8	10.9	26.0	27.8	25.2	6.8	63.0	713	243	955	8.8	74.6	25.4
	1.3	11.9	26.5	28.3	32.3	8.6	72.7	846	296	1141	9.6	74.1	25.9
	1.8	12.4	26.8	28.6	39.8	10.5	84.1	958	365	1323	10.6	72.4	27.6

*BW = body weight; ADG = average daily gain; DMI = dry matter intake; ME = metabolizable energy; TDN = total digestible nutrients; CP = crude protein; RDP = rumen degradable protein; RUP = rumen undegradable protein. [1]Winter = 22°C of maximum temperature and 65% of relative humidity; Summer = 29°C of maximum temperature and 79% of relative humidity.

Table 17.4b - Minerals requirements for **ZEBU** beef cattle **STEERS**, in a **FEEDLOT** system

Average BW kg	ADG kg	Macrominerals, g							Microminerals, mg							
		Ca	P	Ca:P	Mg	Na	K	S	Cu	Co	Cr	Fe	Mn	Mo	Se	Zn
210	0.3	9.88	6.70	1.47	3.78	4.48	11.24	3.92	29.97	3.28	8.08	855.60	91.27	1.40	2.04	146.95
	0.8	19.35	10.99	1.76	4.28	6.03	13.01	5.78	34.49	3.30	11.39	879.29	96.07	1.43	2.78	218.33
	1.3	28.92	15.33	1.89	4.79	7.60	14.80	7.66	39.07	3.32	14.74	903.23	100.93	1.46	3.53	290.44
	1.8	38.54	19.69	1.96	5.30	9.17	16.60	9.55	43.67	3.35	18.11	927.30	105.82	1.48	4.28	362.98
270	0.3	10.41	7.66	1.36	4.78	5.42	14.18	5.02	38.02	4.21	10.18	1097.02	117.22	1.80	2.49	187.95
	0.8	18.68	11.55	1.62	5.28	6.85	16.02	7.39	42.97	4.23	14.09	1122.30	123.19	1.83	3.22	278.03
	1.3	27.04	15.49	1.75	5.79	8.30	17.87	9.79	47.97	4.26	18.04	1147.84	129.22	1.86	3.95	369.04
	1.8	35.45	19.45	1.82	6.30	9.75	19.73	12.19	53.00	4.28	22.01	1173.54	135.29	1.89	4.69	460.58
330	0.3	11.15	8.68	1.28	5.78	6.39	17.13	6.12	46.04	5.15	12.25	1338.30	143.15	2.19	2.94	228.77
	0.8	18.58	12.29	1.51	6.28	7.73	19.01	9.00	51.35	5.17	16.72	1364.93	150.25	2.23	3.66	337.25
	1.3	26.08	15.93	1.64	6.79	9.09	20.91	11.90	56.72	5.19	21.22	1391.83	157.41	2.26	4.38	446.84
	1.8	33.62	19.59	1.72	7.30	10.45	22.82	14.82	62.12	5.21	25.76	1418.89	164.63	2.30	5.11	557.08
390	0.3	12.01	9.74	1.23	6.78	7.37	20.06	7.22	54.03	6.08	14.31	1579.48	169.06	2.59	3.39	269.44
	0.8	18.80	13.12	1.43	7.28	8.64	21.99	10.59	59.67	6.10	19.29	1607.28	177.26	2.63	4.10	396.07
	1.3	25.65	16.53	1.55	7.79	9.92	23.93	14.00	65.37	6.12	24.32	1635.37	185.54	2.66	4.82	523.99
	1.8	32.55	19.97	1.63	8.31	11.21	25.88	17.43	71.10	6.14	29.38	1663.62	193.87	2.70	5.53	652.68
450	0.3	12.95	10.83	1.20	7.78	8.35	23.00	8.32	62.01	7.01	16.35	1820.58	194.97	2.98	3.85	309.99
	0.8	19.24	14.03	1.37	8.28	9.57	24.96	12.19	67.94	7.03	21.82	1849.43	204.24	3.02	4.55	454.56
	1.3	25.58	17.26	1.48	8.79	10.79	26.94	16.09	73.94	7.06	27.35	1878.58	213.60	3.06	5.25	600.61
	1.8	31.97	20.50	1.56	9.31	12.02	28.93	20.02	79.97	7.08	32.90	1907.90	223.02	3.10	5.96	747.54
510	0.3	13.95	10.15	1.37	8.77	9.34	25.93	9.42	69.97	7.94	18.38	2061.63	220.85	3.38	4.30	350.44
	0.8	19.82	10.15	1.95	9.28	10.51	27.92	13.78	76.17	7.97	24.32	2091.43	231.18	3.42	4.99	512.78
	1.3	25.76	10.15	2.54	9.79	11.69	29.93	18.18	82.44	7.99	30.31	2121.53	241.61	3.46	5.69	676.78
	1.8	31.73	10.15	3.12	10.31	12.87	31.96	22.61	88.75	8.01	36.35	2151.81	252.10	3.51	6.40	841.76
570	0.3	11.74	11.35	1.03	9.77	10.34	28.86	10.51	77.92	8.88	20.39	2302.63	246.73	3.78	4.76	390.80
	0.8	11.74	11.35	1.03	10.28	11.46	30.88	15.36	84.38	8.90	26.78	2333.30	258.10	3.82	5.44	570.75
	1.3	11.74	11.35	1.03	10.79	12.60	32.92	20.26	90.90	8.92	33.24	2364.28	269.58	3.86	6.14	752.54
	1.8	11.74	11.35	1.03	11.31	13.74	34.98	25.19	97.45	8.94	39.73	2395.44	281.13	3.91	6.84	935.42
630	0.3	12.98	12.54	1.03	10.77	11.34	31.79	11.60	85.86	9.81	22.40	2543.59	272.61	4.17	5.21	431.07
	0.8	12.98	12.54	1.03	11.28	12.42	33.84	16.94	92.55	9.83	29.22	2575.06	284.99	4.22	5.89	628.50
	1.3	12.98	12.54	1.03	11.79	13.52	35.91	22.33	99.31	9.85	36.12	2606.85	297.51	4.26	6.58	827.95
	1.8	12.98	12.54	1.03	12.30	14.63	37.99	27.76	106.10	9.88	43.05	2638.84	310.09	4.31	7.28	1028.59

*BW = body weight; ADG = average daily gain; Ca = calcium; P = phosphorus; Ca:P = ratio calcium/phosphorus; Mg = magnesium; Na = sodium; K = potassium; S = sulfur; Cu = copper; Co = cobalt; Cr = chromium; Fe = iron; Mn = manganese; Mo = molybdenum; Se = selenium; Zn = zinc.

Table 17.4c - Metabolizable amino acids requirements for **ZEBU** beef cattle, **STEERS** in a **FEEDLOT** system

Average BW kg	ADG kg	Essentials, g										Non-Essentials, g							
		Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val	Ala	Asp	Cys	Glu	Gly	Pro	Ser	Tyr
330	0.3	6.21	2.31	6.33	11.57	9.38	1.69	5.76	5.51	0.96	5.92	9.55	12.61	8.06	9.37	8.06	7.88	6.24	5.29
	0.8	16.80	6.26	17.13	31.32	25.38	4.57	15.58	14.91	2.61	16.03	25.86	34.12	21.80	25.37	21.80	21.33	16.89	14.33
	1.3	27.50	10.24	28.04	51.28	41.55	7.47	25.50	24.41	4.27	26.23	42.33	55.85	35.69	41.53	35.69	34.92	27.65	23.45
	1.8	38.27	14.25	39.01	71.35	57.82	10.40	35.49	33.97	5.94	36.50	58.89	77.71	49.66	57.79	49.66	48.58	38.47	32.63
390	0.3	6.03	2.34	6.26	11.37	9.30	1.66	5.69	5.45	0.96	5.89	9.24	12.33	7.67	9.22	7.67	7.54	6.07	5.24
	0.8	16.31	6.32	16.94	30.77	25.17	4.50	15.40	14.74	2.59	15.95	24.99	33.36	20.77	24.94	20.77	20.41	16.44	14.19
	1.3	26.71	10.34	27.72	50.36	41.21	7.37	25.22	24.13	4.24	26.12	40.91	54.60	33.99	40.83	33.99	33.41	26.91	23.23
	1.8	37.16	14.39	38.57	70.08	57.34	10.25	35.09	33.57	5.90	36.34	56.93	75.98	47.30	56.82	47.30	46.49	37.44	32.32
450	0.3	5.88	2.36	6.20	11.19	9.23	1.64	5.64	5.39	0.95	5.87	8.97	12.09	7.36	9.08	7.36	7.26	5.93	5.20
	0.8	15.91	6.37	16.77	30.30	24.99	4.45	15.25	14.59	2.58	15.89	24.28	32.72	19.92	24.58	19.92	19.65	16.06	14.08
	1.3	26.04	10.43	27.45	49.60	40.91	7.28	24.97	23.89	4.22	26.02	39.74	53.56	32.61	40.24	32.61	32.17	26.29	23.04
	1.8	36.24	14.52	38.20	69.01	56.93	10.13	34.75	33.24	5.88	36.20	55.30	74.53	45.37	56.00	45.37	44.77	36.58	32.06
510	0.3	5.75	2.37	6.14	11.05	9.18	1.62	5.59	5.34	0.95	5.85	8.75	11.89	7.10	8.97	7.10	7.03	5.81	5.16
	0.8	15.56	6.42	16.63	29.89	24.84	4.40	15.13	14.46	2.57	15.84	23.67	32.18	19.20	24.27	19.20	19.02	15.74	13.98
	1.3	25.48	10.51	27.22	48.93	40.66	7.20	24.76	23.68	4.21	25.93	38.75	52.67	31.44	39.74	31.44	31.13	25.76	22.88
	1.8	35.45	14.63	37.88	68.09	56.57	10.02	34.45	32.95	5.85	36.08	53.91	73.29	43.74	55.29	43.74	43.31	35.85	31.83
570	0.3	5.64	2.39	6.10	10.91	9.13	1.61	5.55	5.30	0.95	5.83	8.55	11.71	6.87	8.87	6.87	6.82	5.71	5.13
	0.8	15.26	6.46	16.50	29.54	24.70	4.36	15.01	14.35	2.56	15.79	23.14	31.70	18.59	24.00	18.59	18.47	15.46	13.89
	1.3	24.98	10.58	27.02	48.35	40.43	7.13	24.57	23.49	4.19	25.85	37.88	51.89	30.43	39.29	30.43	30.23	25.30	22.73
	1.8	34.76	14.73	37.59	67.28	56.26	9.92	34.19	32.69	5.83	35.97	52.71	72.20	42.34	54.67	42.34	42.06	35.20	31.63
630	0.3	5.54	2.40	6.06	10.80	9.08	1.60	5.51	5.27	0.94	5.82	8.38	11.56	6.67	8.78	6.67	6.65	5.62	5.10
	0.8	15.00	6.50	16.39	29.22	24.58	4.32	14.91	14.25	2.55	15.75	22.68	31.27	18.06	23.76	18.06	17.98	15.21	13.81
	1.3	24.55	10.65	26.83	47.84	40.23	7.07	24.41	23.33	4.18	25.78	37.12	51.19	29.56	38.89	29.56	29.44	24.89	22.61
	1.8	34.16	14.81	37.34	66.56	55.98	9.83	33.96	32.46	5.81	35.87	51.65	71.23	41.13	54.12	41.13	40.96	34.64	31.45

*BW = body weight; ADG = average daily gain; Arg = Arginine; His = histidine; Ile = isoleucine; Leu = leucine; Lys = lysine; Met = methionine; Phe = phenylanine; Thr = threonine; Trp = tryptophan; Val = valine; Ala = alanine; Asp = aspartic acid; Cys = cystine; Glu = glutamic acid; Gly = glycine; Pro = proline; Ser = serine; Tyr = tyrosine.

Table 17.5a - Nutritional requirements of **ZEBU** beef cattle, **HEIFERS** in **FEEDLOT** system

Average BW kg	ADG kg	DMI kg	Intake of water[1], L		Energy			Protein					
			Summer	Winter	ME, Mcal	TDN, kg	TDN, %	RDP, g	RUP, g	CP, g	CP,%	RDP, % CP	RUP, % CP
210	0.3	3.5	9.0	10.8	8.4	2.3	64.9	255	133	388	11.1	65.8	34.2
	0.8	5.0	9.8	11.5	12.2	3.3	66.5	388	187	575	11.6	67.5	32.5
	1.3	6.0	10.3	12.0	16.3	4.3	72.5	515	247	762	12.7	67.6	32.4
	1.8	6.6	10.5	12.3	20.4	5.4	82.1	634	314	948	14.5	66.9	33.1
270	0.3	4.5	11.7	13.4	10.0	2.7	61.3	313	150	463	10.4	67.6	32.4
	0.8	5.9	12.4	14.1	14.4	3.9	65.6	458	215	673	11.4	68.0	32.0
	1.3	6.9	12.9	14.6	19.0	5.1	72.9	596	288	883	12.7	67.4	32.6
	1.8	7.5	13.2	14.9	23.7	6.2	83.1	725	368	1092	14.5	66.3	33.7
330	0.3	5.4	14.2	15.9	11.6	3.2	59.2	368	172	541	10.1	68.1	31.9
	0.8	6.8	14.9	16.6	16.5	4.5	65.2	528	256	785	11.5	67.3	32.7
	1.3	7.8	15.4	17.1	21.6	5.8	73.4	679	349	1028	13.1	66.1	33.9
	1.8	8.4	15.7	17.4	26.8	7.1	84.0	819	450	1270	15.1	64.5	35.5
390	0.3	6.2	16.6	18.3	13.1	3.6	57.8	408	166	575	9.2	71.0	29.0
	0.8	7.7	17.3	19.0	18.5	5.0	65.0	561	221	782	10.2	71.7	28.3
	1.3	8.7	17.8	19.5	24.1	6.4	73.8	703	286	988	11.3	71.1	28.9
	1.8	9.3	18.1	19.8	29.9	7.9	84.8	831	361	1192	12.9	69.7	30.3
450	0.3	7.1	18.9	20.6	14.5	4.0	56.9	451	173	625	8.9	72.2	27.8
	0.8	8.5	19.6	21.3	20.4	5.5	64.8	605	222	827	9.7	73.2	26.8
	1.3	9.5	20.1	21.8	26.6	7.1	74.2	746	281	1026	10.8	72.7	27.3
	1.8	10.1	20.4	22.1	32.9	8.7	85.6	871	352	1223	12.1	71.2	28.8
510	0.3	7.9	21.1	22.8	16.0	4.4	56.2	492	181	673	8.6	73.1	26.9
	0.8	9.3	21.8	23.5	22.3	6.0	64.8	646	223	869	9.3	74.3	25.7
	1.3	10.3	22.3	24.0	29.0	7.7	74.6	785	278	1063	10.3	73.9	26.1
	1.8	10.9	22.6	24.3	35.9	9.4	86.3	906	347	1253	11.5	72.3	27.7
570	0.3	8.6	23.2	25.0	17.4	4.8	55.6	530	189	719	8.3	73.7	26.3
	0.8	10.1	24.0	25.7	24.2	6.5	64.8	685	226	910	9.0	75.2	24.8
	1.3	11.1	24.4	26.2	31.3	8.3	75.0	821	276	1097	9.9	74.8	25.2
	1.8	11.7	24.7	26.5	38.7	10.2	87.0	937	344	1281	11.0	73.1	26.9
630	0.3	9.4	25.3	27.1	18.7	5.2	55.2	567	198	765	8.1	74.1	25.9
	0.8	10.9	26.0	27.8	26.0	7.0	64.8	721	229	950	8.7	75.9	24.1
	1.3	11.9	26.5	28.3	33.6	9.0	75.4	854	277	1131	9.5	75.5	24.5
	1.8	12.4	26.8	28.6	41.6	10.9	87.6	963	344	1307	10.5	73.7	26.3

*BW = body weight; ADG = average daily gain; DMI = dry matter intake; ME = metabolizable energy; TDN = total digestible nutrients; CP = crude protein; RDP = rumen degradable protein; RUP = rumen undegradable protein. [1]Winter = 22°C of maximum temperature and 65% of relative humidity; Summer = 29°C of maximum temperature and 79% of relative humidity.

Table 17.5b - Minerals requirements for **ZEBU** beef cattle, **HEIFERS** in a **FEEDLOT** system

Average BW kg	ADG kg	Macrominerals, g							Microminerals, mg							
		Ca	P	Ca:P	Mg	Na	K	S	Cu	Co	Cr	Fe	Mn	Mo	Se	Zn
210	0.3	9.85	6.69	1.47	3.78	4.47	11.24	3.93	29.98	3.28	8.09	855.63	91.29	1.40	2.04	147.32
	0.8	19.27	10.97	1.76	4.28	6.02	13.01	5.81	34.52	3.30	11.43	879.38	96.14	1.43	2.78	219.32
	1.3	28.79	15.29	1.88	4.79	7.58	14.81	7.70	39.10	3.32	14.80	903.37	101.03	1.46	3.53	292.06
	1.8	38.37	19.64	1.95	5.30	9.16	16.61	9.61	43.72	3.35	18.19	927.51	105.96	1.48	4.28	365.24
270	0.3	10.38	7.65	1.36	4.78	5.42	14.19	5.04	38.03	4.21	10.19	1097.06	117.25	1.80	2.49	188.48
	0.8	18.61	11.53	1.61	5.28	6.85	16.02	7.43	43.00	4.23	14.13	1122.42	123.28	1.83	3.21	279.47
	1.3	26.92	15.45	1.74	5.79	8.29	17.88	9.85	48.02	4.26	18.11	1148.03	129.36	1.86	3.95	371.39
	1.8	35.28	19.39	1.82	6.30	9.74	19.74	12.28	53.07	4.28	22.11	1173.79	135.49	1.89	4.69	463.86
330	0.3	11.12	8.67	1.28	5.78	6.39	17.13	6.14	46.05	5.15	12.27	1338.35	143.19	2.19	2.94	229.47
	0.8	18.50	12.26	1.51	6.28	7.72	19.01	9.05	51.39	5.17	16.77	1365.06	150.36	2.23	3.66	339.16
	1.3	25.95	15.88	1.63	6.79	9.07	20.92	11.98	56.78	5.19	21.31	1392.04	157.61	2.26	4.38	449.96
	1.8	33.45	19.53	1.71	7.30	10.43	22.83	14.94	62.20	5.21	25.88	1419.18	164.89	2.30	5.11	561.43
390	0.3	11.98	9.74	1.23	6.78	7.36	20.06	7.25	54.05	6.08	14.33	1579.53	169.12	2.59	3.39	270.33
	0.8	18.72	13.10	1.43	7.28	8.63	21.99	10.66	59.71	6.10	19.36	1607.43	177.40	2.63	4.10	398.47
	1.3	25.53	16.49	1.55	7.79	9.91	23.94	14.11	65.44	6.12	24.43	1635.61	185.77	2.66	4.81	527.93
	1.8	32.38	19.91	1.63	8.31	11.19	25.90	17.58	71.19	6.14	29.53	1663.96	194.20	2.70	5.53	658.16
450	0.3	12.92	10.82	1.19	7.78	8.35	23.00	8.35	62.03	7.01	16.38	1820.64	195.03	2.98	3.85	311.07
	0.8	19.16	14.00	1.37	8.28	9.56	24.96	12.27	67.99	7.03	21.90	1849.60	204.41	3.02	4.55	457.48
	1.3	25.46	17.21	1.48	8.79	10.78	26.95	16.23	74.01	7.06	27.47	1878.84	213.88	3.06	5.25	605.39
	1.8	31.80	20.44	1.56	9.31	12.01	28.94	20.21	80.07	7.08	33.08	1908.26	223.42	3.10	5.96	754.18
510	0.3	13.92	10.15	1.37	8.77	9.34	25.93	9.45	69.99	7.94	18.41	2061.70	220.93	3.38	4.30	351.71
	0.8	19.75	10.15	1.94	9.28	10.50	27.93	13.87	76.22	7.97	24.40	2091.60	231.38	3.42	4.99	516.22
	1.3	25.64	10.15	2.52	9.79	11.67	29.94	18.34	82.52	7.99	30.46	2121.82	241.94	3.47	5.69	682.41
	1.8	31.56	10.15	3.11	10.31	12.85	31.97	22.83	88.86	8.01	36.55	2152.21	252.57	3.51	6.40	849.60
570	0.3	11.74	11.35	1.03	9.77	10.33	28.86	10.55	77.94	8.88	20.43	2302.70	246.82	3.78	4.76	392.27
	0.8	11.74	11.35	1.03	10.28	11.45	30.89	15.47	84.43	8.90	26.88	2333.49	258.33	3.82	5.44	574.73
	1.3	11.74	11.35	1.03	10.79	12.58	32.93	20.44	90.98	8.92	33.40	2364.59	269.96	3.87	6.14	759.06
	1.8	11.74	11.35	1.03	11.31	13.72	34.99	25.44	97.58	8.94	39.96	2395.87	281.66	3.91	6.83	944.49
630	0.3	12.98	12.54	1.03	10.77	11.33	31.79	11.65	85.88	9.81	22.44	2543.67	272.70	4.17	5.21	432.75
	0.8	12.98	12.54	1.03	11.28	12.42	33.84	17.07	92.61	9.83	29.33	2575.26	285.26	4.22	5.89	633.03
	1.3	12.98	12.54	1.03	11.79	13.51	35.92	22.54	99.40	9.85	36.30	2607.18	297.94	4.27	6.58	835.37
	1.8	12.98	12.54	1.03	12.31	14.61	38.00	28.05	106.24	9.88	43.30	2639.29	310.70	4.31	7.27	1038.91

*BW = body weight; ADG = average daily gain; Ca = calcium; P = phosphorus; Ca:P = ratio calcium/phosphorus; Mg = magnesium; Na = sodium; K = potassium; S = sulfur; Cu = copper; Co = cobalt; Cr = chromium; Fe = iron; Mn = manganese; Mo = molybdenum; Se = selenium; Zn = zinc.

Table 17.5c - Metabolizable amino acids requirements for **ZEBU** beef cattle, **HEIFERS** in a **FEEDLOT** system

Average BW kg	ADG kg	Essentials, g										Non-Essentials, g							
		Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val	Ala	Asp	Cys	Glu	Gly	Pro	Ser	Tyr
330	0.3	6.19	2.31	6.32	11.56	9.37	1.69	5.75	5.51	0.96	5.92	9.53	12.58	8.03	9.36	8.03	7.86	6.23	5.29
	0.8	16.77	6.26	17.11	31.28	25.37	4.56	15.57	14.90	2.60	16.02	25.79	34.06	21.73	25.34	21.73	21.26	16.86	14.32
	1.3	27.44	10.25	28.02	51.21	41.53	7.47	25.48	24.39	4.26	26.22	42.22	55.76	35.57	41.48	35.57	34.81	27.60	23.43
	1.8	38.19	14.26	38.98	71.26	57.78	10.39	35.46	33.94	5.93	36.49	58.75	77.58	49.49	57.72	49.49	48.43	38.40	32.61
390	0.3	6.01	2.34	6.25	11.35	9.30	1.66	5.69	5.44	0.96	5.89	9.21	12.30	7.64	9.20	7.64	7.52	6.06	5.24
	0.8	16.28	6.32	16.92	30.72	25.16	4.50	15.39	14.73	2.59	15.95	24.93	33.30	20.69	24.91	20.69	20.34	16.40	14.18
	1.3	26.65	10.35	27.70	50.29	41.18	7.36	25.19	24.10	4.24	26.11	40.81	54.51	33.87	40.78	33.87	33.30	26.85	23.21
	1.8	37.08	14.41	38.54	69.98	57.30	10.24	35.05	33.54	5.90	36.33	56.78	75.85	47.12	56.74	47.12	46.33	37.36	32.30
450	0.3	5.86	2.36	6.19	11.18	9.23	1.64	5.63	5.39	0.95	5.87	8.95	12.07	7.33	9.07	7.33	7.24	5.92	5.20
	0.8	15.87	6.38	16.76	30.25	24.98	4.44	15.24	14.58	2.58	15.89	24.21	32.66	19.84	24.55	19.84	19.58	16.03	14.06
	1.3	25.98	10.44	27.43	49.52	40.89	7.27	24.95	23.86	4.22	26.01	39.63	53.47	32.48	40.19	32.48	32.06	26.23	23.02
	1.8	36.15	14.53	38.17	68.91	56.89	10.11	34.71	33.20	5.87	36.19	55.15	74.39	45.19	55.92	45.19	44.61	36.50	32.04
510	0.3	5.74	2.37	6.14	11.03	9.17	1.62	5.58	5.34	0.95	5.85	8.72	11.87	7.07	8.96	7.07	7.00	5.80	5.16
	0.8	15.52	6.43	16.61	29.85	24.82	4.39	15.11	14.45	2.57	15.83	23.60	32.11	19.12	24.24	19.12	18.94	15.70	13.96
	1.3	25.41	10.52	27.20	48.86	40.63	7.19	24.74	23.65	4.20	25.92	38.63	52.57	31.30	39.68	31.30	31.01	25.70	22.86
	1.8	35.36	14.64	37.84	67.98	56.53	10.00	34.42	32.91	5.85	36.06	53.76	73.15	43.56	55.21	43.56	43.15	35.76	31.81
570	0.3	5.62	2.39	6.09	10.90	9.12	1.61	5.54	5.30	0.95	5.83	8.52	11.69	6.84	8.85	6.84	6.80	5.70	5.13
	0.8	15.22	6.47	16.49	29.49	24.68	4.35	15.00	14.34	2.56	15.79	23.07	31.63	18.51	23.97	18.51	18.39	15.42	13.88
	1.3	24.92	10.59	26.99	48.28	40.40	7.12	24.55	23.47	4.19	25.84	37.77	51.78	30.30	39.23	30.30	30.11	25.24	22.72
	1.8	34.67	14.74	37.55	67.17	56.22	9.91	34.16	32.66	5.83	35.96	52.55	72.05	42.16	54.59	42.16	41.89	35.12	31.61
630	0.3	5.53	2.41	6.05	10.78	9.07	1.59	5.50	5.26	0.94	5.82	8.35	11.53	6.64	8.76	6.64	6.62	5.60	5.10
	0.8	14.96	6.51	16.38	29.17	24.56	4.31	14.89	14.24	2.55	15.74	22.60	31.21	17.97	23.72	17.97	17.91	15.17	13.80
	1.3	24.48	10.66	26.81	47.76	40.20	7.06	24.38	23.30	4.17	25.77	37.00	51.09	29.42	38.83	29.42	29.32	24.83	22.59
	1.8	34.07	14.83	37.30	66.45	55.94	9.82	33.93	32.43	5.81	35.86	51.49	71.08	40.94	54.03	40.94	40.80	34.55	31.43

*BW = body weight; ADG = average daily gain; Arg = Arginine; His = histidine; Ile = isoleucine; Leu = leucine; Lys = lysine; Met = methionine; Phe = phenylanine; Thr = threonine; Trp = tryptophan; Val = valine; Ala = alanine; Asp = aspartic acid; Cys = cystine; Glu = glutamic acid; Gly = glycine; Pro = proline; Ser = serine; Tyr = tyrosine.

Table 17.6a - Nutritional requirements of **CROSSBRED** beef cattle, **BULLS** in **FEEDLOT** system

Average BW kg	ADG kg	DMI kg	Intake of water[1], L		Energy			Protein					
			Summer	Winter	ME, Mcal	TDN, kg	TDN, %	RDP, g	RUP, g	CP, g	CP,%	RDP, % CP	RUP, % CP
210	0.3	4.0	9.3	11.0	8.1	2.2	55.7	251	128	378	9.4	66.2	33.8
	0.8	5.6	10.1	11.8	11.5	3.2	56.2	370	178	548	9.7	67.5	32.5
	1.3	6.9	10.7	12.4	14.9	4.1	59.1	485	233	718	10.4	67.5	32.5
	1.8	7.9	11.2	12.9	18.5	5.0	63.4	594	293	888	11.2	66.9	33.1
270	0.3	4.8	11.8	13.6	9.6	2.7	55.7	302	143	446	9.3	67.8	32.2
	0.8	6.4	12.6	14.3	13.3	3.7	57.6	429	198	627	9.8	68.4	31.6
	1.3	7.7	13.3	15.0	17.2	4.7	61.2	551	258	808	10.5	68.1	31.9
	1.8	8.6	13.7	15.5	21.2	5.7	66.1	665	324	989	11.4	67.3	32.7
330	0.3	5.5	14.2	16.0	11.0	3.1	55.8	351	160	511	9.3	68.6	31.4
	0.8	7.1	15.0	16.7	15.1	4.2	58.7	485	221	707	10.0	68.7	31.3
	1.3	8.4	15.6	17.4	19.4	5.3	63.0	613	289	902	10.8	68.0	32.0
	1.8	9.3	16.1	17.9	23.7	6.4	68.3	733	363	1096	11.7	66.9	33.1
390	0.3	6.1	16.5	18.3	12.4	3.4	55.8	398	181	579	9.4	68.7	31.3
	0.8	7.7	17.3	19.0	16.8	4.6	59.6	542	254	796	10.3	68.1	31.9
	1.3	9.0	17.9	19.7	21.5	5.8	64.5	678	335	1013	11.2	66.9	33.1
	1.8	10.0	18.4	20.1	26.2	7.0	70.3	806	424	1229	12.3	65.5	34.5
450	0.3	6.8	18.7	20.5	13.7	3.8	55.9	438	191	629	9.3	69.6	30.4
	0.8	8.4	19.5	21.2	18.5	5.1	60.4	583	259	843	10.1	69.2	30.8
	1.3	9.7	20.1	21.9	23.5	6.4	65.7	719	336	1055	10.9	68.2	31.8
	1.8	10.7	20.6	22.4	28.7	7.7	71.9	845	421	1266	11.9	66.7	33.3
510	0.3	7.4	20.9	22.6	15.0	4.1	56.0	476	201	678	9.2	70.3	29.7
	0.8	9.0	21.6	23.4	20.1	5.5	61.1	622	265	887	9.9	70.1	29.9
	1.3	10.3	22.3	24.0	25.5	6.9	66.9	757	338	1095	10.6	69.2	30.8
	1.8	11.3	22.8	24.5	31.0	8.3	73.4	881	420	1301	11.5	67.7	32.3
570	0.3	8.0	22.9	24.7	16.3	4.5	56.1	513	212	725	9.1	70.7	29.3
	0.8	9.6	23.7	25.4	21.7	5.9	61.7	658	272	930	9.7	70.8	29.2
	1.3	10.9	24.3	26.1	27.4	7.4	67.8	793	341	1134	10.4	69.9	30.1
	1.8	11.9	24.8	26.5	33.3	8.9	74.7	913	422	1335	11.2	68.4	31.6
630	0.3	8.6	24.9	26.7	17.5	4.8	56.2	547	223	770	9.0	71.0	29.0
	0.8	10.2	25.7	27.5	23.3	6.3	62.2	693	279	972	9.5	71.3	28.7
	1.3	11.5	26.4	28.1	29.3	7.9	68.7	825	346	1171	10.2	70.5	29.5
	1.8	12.5	26.8	28.6	35.6	9.5	75.9	943	425	1367	11.0	68.9	31.1

*BW = body weight; ADG = average daily gain; DMI = dry matter intake; ME = metabolizable energy; TDN = total digestible nutrients; CP = crude protein; RDP = rumen degradable protein; RUP = rumen undegradable protein. [1]Winter = 22°C of maximum temperature and 65% of relative humidity; Summer = 29°C of maximum temperature and 79% of relative humidity.

Table 17.6b - Minerals requirements for **CROSSBRED** beef cattle, **BULLS** in a **FEEDLOT** system

Average BW kg	ADG kg	Macrominerals, g							Microminerals, mg							
		Ca	P	Ca:P	Mg	Na	K	S	Cu	Co	Cr	Fe	Mn	Mo	Se	Zn
210	0.3	10.65	7.11	1.50	3.74	4.69	11.24	3.91	29.96	3.28	8.07	855.58	91.25	1.40	2.04	146.72
	0.8	21.45	12.10	1.77	4.16	6.60	13.02	5.76	34.48	3.30	11.37	879.23	96.03	1.43	2.78	217.69
	1.3	32.36	17.15	1.89	4.59	8.53	14.82	7.63	39.04	3.32	14.71	903.13	100.86	1.46	3.53	289.39
	1.8	43.33	22.23	1.95	5.01	10.48	16.63	9.51	43.63	3.35	18.06	927.17	105.72	1.48	4.28	361.52
270	0.3	11.38	8.12	1.40	4.72	5.69	14.24	5.00	38.01	4.21	10.16	1096.97	117.18	1.79	2.49	187.31
	0.8	21.30	12.79	1.67	5.12	7.57	16.18	7.34	42.93	4.23	14.04	1122.17	123.08	1.83	3.22	276.31
	1.3	31.33	17.52	1.79	5.52	9.48	18.14	9.71	47.91	4.26	17.95	1147.62	129.04	1.86	3.95	366.21
	1.8	41.42	22.27	1.86	5.92	11.39	20.11	12.09	52.91	4.28	21.89	1173.23	135.04	1.89	4.69	456.66
330	0.3	12.24	9.17	1.33	5.71	6.69	17.24	6.09	46.02	5.15	12.22	1338.23	143.08	2.19	2.94	227.68
	0.8	21.52	13.61	1.58	6.08	8.56	19.31	8.91	51.30	5.17	16.63	1364.72	150.07	2.23	3.66	334.30
	1.3	30.89	18.09	1.71	6.46	10.44	21.40	11.76	56.63	5.19	21.08	1391.49	157.12	2.26	4.38	442.01
	1.8	40.32	22.60	1.78	6.85	12.33	23.51	14.63	62.00	5.21	25.56	1418.42	164.22	2.30	5.11	550.36
390	0.3	13.18	10.25	1.28	6.69	7.70	20.22	7.18	54.00	6.08	14.27	1579.38	168.97	2.59	3.39	267.86
	0.8	21.95	14.50	1.51	7.06	9.54	22.41	10.48	59.60	6.10	19.17	1607.02	177.00	2.62	4.10	391.78
	1.3	30.82	18.79	1.64	7.42	11.41	24.63	13.81	65.25	6.12	24.12	1634.93	185.11	2.66	4.82	516.97
	1.8	39.73	23.11	1.72	7.79	13.28	26.85	17.16	70.93	6.15	29.11	1663.02	193.28	2.70	5.54	642.91
450	0.3	14.17	11.36	1.25	7.68	8.71	23.20	8.26	61.97	7.01	16.29	1820.47	194.84	2.98	3.85	307.88
	0.8	22.54	15.45	1.46	8.03	10.54	25.50	12.03	67.85	7.03	21.67	1849.11	203.89	3.02	4.55	448.85
	1.3	30.98	19.58	1.58	8.38	12.38	27.82	15.83	73.79	7.06	27.09	1878.05	213.04	3.06	5.26	591.25
	1.8	39.48	23.74	1.66	8.74	14.24	30.16	19.66	79.76	7.08	32.55	1907.16	222.24	3.10	5.97	734.51
510	0.3	15.21	12.48	1.22	8.67	9.72	26.17	9.34	69.93	7.94	18.31	2061.49	220.70	3.38	4.30	347.77
	0.8	23.23	16.44	1.41	9.01	11.53	28.57	13.57	76.07	7.97	24.13	2091.05	230.75	3.42	5.00	505.55
	1.3	31.33	20.44	1.53	9.35	13.37	30.99	17.85	82.27	7.99	30.01	2120.92	240.91	3.46	5.70	664.95
	1.8	39.48	24.46	1.61	9.70	15.21	33.42	22.15	88.50	8.01	35.92	2150.96	251.13	3.50	6.41	825.30
570	0.3	11.74	11.35	1.03	9.67	10.73	29.13	10.42	77.88	8.88	20.31	2302.47	246.54	3.78	4.76	387.54
	0.8	11.74	11.35	1.03	9.99	12.53	31.62	15.12	84.25	8.90	26.56	2332.87	257.58	3.82	5.45	561.95
	1.3	11.74	11.35	1.03	10.33	14.35	34.14	19.86	90.70	8.92	32.87	2363.58	268.73	3.86	6.14	738.13
	1.8	11.74	11.35	1.03	10.66	16.18	36.67	24.63	97.18	8.94	39.22	2394.48	279.95	3.91	6.84	915.37
630	0.3	12.98	12.54	1.03	10.66	11.75	32.10	11.50	85.81	9.81	22.31	2543.42	272.38	4.17	5.21	427.22
	0.8	12.98	12.54	1.03	10.98	13.54	34.67	16.65	92.41	9.83	28.97	2574.59	284.38	4.22	5.90	618.07
	1.3	12.98	12.54	1.03	11.30	15.34	37.27	21.86	99.08	9.85	35.69	2606.08	296.51	4.26	6.59	810.87
	1.8	12.98	12.54	1.03	11.63	17.16	39.89	27.09	105.79	9.88	42.46	2637.77	308.70	4.31	7.28	1004.82

*BW = body weight; ADG = average daily gain; Ca = calcium; P = phosphorus; Ca:P = ratio calcium/phosphorus; Mg = magnesium; Na = sodium; K = potassium; S = sulfur; Cu = copper; Co = cobalt; Cr = chromium; Fe = iron; Mn = manganese; Mo = molybdenum; Se = selenium; Zn = zinc.

Table 17.6c - Metabolizable amino acids requirements for **CROSSBRED** beef cattle, **BULLS** in a **FEEDLOT** system

Average BW kg	ADG kg	Essentials, g										Non-Essentials, g							
		Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val	Ala	Asp	Cys	Glu	Gly	Pro	Ser	Tyr
330	0.3	6.23	2.31	6.34	11.60	9.39	1.69	5.76	5.52	0.96	5.92	9.59	12.64	8.10	9.39	8.10	7.92	6.26	5.30
	0.8	16.86	6.25	17.15	31.39	25.41	4.57	15.60	14.93	2.61	16.03	25.95	34.20	21.92	25.42	21.92	21.44	16.94	14.34
	1.3	27.59	10.23	28.07	51.38	41.59	7.49	25.53	24.44	4.27	26.25	42.49	55.99	35.89	41.61	35.89	35.09	27.73	23.47
	1.8	38.39	14.24	39.06	71.49	57.87	10.42	35.53	34.01	5.94	36.52	59.12	77.90	49.94	57.90	49.94	48.82	38.59	32.66
390	0.3	6.05	2.33	6.27	11.40	9.31	1.67	5.70	5.45	0.96	5.90	9.28	12.36	7.73	9.24	7.73	7.59	6.10	5.25
	0.8	16.38	6.31	16.96	30.84	25.20	4.51	15.43	14.76	2.59	15.96	25.11	33.46	20.91	25.00	20.91	20.54	16.50	14.21
	1.3	26.82	10.33	27.77	50.49	41.26	7.38	25.25	24.17	4.25	26.13	41.11	54.78	34.23	40.93	34.23	33.62	27.01	23.26
	1.8	37.31	14.37	38.63	70.25	57.40	10.27	35.14	33.63	5.91	36.36	57.20	76.22	47.62	56.95	47.62	46.78	37.58	32.36
450	0.3	5.91	2.35	6.21	11.23	9.25	1.65	5.65	5.40	0.95	5.88	9.02	12.13	7.42	9.11	7.42	7.31	5.96	5.21
	0.8	15.99	6.36	16.80	30.39	25.03	4.46	15.28	14.62	2.58	15.90	24.41	32.84	20.08	24.65	20.08	19.80	16.13	14.10
	1.3	26.17	10.42	27.50	49.74	40.97	7.29	25.02	23.93	4.23	26.03	39.96	53.76	32.87	40.35	32.87	32.41	26.41	23.08
	1.8	36.41	14.49	38.27	69.21	57.01	10.15	34.81	33.30	5.88	36.23	55.61	74.80	45.73	56.15	45.73	45.09	36.74	32.11
510	0.3	5.78	2.37	6.16	11.08	9.19	1.63	5.60	5.36	0.95	5.86	8.80	11.94	7.16	9.00	7.16	7.08	5.84	5.17
	0.8	15.65	6.41	16.66	29.99	24.88	4.41	15.16	14.50	2.57	15.85	23.82	32.31	19.38	24.35	19.38	19.17	15.82	14.00
	1.3	25.61	10.49	27.28	49.10	40.72	7.22	24.81	23.73	4.21	25.95	38.99	52.89	31.72	39.86	31.72	31.38	25.89	22.92
	1.8	35.64	14.60	37.96	68.31	56.66	10.04	34.52	33.02	5.86	36.11	54.25	73.59	44.14	55.46	44.14	43.67	36.02	31.89
570	0.3	5.67	2.38	6.11	10.95	9.14	1.61	5.56	5.32	0.95	5.84	8.61	11.77	6.94	8.90	6.94	6.88	5.74	5.14
	0.8	15.35	6.45	16.54	29.65	24.74	4.37	15.05	14.39	2.56	15.81	23.30	31.84	18.78	24.08	18.78	18.63	15.54	13.91
	1.3	25.13	10.56	27.08	48.53	40.50	7.15	24.63	23.55	4.20	25.87	38.14	52.12	30.73	39.43	30.73	30.50	25.44	22.78
	1.8	34.97	14.70	37.68	67.53	56.36	9.95	34.27	32.77	5.84	36.00	53.07	72.53	42.76	54.86	42.76	42.44	35.40	31.69
630	0.3	5.58	2.40	6.07	10.84	9.10	1.60	5.52	5.28	0.94	5.83	8.44	11.61	6.74	8.81	6.74	6.71	5.65	5.11
	0.8	15.09	6.49	16.43	29.34	24.62	4.33	14.95	14.29	2.55	15.77	22.85	31.43	18.25	23.85	18.25	18.16	15.30	13.84
	1.3	24.71	10.62	26.90	48.03	40.31	7.09	24.47	23.39	4.18	25.81	37.40	51.45	29.87	39.04	29.87	29.73	25.04	22.65
	1.8	34.38	14.78	37.43	66.82	56.08	9.87	34.05	32.54	5.82	35.91	52.03	71.58	41.57	54.32	41.57	41.36	34.84	31.52

*BW = body weight; ADG = average daily gain; Arg = Arginine; His = histidine; Ile = isoleucine; Leu = leucine; Lys = lysine; Met = methionine; Phe = phenylanine; Thr = threonine; Trp = tryptophan; Val = valine; Ala = alanine; Asp = aspartic acid; Cys = cystine; Glu = glutamic acid; Gly = glycine; Pro = proline; Ser = serine; Tyr = tyrosine.

Table 17.7a - Nutritional requirements of **CROSSBRED** beef cattle, **STEERS** in **FEEDLOT** system

Average BW kg	ADG kg	DMI kg	Intake of water[1], L		Energy			Protein					
			Summer	Winter	ME, Mcal	TDN, kg	TDN, %	RDP, g	RUP, g	CP, g	CP,%	RDP, % CP	RUP, % CP
210	0.3	4.0	9.3	11.0	8.2	2.3	56.3	254	128	382	9.5	66.4	33.6
	0.8	5.6	10.1	11.8	11.8	3.3	57.7	379	179	558	9.9	68.0	32.0
	1.3	6.9	10.7	12.4	15.6	4.2	61.2	500	235	735	10.6	68.0	32.0
	1.8	7.9	11.2	12.9	19.4	5.2	66.1	614	297	911	11.5	67.4	32.6
270	0.3	4.8	11.8	13.6	9.8	2.7	56.6	307	145	452	9.5	68.0	32.0
	0.8	6.4	12.6	14.3	13.8	3.8	59.4	442	202	644	10.1	68.7	31.3
	1.3	7.7	13.3	15.0	18.0	4.9	63.8	571	265	835	10.9	68.3	31.7
	1.8	8.6	13.7	15.5	22.3	6.0	69.3	692	335	1026	11.9	67.4	32.6
330	0.3	5.5	14.2	16.0	11.3	3.1	56.8	358	163	521	9.5	68.7	31.3
	0.8	7.1	15.0	16.7	15.7	4.3	60.8	503	230	733	10.4	68.6	31.4
	1.3	8.4	15.6	17.4	20.4	5.5	65.9	640	304	944	11.3	67.8	32.2
	1.8	9.3	16.1	17.9	25.2	6.7	72.0	768	386	1155	12.4	66.5	33.5
390	0.3	6.1	16.5	18.3	12.7	3.5	57.0	403	175	577	9.4	69.7	30.3
	0.8	7.7	17.3	19.0	17.6	4.8	61.9	551	240	791	10.2	69.7	30.3
	1.3	9.0	17.9	19.7	22.7	6.1	67.7	691	313	1004	11.1	68.8	31.2
	1.8	10.0	18.4	20.1	27.9	7.4	74.3	820	395	1215	12.1	67.5	32.5
450	0.3	6.8	18.7	20.5	14.1	3.9	57.2	444	184	627	9.2	70.7	29.3
	0.8	8.4	19.5	21.2	19.4	5.3	62.9	594	243	836	10.0	71.0	29.0
	1.3	9.7	20.1	21.9	24.9	6.7	69.3	733	311	1044	10.8	70.2	29.8
	1.8	10.7	20.6	22.4	30.6	8.1	76.4	859	390	1249	11.7	68.8	31.2
510	0.3	7.4	20.9	22.6	15.4	4.3	57.4	482	193	676	9.1	71.4	28.6
	0.8	9.0	21.6	23.4	21.2	5.7	63.8	633	247	880	9.8	72.0	28.0
	1.3	10.3	22.3	24.0	27.1	7.3	70.6	771	311	1082	10.5	71.3	28.7
	1.8	11.3	22.8	24.5	33.2	8.8	78.2	895	387	1282	11.4	69.8	30.2
570	0.3	8.0	22.9	24.7	16.8	4.6	57.6	519	203	722	9.0	71.9	28.1
	0.8	9.6	23.7	25.4	22.9	6.2	64.5	671	252	922	9.6	72.7	27.3
	1.3	10.9	24.3	26.1	29.3	7.8	71.8	807	312	1119	10.3	72.1	27.9
	1.8	11.9	24.8	26.5	35.8	9.5	79.8	927	387	1313	11.1	70.6	29.4
630	0.3	8.6	24.9	26.7	18.1	5.0	57.8	555	213	768	8.9	72.2	27.8
	0.8	10.2	25.7	27.5	24.6	6.6	65.2	706	257	963	9.4	73.3	26.7
	1.3	11.5	26.4	28.1	31.3	8.4	72.9	840	315	1155	10.1	72.7	27.3
	1.8	12.5	26.8	28.6	38.3	10.1	81.2	955	388	1343	10.8	71.1	28.9

*BW = body weight; ADG = average daily gain; DMI = dry matter intake; ME = metabolizable energy; TDN = total digestible nutrients; CP = crude protein; RDP = rumen degradable protein; RUP = rumen undegradable protein. [1]Winter = 22°C of maximum temperature and 65% of relative humidity; Summer = 29°C of maximum temperature and 79% of relative humidity.

Table 17.7b - Minerals requirements for **CROSSBRED** beef cattle, **STEERS** in a **FEEDLOT** system

Average BW kg	ADG kg	Macrominerals, g							Microminerals, mg							
		Ca	P	Ca:P	Mg	Na	K	S	Cu	Co	Cr	Fe	Mn	Mo	Se	Zn
210	0.3	10.65	7.11	1.50	3.74	4.69	11.24	3.91	29.96	3.28	8.07	855.59	91.26	1.40	2.04	146.81
	0.8	21.44	12.10	1.77	4.16	6.60	13.02	5.77	34.48	3.30	11.38	879.25	96.05	1.43	2.78	217.93
	1.3	32.34	17.14	1.89	4.59	8.53	14.82	7.64	39.05	3.32	14.72	903.16	100.89	1.46	3.53	289.79
	1.8	43.30	22.21	1.95	5.01	10.47	16.64	9.53	43.64	3.35	18.08	927.22	105.76	1.48	4.28	362.07
270	0.3	11.36	8.11	1.40	4.72	5.69	14.25	5.01	38.01	4.21	10.17	1097.00	117.20	1.79	2.49	187.64
	0.8	21.27	12.78	1.66	5.11	7.57	16.19	7.37	42.95	4.23	14.06	1122.24	123.14	1.83	3.22	277.19
	1.3	31.27	17.50	1.79	5.51	9.47	18.15	9.75	47.94	4.26	18.00	1147.73	129.13	1.86	3.95	367.66
	1.8	41.33	22.24	1.86	5.92	11.39	20.13	12.14	52.96	4.28	21.95	1173.38	135.17	1.89	4.69	458.66
330	0.3	12.22	9.16	1.33	5.70	6.69	17.24	6.11	46.03	5.15	12.24	1338.27	143.12	2.19	2.94	228.27
	0.8	21.46	13.59	1.58	6.08	8.55	19.32	8.96	51.33	5.17	16.68	1364.84	150.16	2.23	3.66	335.90
	1.3	30.81	18.06	1.71	6.46	10.43	21.42	11.84	56.68	5.19	21.16	1391.68	157.28	2.26	4.38	444.64
	1.8	40.20	22.56	1.78	6.84	12.32	23.54	14.73	62.06	5.21	25.67	1418.68	164.44	2.30	5.11	554.02
390	0.3	13.15	10.25	1.28	6.69	7.70	20.23	7.20	54.02	6.08	14.29	1579.44	169.02	2.59	3.39	268.74
	0.8	21.89	14.48	1.51	7.05	9.54	22.43	10.54	59.64	6.10	19.24	1607.17	177.15	2.62	4.10	394.19
	1.3	30.71	18.75	1.64	7.42	11.40	24.65	13.91	65.32	6.12	24.23	1635.18	185.35	2.66	4.82	520.91
	1.8	39.59	23.06	1.72	7.78	13.27	26.89	17.31	71.03	6.14	29.26	1663.36	193.61	2.70	5.54	648.39
450	0.3	14.14	11.35	1.25	7.68	8.71	23.20	8.30	61.99	7.01	16.33	1820.53	194.91	2.98	3.85	309.08
	0.8	22.46	15.42	1.46	8.03	10.54	25.52	12.12	67.90	7.03	21.75	1849.30	204.09	3.02	4.55	452.10
	1.3	30.87	19.54	1.58	8.38	12.38	27.85	15.98	73.87	7.06	27.24	1878.35	213.36	3.06	5.26	596.59
	1.8	39.32	23.68	1.66	8.73	14.23	30.20	19.87	79.88	7.08	32.75	1907.58	222.69	3.10	5.97	741.94
510	0.3	15.18	12.46	1.22	8.67	9.72	26.18	9.38	69.95	7.94	18.35	2061.57	220.79	3.38	4.30	349.31
	0.8	23.15	16.41	1.41	9.01	11.53	28.59	13.69	76.13	7.97	24.24	2091.27	231.00	3.42	5.00	509.71
	1.3	31.20	20.39	1.53	9.35	13.36	31.03	18.04	82.37	7.99	30.18	2121.27	241.31	3.46	5.70	671.76
	1.8	39.30	24.39	1.61	9.69	15.20	33.48	22.42	88.64	8.01	36.17	2151.45	251.69	3.51	6.40	834.78
570	0.3	11.74	11.35	1.03	9.67	10.73	29.14	10.47	77.90	8.88	20.36	2302.57	246.65	3.78	4.76	389.43
	0.8	11.74	11.35	1.03	9.99	12.53	31.65	15.26	84.32	8.90	26.69	2333.12	257.88	3.82	5.45	567.05
	1.3	11.74	11.35	1.03	10.32	14.35	34.18	20.09	90.81	8.92	33.08	2363.99	269.22	3.86	6.14	746.49
	1.8	11.74	11.35	1.03	10.66	16.17	36.73	24.95	97.34	8.94	39.52	2395.04	280.63	3.91	6.84	927.00
630	0.3	12.98	12.54	1.03	10.66	11.75	32.11	11.56	85.84	9.81	22.36	2543.52	272.51	4.17	5.21	429.47
	0.8	12.98	12.54	1.03	10.98	13.53	34.70	16.82	92.49	9.83	29.12	2574.87	284.74	4.22	5.90	624.15
	1.3	12.98	12.54	1.03	11.30	15.34	37.32	22.14	99.21	9.85	35.94	2606.54	297.09	4.26	6.59	820.83
	1.8	12.98	12.54	1.03	11.62	17.15	39.96	27.48	105.97	9.88	42.81	2638.39	309.52	4.31	7.28	1018.68

*BW = body weight; ADG = average daily gain; Ca = calcium; P = phosphorus; Ca:P = ratio calcium/phosphorus; Mg = magnesium; Na = sodium; K = potassium; S = sulfur; Cu = copper; Co = cobalt; Cr = chromium; Fe = iron; Mn = manganese; Mo = molybdenum; Se = selenium; Zn = zinc.

Table 17.7c - Metabolizable amino acids requirements for **CROSSBRED** beef cattle, **STEERS** in a **FEEDLOT** system

Average BW kg	ADG kg	Essentials, g										Non-Essentials, g							
		Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val	Ala	Asp	Cys	Glu	Gly	Pro	Ser	Tyr
330	0.3	6.22	2.31	6.33	11.58	9.38	1.69	5.76	5.51	0.96	5.92	9.57	12.62	8.08	9.38	8.08	7.90	6.25	5.30
	0.8	16.83	6.25	17.14	31.35	25.40	4.57	15.59	14.92	2.61	16.03	25.90	34.15	21.86	25.39	21.86	21.38	16.91	14.33
	1.3	27.54	10.24	28.05	51.32	41.57	7.48	25.52	24.43	4.27	26.24	42.40	55.91	35.78	41.57	35.78	34.99	27.69	23.46
	1.8	38.32	14.24	39.04	71.41	57.84	10.41	35.51	33.99	5.94	36.51	59.00	77.79	49.79	57.84	49.79	48.69	38.53	32.64
390	0.3	6.04	2.33	6.26	11.38	9.31	1.66	5.70	5.45	0.96	5.90	9.25	12.34	7.70	9.23	7.70	7.56	6.08	5.25
	0.8	16.34	6.32	16.95	30.80	25.19	4.50	15.41	14.75	2.59	15.96	25.05	33.40	20.83	24.97	20.83	20.47	16.47	14.20
	1.3	26.75	10.34	27.74	50.42	41.23	7.37	25.23	24.14	4.24	26.12	41.00	54.68	34.10	40.87	34.10	33.50	26.95	23.24
	1.8	37.23	14.39	38.60	70.16	57.37	10.26	35.11	33.59	5.91	36.35	57.05	76.08	47.44	56.87	47.44	46.61	37.50	32.34
450	0.3	5.89	2.35	6.20	11.21	9.24	1.64	5.64	5.40	0.95	5.87	8.99	12.11	7.38	9.09	7.38	7.28	5.95	5.20
	0.8	15.94	6.37	16.78	30.34	25.01	4.45	15.27	14.60	2.58	15.90	24.34	32.77	19.99	24.61	19.99	19.71	16.09	14.08
	1.3	26.10	10.43	27.48	49.66	40.94	7.28	24.99	23.91	4.22	26.02	39.84	53.65	32.72	40.29	32.72	32.27	26.34	23.06
	1.8	36.31	14.51	38.23	69.10	56.96	10.14	34.77	33.26	5.88	36.21	55.43	74.65	45.52	56.06	45.52	44.90	36.65	32.08
510	0.3	5.76	2.37	6.15	11.06	9.18	1.63	5.59	5.35	0.95	5.85	8.77	11.91	7.12	8.98	7.12	7.05	5.83	5.17
	0.8	15.60	6.42	16.64	29.94	24.85	4.40	15.14	14.48	2.57	15.84	23.73	32.23	19.28	24.31	19.28	19.08	15.77	13.99
	1.3	25.53	10.50	27.25	49.00	40.69	7.21	24.78	23.70	4.21	25.94	38.85	52.76	31.55	39.79	31.55	31.23	25.82	22.90
	1.8	35.53	14.62	37.91	68.18	56.61	10.03	34.48	32.98	5.85	36.09	54.06	73.41	43.91	55.36	43.91	43.46	35.92	31.86
570	0.3	5.65	2.39	6.10	10.93	9.13	1.61	5.55	5.31	0.95	5.84	8.57	11.73	6.90	8.88	6.90	6.85	5.72	5.14
	0.8	15.30	6.46	16.52	29.58	24.72	4.36	15.03	14.37	2.56	15.80	23.21	31.76	18.67	24.04	18.67	18.53	15.49	13.90
	1.3	25.05	10.57	27.04	48.43	40.46	7.14	24.60	23.52	4.19	25.86	37.99	51.99	30.56	39.35	30.56	30.34	25.36	22.75
	1.8	34.85	14.71	37.63	67.38	56.30	9.93	34.23	32.72	5.83	35.98	52.86	72.34	42.52	54.75	42.52	42.22	35.28	31.66
630	0.3	5.56	2.40	6.06	10.82	9.09	1.60	5.51	5.27	0.94	5.82	8.40	11.58	6.70	8.79	6.70	6.67	5.63	5.11
	0.8	15.04	6.50	16.41	29.27	24.60	4.32	14.93	14.27	2.55	15.76	22.75	31.34	18.14	23.80	18.14	18.06	15.24	13.82
	1.3	24.61	10.64	26.86	47.91	40.26	7.08	24.43	23.35	4.18	25.79	37.23	51.30	29.69	38.95	29.69	29.56	24.95	22.63
	1.8	34.25	14.80	37.38	66.67	56.02	9.85	34.00	32.50	5.81	35.89	51.81	71.38	41.31	54.20	41.31	41.13	34.72	31.48

*BW = body weight; ADG = average daily gain; Arg = Arginine; His = histidine; Ile = isoleucine; Leu = leucine; Lys = lysine; Met = methionine; Phe = phenylanine; Thr = threonine; Trp = tryptophan; Val = valine; Ala = alanine; Asp = aspartic acid; Cys = cystine; Glu = glutamic acid; Gly = glycine; Pro = proline; Ser = serine; Tyr = tyrosine.

Table 17.8a - Nutritional requirements of **CROSSBRED** beef cattle, **HEIFERS** in **FEEDLOT** system

Average BW kg	ADG kg	DMI kg	Intake of water[1], L		Energy			Protein					
			Summer	Winter	ME, Mcal	TDN, kg	TDN, %	RDP, g	RUP, g	CP, g	CP,%	RDP, % CP	RUP, % CP
210	0.3	4.0	9.3	11.0	8.4	2.3	57.4	259	129	387	9.6	66.8	33.2
	0.8	5.6	10.1	11.8	12.3	3.4	59.7	392	181	572	10.2	68.4	31.6
	1.3	6.9	10.7	12.4	16.3	4.4	63.9	518	239	757	10.9	68.5	31.5
	1.8	7.9	11.2	12.9	20.4	5.5	69.4	638	303	941	11.9	67.8	32.2
270	0.3	4.8	11.8	13.6	10.0	2.8	57.8	314	147	461	9.6	68.2	31.8
	0.8	6.4	12.6	14.3	14.4	3.9	61.7	459	208	667	10.5	68.8	31.2
	1.3	7.7	13.3	15.0	19.0	5.1	66.9	596	277	873	11.4	68.3	31.7
	1.8	8.6	13.7	15.5	23.7	6.3	73.1	725	353	1078	12.5	67.2	32.8
330	0.3	5.5	14.2	16.0	11.6	3.2	58.2	368	168	536	9.8	68.6	31.4
	0.8	7.1	15.0	16.7	16.5	4.5	63.4	526	246	773	10.9	68.1	31.9
	1.3	8.4	15.6	17.4	21.6	5.8	69.4	676	332	1008	12.1	67.0	33.0
	1.8	9.3	16.1	17.9	26.8	7.1	76.3	814	428	1242	13.3	65.5	34.5
390	0.3	6.1	16.5	18.3	13.1	3.6	58.5	408	167	575	9.4	70.9	29.1
	0.8	7.7	17.3	19.0	18.5	5.0	64.7	562	222	785	10.1	71.7	28.3
	1.3	9.0	17.9	19.7	24.1	6.5	71.5	705	288	993	11.0	71.0	29.0
	1.8	10.0	18.4	20.1	29.9	7.9	79.0	835	364	1198	12.0	69.7	30.3
450	0.3	6.8	18.7	20.5	14.5	4.0	58.8	450	175	625	9.2	72.0	28.0
	0.8	8.4	19.5	21.2	20.4	5.5	65.9	606	224	829	9.9	73.0	27.0
	1.3	9.7	20.1	21.9	26.6	7.1	73.3	748	284	1031	10.7	72.5	27.5
	1.8	10.7	20.6	22.4	32.9	8.7	81.4	874	356	1230	11.5	71.0	29.0
510	0.3	7.4	20.9	22.6	16.0	4.4	59.1	490	184	673	9.1	72.7	27.3
	0.8	9.0	21.6	23.4	22.3	6.0	66.9	646	226	872	9.7	74.1	25.9
	1.3	10.3	22.3	24.0	28.9	7.7	74.9	786	282	1068	10.4	73.6	26.4
	1.8	11.3	22.8	24.5	35.8	9.4	83.5	909	352	1260	11.2	72.1	27.9
570	0.3	8.0	22.9	24.7	17.3	4.8	59.3	527	193	720	9.0	73.2	26.8
	0.8	9.6	23.7	25.4	24.2	6.5	67.8	684	230	913	9.5	74.9	25.1
	1.3	10.9	24.3	26.1	31.3	8.3	76.3	822	281	1103	10.1	74.5	25.5
	1.8	11.9	24.8	26.5	38.6	10.1	85.4	939	350	1289	10.8	72.8	27.2
630	0.3	8.6	24.9	26.7	18.7	5.1	59.6	563	202	765	8.9	73.6	26.4
	0.8	10.2	25.7	27.5	26.0	7.0	68.5	719	234	953	9.4	75.4	24.6
	1.3	11.5	26.4	28.1	33.6	8.9	77.6	854	283	1137	9.9	75.1	24.9
	1.8	12.5	26.8	28.6	41.4	10.9	87.1	965	351	1316	10.6	73.3	26.7

*BW = body weight; ADG = average daily gain; DMI = dry matter intake; ME = metabolizable energy; TDN = total digestible nutrients; CP = crude protein; RDP = rumen degradable protein; RUP = rumen undegradable protein. [1]Winter = 22°C of maximum temperature and 65% of relative humidity; Summer = 29°C of maximum temperature and 79% of relative humidity.

Table 17.8b - Minerals requirements for **CROSSBRED** beef cattle, **HEIFERS** in a **FEEDLOT** system

Average BW kg	ADG kg	Macrominerals, g							Microminerals, mg							
		Ca	P	Ca:P	Mg	Na	K	S	Cu	Co	Cr	Fe	Mn	Mo	Se	Zn
210	0.3	10.62	7.10	1.50	3.74	4.69	11.25	3.93	29.97	3.28	8.09	855.63	91.29	1.40	2.04	147.26
	0.8	21.37	12.07	1.77	4.16	6.60	13.03	5.80	34.51	3.30	11.42	879.37	96.13	1.43	2.78	219.16
	1.3	32.22	17.10	1.88	4.58	8.53	14.84	7.70	39.10	3.32	14.79	903.35	101.02	1.46	3.53	291.79
	1.8	43.14	22.16	1.95	5.01	10.47	16.66	9.60	43.71	3.35	18.17	927.48	105.93	1.48	4.28	364.86
270	0.3	11.34	8.10	1.40	4.72	5.69	14.25	5.03	38.03	4.21	10.19	1097.05	117.24	1.80	2.49	188.33
	0.8	21.19	12.75	1.66	5.11	7.57	16.20	7.42	42.99	4.23	14.12	1122.38	123.25	1.83	3.21	279.06
	1.3	31.15	17.45	1.78	5.51	9.47	18.18	9.83	48.00	4.26	18.09	1147.97	129.32	1.86	3.95	370.71
	1.8	41.16	22.18	1.86	5.91	11.38	20.16	12.26	53.05	4.28	22.09	1173.72	135.43	1.89	4.69	462.91
330	0.3	12.19	9.15	1.33	5.70	6.69	17.25	6.14	46.05	5.15	12.27	1338.33	143.18	2.19	2.94	229.22
	0.8	21.38	13.56	1.58	6.08	8.55	19.34	9.03	51.37	5.17	16.75	1365.01	150.32	2.23	3.66	338.46
	1.3	30.67	18.01	1.70	6.46	10.43	21.45	11.95	56.76	5.19	21.28	1391.96	157.54	2.26	4.38	448.82
	1.8	40.02	22.49	1.78	6.84	12.32	23.58	14.89	62.17	5.21	25.84	1419.08	164.79	2.30	5.11	559.84
390	0.3	13.12	10.23	1.28	6.69	7.70	20.23	7.24	54.04	6.08	14.32	1579.51	169.10	2.59	3.39	269.96
	0.8	21.80	14.45	1.51	7.05	9.54	22.45	10.63	59.70	6.10	19.33	1607.37	177.34	2.63	4.10	397.47
	1.3	30.57	18.70	1.63	7.41	11.40	24.69	14.06	65.41	6.12	24.38	1635.51	185.68	2.66	4.81	526.28
	1.8	39.40	22.98	1.71	7.78	13.26	26.94	17.51	71.16	6.14	29.47	1663.82	194.06	2.70	5.53	655.86
450	0.3	14.11	11.34	1.24	7.68	8.71	23.21	8.34	62.02	7.01	16.37	1820.62	195.00	2.98	3.85	310.57
	0.8	22.38	15.39	1.45	8.03	10.53	25.54	12.23	67.97	7.03	21.86	1849.52	204.33	3.02	4.55	456.14
	1.3	30.73	19.48	1.58	8.38	12.37	27.89	16.16	73.98	7.06	27.41	1878.72	213.75	3.06	5.25	603.20
	1.8	39.13	23.60	1.66	8.73	14.22	30.26	20.12	80.02	7.08	33.00	1908.10	223.23	3.10	5.96	751.13
510	0.3	15.14	12.45	1.22	8.67	9.72	26.19	9.43	69.98	7.94	18.39	2061.66	220.89	3.38	4.30	351.09
	0.8	23.06	16.37	1.41	9.01	11.53	28.62	13.82	76.20	7.97	24.36	2091.52	231.28	3.42	4.99	514.53
	1.3	31.06	20.33	1.53	9.35	13.35	31.07	18.26	82.48	7.99	30.39	2121.68	241.78	3.46	5.69	679.65
	1.8	39.10	24.31	1.61	9.69	15.19	33.54	22.72	88.81	8.01	36.45	2152.02	252.34	3.51	6.40	845.75
570	0.3	11.74	11.35	1.03	9.66	10.73	29.15	10.53	77.93	8.88	20.41	2302.66	246.78	3.78	4.76	391.51
	0.8	11.74	11.35	1.03	9.99	12.53	31.68	15.41	84.40	8.90	26.83	2333.39	258.21	3.82	5.44	572.68
	1.3	11.74	11.35	1.03	10.32	14.34	34.23	20.35	90.94	8.92	33.32	2364.43	269.76	3.86	6.14	755.70
	1.8	11.74	11.35	1.03	10.65	16.17	36.79	25.31	97.51	8.94	39.84	2395.65	281.38	3.91	6.84	939.81
630	0.3	12.98	12.54	1.03	10.66	11.74	32.12	11.63	85.87	9.81	22.42	2543.63	272.65	4.17	5.21	431.85
	0.8	12.98	12.54	1.03	10.97	13.53	34.73	17.00	92.58	9.83	29.27	2575.15	285.11	4.22	5.89	630.60
	1.3	12.98	12.54	1.03	11.29	15.33	37.37	22.43	99.35	9.85	36.20	2607.01	297.71	4.26	6.58	831.39
	1.8	12.98	12.54	1.03	11.62	17.14	40.03	27.89	106.16	9.88	43.17	2639.05	310.37	4.31	7.27	1033.37

*BW = body weight; ADG = average daily gain; Ca = calcium; P = phosphorus; Ca:P = ratio calcium/phosphorus; Mg = magnesium; Na = sodium; K = potassium; S = sulfur; Cu = copper; Co = cobalt; Cr = chromium; Fe = iron; Mn = manganese; Mo = molybdenum; Se = selenium; Zn = zinc.

Table 17.8c - Metabolizable amino acids requirements for **CROSSBRED** beef cattle, **HEIFERS** in a **FEEDLOT** system

Average BW kg	ADG kg	Essentials, g										Non-Essentials, g							
		Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val	Ala	Asp	Cys	Glu	Gly	Pro	Ser	Tyr
330	0.3	6.20	2.31	6.33	11.56	9.38	1.69	5.75	5.51	0.96	5.92	9.54	12.59	8.04	9.37	8.04	7.87	6.23	5.29
	0.8	16.78	6.26	17.12	31.30	25.37	4.56	15.57	14.90	2.61	16.02	25.82	34.08	21.76	25.35	21.76	21.29	16.87	14.32
	1.3	27.46	10.25	28.02	51.23	41.54	7.47	25.49	24.40	4.26	26.23	42.26	55.79	35.61	41.50	35.61	34.85	27.62	23.44
	1.8	38.22	14.26	38.99	71.29	57.80	10.39	35.47	33.95	5.93	36.49	58.80	77.63	49.55	57.74	49.55	48.49	38.43	32.61
390	0.3	6.02	2.34	6.25	11.36	9.30	1.66	5.69	5.44	0.96	5.89	9.22	12.31	7.66	9.21	7.66	7.53	6.07	5.24
	0.8	16.29	6.32	16.93	30.74	25.16	4.50	15.40	14.73	2.59	15.95	24.96	33.32	20.72	24.92	20.72	20.37	16.42	14.18
	1.3	26.67	10.35	27.71	50.32	41.19	7.36	25.20	24.11	4.24	26.11	40.85	54.55	33.92	40.80	33.92	33.35	26.88	23.22
	1.8	37.11	14.40	38.55	70.02	57.32	10.24	35.07	33.55	5.90	36.33	56.84	75.90	47.20	56.77	47.20	46.40	37.40	32.31
450	0.3	5.87	2.36	6.19	11.19	9.23	1.64	5.63	5.39	0.95	5.87	8.96	12.08	7.34	9.08	7.34	7.25	5.93	5.20
	0.8	15.89	6.38	16.76	30.27	24.98	4.44	15.25	14.58	2.58	15.89	24.24	32.69	19.88	24.57	19.88	19.62	16.04	14.07
	1.3	26.01	10.44	27.44	49.56	40.90	7.27	24.96	23.87	4.22	26.01	39.68	53.51	32.53	40.21	32.53	32.11	26.26	23.03
	1.8	36.19	14.52	38.18	68.96	56.91	10.12	34.73	33.22	5.87	36.19	55.22	74.46	45.27	55.95	45.27	44.68	36.54	32.05
510	0.3	5.74	2.37	6.14	11.04	9.17	1.62	5.59	5.34	0.95	5.85	8.73	11.88	7.08	8.96	7.08	7.01	5.81	5.16
	0.8	15.54	6.42	16.62	29.87	24.83	4.39	15.12	14.46	2.57	15.84	23.63	32.14	19.16	24.26	19.16	18.98	15.72	13.97
	1.3	25.44	10.52	27.21	48.90	40.64	7.19	24.75	23.67	4.20	25.92	38.69	52.62	31.37	39.71	31.37	31.07	25.73	22.87
	1.8	35.40	14.63	37.86	68.04	56.55	10.01	34.44	32.93	5.85	36.07	53.83	73.21	43.65	55.25	43.65	43.23	35.80	31.82
570	0.3	5.63	2.39	6.10	10.91	9.12	1.61	5.54	5.30	0.95	5.83	8.54	11.70	6.85	8.86	6.85	6.81	5.70	5.13
	0.8	15.24	6.47	16.50	29.52	24.69	4.35	15.00	14.34	2.56	15.79	23.11	31.67	18.55	23.98	18.55	18.43	15.44	13.88
	1.3	24.95	10.59	27.00	48.32	40.42	7.12	24.56	23.48	4.19	25.85	37.83	51.84	30.37	39.26	30.37	30.17	25.27	22.73
	1.8	34.72	14.73	37.57	67.23	56.24	9.91	34.18	32.67	5.83	35.96	52.63	72.13	42.26	54.63	42.26	41.98	35.16	31.62
630	0.3	5.53	2.40	6.05	10.79	9.08	1.59	5.51	5.26	0.94	5.82	8.37	11.54	6.66	8.77	6.66	6.63	5.61	5.10
	0.8	14.98	6.51	16.38	29.20	24.57	4.32	14.90	14.24	2.55	15.75	22.64	31.24	18.02	23.74	18.02	17.95	15.19	13.80
	1.3	24.52	10.65	26.82	47.80	40.22	7.06	24.40	23.32	4.18	25.78	37.07	51.14	29.49	38.86	29.49	29.38	24.86	22.60
	1.8	34.11	14.82	37.32	66.51	55.96	9.83	33.95	32.44	5.81	35.87	51.57	71.16	41.04	54.08	41.04	40.89	34.59	31.44

*BW = body weight; ADG = average daily gain; Arg = Arginine; His = histidine; Ile = isoleucine; Leu = leucine; Lys = lysine; Met = methionine; Phe = phenylanine; Thr = threonine; Trp = tryptophan; Val = valine; Ala = alanine; Asp = aspartic acid; Cys = cystine; Glu = glutamic acid; Gly = glycine; Pro = proline; Ser = serine; Tyr = tyrosine.

Table 17.9a - Nutritional requirements of **CROSSBRED** dairy cattle, **BULLS** in **FEEDLOT** system

Average BW kg	ADG kg	DMI kg	Intake of water[1], L		Energy			Protein					
			Summer	Winter	ME, Mcal	TDN, kg	TDN, %	RDP, g	RUP, g	CP, g	CP,%	RDP, % CP	RUP, % CP
210	0.3	3.0	8.8	10.5	8.3	2.2	72.7	247	129	376	12.4	65.6	34.4
	0.8	4.8	9.7	11.4	11.8	3.2	66.6	369	175	544	11.4	67.9	32.1
	1.3	6.0	10.3	12.0	15.3	4.1	68.6	485	227	712	11.8	68.1	31.9
	1.8	6.8	10.6	12.4	19.0	5.0	74.5	593	285	878	13.0	67.5	32.5
270	0.3	4.0	11.5	13.2	9.8	2.6	66.0	300	143	442	11.1	67.7	32.3
	0.8	5.7	12.3	14.0	13.7	3.7	64.6	429	191	620	10.8	69.2	30.8
	1.3	7.0	12.9	14.6	17.6	4.7	68.1	551	247	797	11.4	69.0	31.0
	1.8	7.7	13.3	15.0	21.7	5.8	74.6	664	310	974	12.6	68.2	31.8
330	0.3	4.9	14.0	15.7	11.2	3.1	62.1	349	157	507	10.3	68.9	31.1
	0.8	6.6	14.8	16.5	15.5	4.2	63.3	485	211	696	10.5	69.7	30.3
	1.3	7.9	15.4	17.1	19.9	5.3	67.8	613	272	885	11.2	69.3	30.7
	1.8	8.7	15.8	17.5	24.3	6.5	74.8	730	342	1072	12.4	68.1	31.9
390	0.3	5.8	16.4	18.1	12.6	3.4	59.5	399	181	580	10.0	68.9	31.1
	0.8	7.5	17.2	18.9	17.2	4.7	62.4	548	253	801	10.7	68.4	31.6
	1.3	8.8	17.8	19.5	22.0	5.9	67.6	686	335	1021	11.7	67.2	32.8
	1.8	9.5	18.2	19.9	26.8	7.1	75.0	814	426	1239	13.0	65.7	34.3
450	0.3	6.6	18.7	20.4	13.9	3.8	57.7	440	190	630	9.5	69.9	30.1
	0.8	8.4	19.5	21.2	18.9	5.2	61.7	590	257	847	10.1	69.6	30.4
	1.3	9.6	20.1	21.8	24.1	6.5	67.5	728	335	1063	11.1	68.5	31.5
	1.8	10.4	20.5	22.2	29.3	7.8	75.2	854	423	1277	12.3	66.9	33.1
510	0.3	7.4	20.9	22.6	15.2	4.2	56.4	479	199	679	9.1	70.6	29.4
	0.8	9.2	21.7	23.4	20.5	5.6	61.2	630	262	892	9.7	70.6	29.4
	1.3	10.4	22.3	24.1	26.1	7.0	67.5	767	337	1104	10.6	69.5	30.5
	1.8	11.2	22.7	24.4	31.7	8.4	75.5	890	423	1313	11.8	67.8	32.2
570	0.3	8.2	23.0	24.8	16.4	4.5	55.3	516	209	725	8.8	71.2	28.8
	0.8	10.0	23.9	25.6	22.1	6.0	60.8	667	268	935	9.4	71.3	28.7
	1.3	11.2	24.5	26.2	28.0	7.6	67.5	803	340	1143	10.2	70.2	29.8
	1.8	12.0	24.9	26.6	34.0	9.1	75.7	923	425	1348	11.3	68.5	31.5
630	0.3	9.0	25.1	26.9	17.7	4.9	54.5	552	219	771	8.6	71.6	28.4
	0.8	10.7	26.0	27.7	23.7	6.5	60.5	702	275	977	9.1	71.8	28.2
	1.3	12.0	26.6	28.3	30.0	8.1	67.5	836	345	1181	9.9	70.8	29.2
	1.8	12.7	27.0	28.7	36.3	9.7	75.9	953	428	1381	10.8	69.0	31.0

*BW = body weight; ADG = average daily gain; DMI = dry matter intake; ME = metabolizable energy; TDN = total digestible nutrients; CP = crude protein; RDP = rumen degradable protein; RUP = rumen undegradable protein. [1]Winter = 22°C of maximum temperature and 65% of relative humidity; Summer = 29°C of maximum temperature and 79% of relative humidity.

Table 17.9b - Minerals requirements for **CROSSBRED** dairy cattle, **BULLS** in a **FEEDLOT** system

Average BW kg	ADG kg	Macrominerals, g							Microminerals, mg							
		Ca	P	Ca:P	Mg	Na	K	S	Cu	Co	Cr	Fe	Mn	Mo	Se	Zn
210	0.3	10.65	7.11	1.50	3.74	4.69	11.24	3.91	29.96	3.28	8.07	855.58	91.25	1.40	2.04	146.76
	0.8	21.44	12.10	1.77	4.16	6.60	13.02	5.77	34.48	3.30	11.38	879.24	96.04	1.43	2.78	217.82
	1.3	32.35	17.15	1.89	4.59	8.53	14.82	7.64	39.05	3.32	14.71	903.15	100.88	1.46	3.53	289.60
	1.8	43.31	22.22	1.95	5.01	10.48	16.63	9.52	43.64	3.35	18.07	927.19	105.74	1.48	4.28	361.81
270	0.3	11.38	8.12	1.40	4.72	5.69	14.24	5.00	38.00	4.21	10.16	1096.97	117.18	1.79	2.49	187.30
	0.8	21.31	12.79	1.67	5.12	7.57	16.18	7.34	42.93	4.23	14.03	1122.16	123.08	1.83	3.22	276.26
	1.3	31.33	17.52	1.79	5.52	9.48	18.14	9.71	47.91	4.26	17.95	1147.61	129.04	1.86	3.95	366.14
	1.8	41.42	22.27	1.86	5.92	11.39	20.11	12.08	52.91	4.28	21.89	1173.22	135.04	1.89	4.69	456.55
330	0.3	12.24	9.17	1.33	5.71	6.69	17.24	6.09	46.01	5.15	12.22	1338.22	143.08	2.19	2.94	227.58
	0.8	21.52	13.61	1.58	6.08	8.56	19.31	8.91	51.29	5.17	16.62	1364.71	150.05	2.23	3.66	334.04
	1.3	30.90	18.10	1.71	6.46	10.44	21.40	11.75	56.62	5.19	21.07	1391.47	157.10	2.26	4.38	441.59
	1.8	40.34	22.61	1.78	6.85	12.33	23.50	14.62	61.98	5.21	25.54	1418.38	164.18	2.30	5.11	549.78
390	0.3	13.18	10.26	1.29	6.69	7.70	20.22	7.17	54.00	6.08	14.26	1579.37	168.96	2.59	3.39	267.67
	0.8	21.96	14.51	1.51	7.06	9.54	22.41	10.46	59.59	6.10	19.15	1606.99	176.97	2.62	4.10	391.29
	1.3	30.84	18.80	1.64	7.42	11.41	24.62	13.78	65.23	6.12	24.10	1634.88	185.07	2.66	4.82	516.17
	1.8	39.76	23.12	1.72	7.79	13.28	26.85	17.13	70.91	6.15	29.07	1662.95	193.21	2.70	5.54	641.80
450	0.3	14.18	11.36	1.25	7.68	8.71	23.19	8.25	61.97	7.01	16.29	1820.45	194.82	2.98	3.85	307.60
	0.8	22.55	15.46	1.46	8.03	10.54	25.49	12.01	67.84	7.03	21.65	1849.07	203.85	3.02	4.55	448.10
	1.3	31.01	19.59	1.58	8.39	12.38	27.81	15.80	73.77	7.06	27.06	1877.98	212.97	3.06	5.26	590.04
	1.8	39.52	23.76	1.66	8.74	14.24	30.14	19.62	79.73	7.08	32.51	1907.07	222.14	3.10	5.97	732.82
510	0.3	15.21	12.48	1.22	8.67	9.72	26.17	9.33	69.93	7.94	18.30	2061.47	220.67	3.38	4.30	347.39
	0.8	23.25	16.44	1.41	9.01	11.54	28.56	13.55	76.05	7.97	24.10	2091.00	230.69	3.42	5.00	504.54
	1.3	31.36	20.45	1.53	9.36	13.37	30.98	17.80	82.24	7.99	29.96	2120.83	240.81	3.46	5.70	663.29
	1.8	39.52	24.48	1.61	9.70	15.21	33.41	22.09	88.47	8.01	35.86	2150.84	250.99	3.50	6.41	822.99
570	0.3	11.74	11.35	1.03	9.67	10.73	29.13	10.41	77.87	8.88	20.30	2302.45	246.51	3.78	4.76	387.06
	0.8	11.74	11.35	1.03	10.00	12.54	31.62	15.08	84.23	8.90	26.53	2332.81	257.50	3.82	5.45	560.65
	1.3	11.74	11.35	1.03	10.33	14.35	34.13	19.80	90.67	8.92	32.82	2363.48	268.61	3.86	6.14	736.00
	1.8	11.74	11.35	1.03	10.66	16.18	36.65	24.55	97.13	8.94	39.15	2394.33	279.77	3.91	6.84	912.41
630	0.3	12.98	12.54	1.03	10.66	11.75	32.09	11.48	85.80	9.81	22.29	2543.39	272.35	4.17	5.21	426.63
	0.8	12.98	12.54	1.03	10.98	13.54	34.66	16.61	92.39	9.83	28.93	2574.52	284.29	4.22	5.90	616.47
	1.3	12.98	12.54	1.03	11.30	15.35	37.26	21.78	99.05	9.85	35.63	2605.96	296.35	4.26	6.59	808.25
	1.8	12.98	12.54	1.03	11.63	17.16	39.87	26.99	105.74	9.88	42.37	2637.60	308.49	4.31	7.28	1001.18

*BW = body weight; ADG = average daily gain; Ca = calcium; P = phosphorus; Ca:P = ratio calcium/phosphorus; Mg = magnesium; Na = sodium; K = potassium; S = sulfur; Cu = copper; Co = cobalt; Cr = chromium; Fe = iron; Mn = manganese; Mo = molybdenum; Se = selenium; Zn = zinc.

Table 17.9c - Metabolizable amino acids requirements for **CROSSBRED** dairy cattle, **BULLS** in a **FEEDLOT** system

Average BW kg	ADG kg	Essentials, g										Non-Essentials, g							
		Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val	Ala	Asp	Cys	Glu	Gly	Pro	Ser	Tyr
330	0.3	6.23	2.31	6.34	11.60	9.39	1.69	5.76	5.52	0.96	5.92	9.59	12.64	8.10	9.39	8.10	7.92	6.26	5.30
	0.8	16.86	6.25	17.15	31.39	25.41	4.57	15.60	14.93	2.61	16.03	25.96	34.21	21.93	25.42	21.93	21.44	16.95	14.34
	1.3	27.60	10.23	28.08	51.39	41.60	7.49	25.54	24.45	4.27	26.25	42.50	56.00	35.90	41.62	35.90	35.10	27.74	23.48
	1.8	38.40	14.23	39.07	71.50	57.88	10.42	35.53	34.01	5.94	36.52	59.14	77.92	49.96	57.91	49.96	48.85	38.60	32.67
390	0.3	6.06	2.33	6.27	11.40	9.31	1.67	5.70	5.46	0.96	5.90	9.28	12.37	7.73	9.24	7.73	7.59	6.10	5.25
	0.8	16.39	6.31	16.97	30.85	25.21	4.51	15.43	14.77	2.59	15.96	25.13	33.47	20.93	25.01	20.93	20.55	16.51	14.21
	1.3	26.83	10.33	27.77	50.50	41.26	7.38	25.26	24.17	4.25	26.13	41.13	54.80	34.25	40.94	34.25	33.64	27.02	23.26
	1.8	37.33	14.37	38.64	70.27	57.41	10.27	35.15	33.63	5.91	36.36	57.23	76.25	47.66	56.97	47.66	46.81	37.60	32.37
450	0.3	5.91	2.35	6.21	11.23	9.25	1.65	5.65	5.40	0.95	5.88	9.03	12.14	7.43	9.11	7.43	7.32	5.96	5.21
	0.8	16.00	6.36	16.81	30.40	25.03	4.46	15.29	14.62	2.58	15.91	24.43	32.86	20.10	24.66	20.10	19.81	16.14	14.10
	1.3	26.18	10.41	27.51	49.76	40.98	7.30	25.02	23.94	4.23	26.04	39.99	53.79	32.90	40.37	32.90	32.44	26.42	23.08
	1.8	36.43	14.49	38.28	69.24	57.02	10.15	34.82	33.31	5.88	36.23	55.65	74.84	45.78	56.17	45.78	45.13	36.77	32.12
510	0.3	5.79	2.37	6.16	11.09	9.19	1.63	5.60	5.36	0.95	5.86	8.81	11.94	7.17	9.00	7.17	7.09	5.85	5.17
	0.8	15.66	6.41	16.67	30.01	24.88	4.41	15.16	14.50	2.57	15.85	23.84	32.33	19.40	24.36	19.40	19.19	15.83	14.00
	1.3	25.63	10.49	27.29	49.12	40.73	7.22	24.82	23.74	4.21	25.95	39.02	52.92	31.76	39.88	31.76	31.42	25.91	22.92
	1.8	35.67	14.60	37.97	68.35	56.67	10.05	34.53	33.03	5.86	36.11	54.30	73.63	44.19	55.49	44.19	43.72	36.05	31.90
570	0.3	5.68	2.38	6.11	10.96	9.14	1.61	5.56	5.32	0.95	5.84	8.62	11.77	6.95	8.90	6.95	6.89	5.75	5.14
	0.8	15.37	6.45	16.55	29.66	24.75	4.37	15.05	14.39	2.56	15.81	23.32	31.86	18.80	24.10	18.80	18.66	15.55	13.92
	1.3	25.16	10.56	27.09	48.56	40.51	7.15	24.64	23.56	4.20	25.88	38.18	52.16	30.78	39.45	30.78	30.54	25.46	22.78
	1.8	35.00	14.69	37.69	67.56	56.37	9.95	34.28	32.78	5.84	36.01	53.13	72.58	42.83	54.89	42.83	42.49	35.43	31.70
630	0.3	5.58	2.40	6.07	10.85	9.10	1.60	5.53	5.28	0.94	5.83	8.45	11.62	6.75	8.82	6.75	6.72	5.66	5.11
	0.8	15.11	6.49	16.44	29.36	24.63	4.33	14.95	14.29	2.56	15.77	22.87	31.45	18.28	23.86	18.28	18.19	15.31	13.84
	1.3	24.73	10.62	26.91	48.05	40.32	7.09	24.48	23.40	4.18	25.81	37.44	51.49	29.92	39.06	29.92	29.77	25.06	22.66
	1.8	34.41	14.78	37.44	66.86	56.10	9.87	34.06	32.56	5.82	35.91	52.10	71.64	41.64	54.35	41.64	41.42	34.87	31.53

*BW = body weight; ADG = average daily gain; Arg = Arginine; His = histidine; Ile = isoleucine; Leu = leucine; Lys = lysine; Met = methionine; Phe = phenylanine; Thr = threonine; Trp = tryptophan; Val = valine; Ala = alanine; Asp = aspartic acid; Cys = cystine; Glu = glutamic acid; Gly = glycine; Pro = proline; Ser = serine; Tyr = tyrosine.

Table 17.10a - Nutritional requirements of **CROSSBRED** dairy cattle, **STEERS** in **FEEDLOT** system

Average BW kg	ADG kg	DMI, kg	Intake of water[1], L		Energy			Protein					
			Summer	Winter	ME, Mcal	TDN, kg	TDN, %	RDP, g	RUP, g	CP, g	CP,%	RDP, % CP	RUP, % CP
210	0.3	3.0	8.8	10.5	8.4	2.2	73.5	250	130	379	12.5	65.8	34.2
	0.8	4.8	9.7	11.4	12.1	3.2	68.2	377	175	553	11.6	68.3	31.7
	1.3	6.0	10.3	12.0	15.9	4.3	70.8	498	228	725	12.1	68.6	31.4
	1.8	6.8	10.6	12.4	19.7	5.2	77.3	610	287	897	13.2	68.0	32.0
270	0.3	4.0	11.5	13.2	9.9	2.7	66.9	304	144	448	11.2	67.9	32.1
	0.8	5.7	12.3	14.0	14.1	3.8	66.4	440	193	634	11.1	69.5	30.5
	1.3	7.0	12.9	14.6	18.4	4.9	70.6	568	251	819	11.7	69.3	30.7
	1.8	7.7	13.3	15.0	22.7	6.0	77.9	687	317	1004	13.0	68.4	31.6
330	0.3	4.9	14.0	15.7	11.4	3.1	63.1	355	159	515	10.5	69.1	30.9
	0.8	6.6	14.8	16.5	16.0	4.3	65.3	500	216	717	10.8	69.8	30.2
	1.3	7.9	15.4	17.1	20.8	5.6	70.6	635	283	918	11.6	69.2	30.8
	1.8	8.7	15.8	17.5	25.6	6.8	78.4	760	358	1118	12.9	67.9	32.1
390	0.3	5.8	16.4	18.1	12.9	3.5	60.7	403	175	578	10.0	69.8	30.2
	0.8	7.5	17.2	18.9	17.9	4.9	64.5	556	239	796	10.6	69.9	30.1
	1.3	8.8	17.8	19.5	23.1	6.2	70.7	698	314	1012	11.6	68.9	31.1
	1.8	9.5	18.2	19.9	28.4	7.5	78.9	826	400	1226	12.9	67.4	32.6
450	0.3	6.6	18.7	20.4	14.2	3.9	58.9	445	183	628	9.5	70.9	29.1
	0.8	8.4	19.5	21.2	19.7	5.3	64.0	599	242	842	10.1	71.2	28.8
	1.3	9.6	20.1	21.8	25.3	6.8	70.8	740	313	1053	11.0	70.3	29.7
	1.8	10.4	20.5	22.2	31.1	8.2	79.4	867	395	1262	12.2	68.7	31.3
510	0.3	7.4	20.9	22.6	15.6	4.3	57.7	485	192	677	9.1	71.7	28.3
	0.8	9.2	21.7	23.4	21.5	5.8	63.6	640	246	886	9.7	72.3	27.7
	1.3	10.4	22.3	24.1	27.5	7.4	70.9	779	313	1092	10.5	71.4	28.6
	1.8	11.2	22.7	24.4	33.7	8.9	79.8	903	393	1296	11.6	69.7	30.3
570	0.3	8.2	23.0	24.8	16.9	4.7	56.7	523	201	723	8.8	72.3	27.7
	0.8	10.0	23.9	25.6	23.2	6.3	63.3	678	250	928	9.3	73.0	27.0
	1.3	11.2	24.5	26.2	29.7	8.0	71.0	815	314	1130	10.1	72.2	27.8
	1.8	12.0	24.9	26.6	36.3	9.6	80.2	935	393	1328	11.1	70.4	29.6
630	0.3	9.0	25.1	26.9	18.2	5.0	55.9	559	210	769	8.6	72.7	27.3
	0.8	10.7	26.0	27.7	24.9	6.8	63.1	713	256	969	9.0	73.6	26.4
	1.3	12.0	26.6	28.3	31.8	8.5	71.2	849	317	1166	9.7	72.8	27.2
	1.8	12.7	27.0	28.7	38.8	10.3	80.6	963	396	1359	10.7	70.9	29.1

*BW = body weight; ADG = average daily gain; DMI = dry matter intake; ME = metabolizable energy; TDN = total digestible nutrients; CP = crude protein; RDP = rumen degradable protein; RUP = rumen undegradable protein. [1]Winter = 22°C of maximum temperature and 65% of relative humidity; Summer = 29°C of maximum temperature and 79% of relative humidity.

Table 17.10b - Minerals requirements for **CROSSBRED** dairy cattle, **STEERS** in a **FEEDLOT** system

Average BW	ADG	Macrominerals, g							Microminerals, mg							
kg	kg	Ca	P	Ca:P	Mg	Na	K	S	Cu	Co	Cr	Fe	Mn	Mo	Se	Zn
210	0.3	10.65	7.11	1.50	3.74	4.69	11.24	3.91	29.96	3.28	8.07	855.59	91.26	1.40	2.04	146.85
	0.8	21.43	12.10	1.77	4.16	6.60	13.02	5.77	34.49	3.30	11.38	879.27	96.06	1.43	2.78	218.06
	1.3	32.32	17.14	1.89	4.59	8.53	14.83	7.65	39.05	3.32	14.73	903.18	100.90	1.46	3.53	290.00
	1.8	43.28	22.21	1.95	5.01	10.47	16.64	9.54	43.65	3.35	18.09	927.24	105.78	1.48	4.28	362.37
270	0.3	11.37	8.11	1.40	4.72	5.69	14.25	5.01	38.01	4.21	10.17	1097.00	117.20	1.79	2.49	187.62
	0.8	21.27	12.78	1.66	5.12	7.57	16.19	7.37	42.95	4.23	14.06	1122.23	123.13	1.83	3.22	277.14
	1.3	31.27	17.50	1.79	5.51	9.47	18.15	9.75	47.94	4.26	17.99	1147.73	129.13	1.86	3.95	367.57
	1.8	41.34	22.24	1.86	5.92	11.39	20.12	12.14	52.95	4.28	21.95	1173.38	135.16	1.89	4.69	458.55
330	0.3	12.22	9.17	1.33	5.70	6.69	17.24	6.11	46.03	5.15	12.24	1338.26	143.11	2.19	2.94	228.17
	0.8	21.47	13.59	1.58	6.08	8.55	19.32	8.95	51.32	5.17	16.67	1364.82	150.15	2.23	3.66	335.64
	1.3	30.82	18.07	1.71	6.46	10.43	21.42	11.83	56.67	5.19	21.15	1391.65	157.25	2.26	4.38	444.21
	1.8	40.22	22.56	1.78	6.84	12.32	23.53	14.72	62.05	5.21	25.65	1418.64	164.40	2.30	5.11	553.42
390	0.3	13.16	10.25	1.28	6.69	7.70	20.22	7.20	54.02	6.08	14.28	1579.43	169.01	2.59	3.39	268.56
	0.8	21.90	14.48	1.51	7.05	9.54	22.42	10.53	59.63	6.10	19.22	1607.13	177.12	2.62	4.10	393.68
	1.3	30.73	18.76	1.64	7.42	11.40	24.65	13.89	65.30	6.12	24.21	1635.13	185.30	2.66	4.82	520.08
	1.8	39.62	23.07	1.72	7.78	13.27	26.88	17.28	71.01	6.14	29.23	1663.29	193.54	2.70	5.54	647.24
450	0.3	14.15	11.35	1.25	7.68	8.71	23.20	8.29	61.99	7.01	16.32	1820.52	194.89	2.98	3.85	308.80
	0.8	22.48	15.43	1.46	8.03	10.54	25.51	12.10	67.89	7.03	21.73	1849.25	204.04	3.02	4.55	451.34
	1.3	30.90	19.55	1.58	8.38	12.38	27.84	15.95	73.85	7.06	27.20	1878.28	213.28	3.06	5.26	595.33
	1.8	39.36	23.69	1.66	8.74	14.23	30.19	19.82	79.85	7.08	32.71	1907.48	222.58	3.10	5.97	740.19
510	0.3	15.18	12.47	1.22	8.67	9.72	26.17	9.37	69.95	7.94	18.34	2061.55	220.76	3.38	4.30	348.92
	0.8	23.17	16.41	1.41	9.01	11.53	28.58	13.66	76.11	7.97	24.21	2091.22	230.94	3.42	5.00	508.66
	1.3	31.23	20.40	1.53	9.35	13.36	31.02	17.99	82.34	7.99	30.14	2121.18	241.21	3.46	5.70	670.04
	1.8	39.35	24.41	1.61	9.69	15.20	33.46	22.35	88.61	8.01	36.11	2151.33	251.55	3.51	6.40	832.38
570	0.3	11.74	11.35	1.03	9.67	10.73	29.14	10.46	77.90	8.88	20.35	2302.54	246.62	3.78	4.76	388.93
	0.8	11.74	11.35	1.03	9.99	12.53	31.64	15.22	84.31	8.90	26.65	2333.06	257.80	3.82	5.45	565.70
	1.3	11.74	11.35	1.03	10.32	14.35	34.17	20.03	90.78	8.92	33.03	2363.88	269.09	3.86	6.14	744.28
	1.8	11.74	11.35	1.03	10.66	16.18	36.71	24.87	97.30	8.94	39.44	2394.89	280.45	3.91	6.84	923.93
630	0.3	12.98	12.54	1.03	10.66	11.75	32.11	11.54	85.83	9.81	22.35	2543.49	272.48	4.17	5.21	428.85
	0.8	12.98	12.54	1.03	10.98	13.53	34.69	16.77	92.47	9.83	29.08	2574.79	284.64	4.22	5.90	622.49
	1.3	12.98	12.54	1.03	11.30	15.34	37.31	22.06	99.18	9.85	35.87	2606.41	296.93	4.26	6.59	818.11
	1.8	12.98	12.54	1.03	11.62	17.16	39.94	27.38	105.92	9.88	42.71	2638.22	309.29	4.31	7.28	1014.90

*BW = body weight; ADG = average daily gain; Ca = calcium; P = phosphorus; Ca:P = ratio calcium/phosphorus; Mg = magnesium; Na = sodium; K = potassium; S = sulfur; Cu = copper; Co = cobalt; Cr = chromium; Fe = iron; Mn = manganese; Mo = molybdenum; Se = selenium; Zn = zinc.

Table 17.10c - Metabolizable amino acids requirements for **CROSSBRED** dairy cattle, **STEERS** in a **FEEDLOT** system

Average BW kg	ADG kg	Essentials, g										Non-Essentials, g							
		Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val	Ala	Asp	Cys	Glu	Gly	Pro	Ser	Tyr
330	0.3	6.22	2.31	6.33	11.59	9.38	1.69	5.76	5.51	0.96	5.92	9.57	12.62	8.08	9.38	8.08	7.90	6.25	5.30
	0.8	16.83	6.25	17.14	31.36	25.40	4.57	15.59	14.92	2.61	16.03	25.91	34.16	21.87	25.40	21.87	21.39	16.92	14.33
	1.3	27.55	10.24	28.06	51.33	41.57	7.48	25.52	24.43	4.27	26.24	42.41	55.92	35.80	41.57	35.80	35.01	27.70	23.46
	1.8	38.33	14.24	39.04	71.42	57.85	10.41	35.51	33.99	5.94	36.51	59.02	77.81	49.81	57.85	49.81	48.71	38.54	32.65
390	0.3	6.04	2.33	6.26	11.38	9.31	1.66	5.70	5.45	0.96	5.90	9.26	12.35	7.70	9.23	7.70	7.57	6.09	5.25
	0.8	16.35	6.31	16.95	30.81	25.19	4.51	15.42	14.75	2.59	15.96	25.06	33.42	20.85	24.98	20.85	20.48	16.47	14.20
	1.3	26.77	10.34	27.75	50.43	41.23	7.38	25.24	24.15	4.24	26.12	41.02	54.70	34.12	40.89	34.12	33.53	26.97	23.25
	1.8	37.24	14.38	38.61	70.18	57.38	10.26	35.12	33.60	5.91	36.35	57.08	76.11	47.48	56.89	47.48	46.65	37.52	32.34
450	0.3	5.89	2.35	6.20	11.21	9.24	1.64	5.64	5.40	0.95	5.87	9.00	12.12	7.39	9.10	7.39	7.29	5.95	5.21
	0.8	15.95	6.37	16.79	30.35	25.01	4.45	15.27	14.61	2.58	15.90	24.35	32.79	20.01	24.62	20.01	19.73	16.10	14.09
	1.3	26.11	10.42	27.48	49.68	40.95	7.29	25.00	23.91	4.23	26.03	39.87	53.67	32.75	40.31	32.75	32.30	26.36	23.06
	1.8	36.34	14.50	38.24	69.12	56.97	10.14	34.78	33.27	5.88	36.21	55.47	74.68	45.57	56.08	45.57	44.95	36.67	32.09
510	0.3	5.77	2.37	6.15	11.07	9.19	1.63	5.60	5.35	0.95	5.86	8.78	11.92	7.13	8.98	7.13	7.06	5.83	5.17
	0.8	15.61	6.42	16.65	29.95	24.86	4.40	15.14	14.48	2.57	15.85	23.75	32.25	19.30	24.32	19.30	19.10	15.78	13.99
	1.3	25.56	10.50	27.25	49.03	40.69	7.21	24.79	23.71	4.21	25.94	38.88	52.79	31.60	39.81	31.60	31.27	25.83	22.90
	1.8	35.56	14.61	37.92	68.22	56.62	10.03	34.49	32.99	5.86	36.09	54.10	73.46	43.96	55.39	43.96	43.51	35.95	31.87
570	0.3	5.66	2.39	6.11	10.94	9.14	1.61	5.55	5.31	0.95	5.84	8.58	11.74	6.91	8.89	6.91	6.86	5.73	5.14
	0.8	15.31	6.46	16.53	29.60	24.72	4.36	15.03	14.37	2.56	15.80	23.23	31.78	18.70	24.05	18.70	18.56	15.50	13.90
	1.3	25.07	10.57	27.05	48.45	40.47	7.14	24.61	23.53	4.19	25.86	38.03	52.02	30.60	39.37	30.60	30.38	25.38	22.76
	1.8	34.88	14.71	37.64	67.42	56.32	9.94	34.24	32.73	5.83	35.99	52.92	72.39	42.58	54.78	42.58	42.27	35.31	31.67
630	0.3	5.56	2.40	6.07	10.82	9.09	1.60	5.52	5.27	0.94	5.82	8.41	11.59	6.71	8.80	6.71	6.68	5.64	5.11
	0.8	15.05	6.50	16.42	29.29	24.60	4.33	14.93	14.27	2.55	15.76	22.77	31.36	18.17	23.81	18.17	18.08	15.26	13.83
	1.3	24.64	10.63	26.87	47.94	40.27	7.08	24.44	23.36	4.18	25.80	37.28	51.34	29.74	38.98	29.74	29.60	24.98	22.63
	1.8	34.28	14.80	37.39	66.71	56.04	9.85	34.01	32.51	5.82	35.89	51.87	71.43	41.38	54.23	41.38	41.19	34.75	31.49

*BW = body weight; ADG = average daily gain; Arg = Arginine; His = histidine; Ile = isoleucine; Leu = leucine; Lys = lysine; Met = methionine; Phe = phenylanine; Thr = threonine; Trp = tryptophan; Val = valine; Ala = alanine; Asp = aspartic acid; Cys = cystine; Glu = glutamic acid; Gly = glycine; Pro = proline; Ser = serine; Tyr = tyrosine.

Table 17.11a - Nutritional requirements of **CROSSBRED** dairy cattle, **HEIFERS** in **FEEDLOT** system

Average BW kg	ADG kg	DMI kg	Intake of water[1], L		Energy			Protein					
			Summer	Winter	ME, Mcal	TDN, kg	TDN, %	RDP, g	RUP, g	CP, g	CP,%	RDP, % CP	RUP, % CP
210	0.3	3.0	8.8	10.5	8.5	2.3	74.4	253	129	382	12.6	66.2	33.8
	0.8	4.8	9.7	11.4	12.3	3.3	69.5	384	175	559	11.7	68.7	31.3
	1.3	6.0	10.3	12.0	16.3	4.4	72.5	507	228	736	12.2	69.0	31.0
	1.8	6.8	10.6	12.4	20.3	5.4	79.3	622	289	911	13.5	68.3	31.7
270	0.3	4.0	11.5	13.2	10.1	2.7	67.9	308	143	452	11.3	68.3	31.7
	0.8	5.7	12.3	14.0	14.4	3.9	67.9	449	195	644	11.2	69.7	30.3
	1.3	7.0	12.9	14.6	18.9	5.1	72.5	581	255	836	12.0	69.5	30.5
	1.8	7.7	13.3	15.0	23.5	6.2	80.2	703	324	1026	13.3	68.5	31.5
330	0.3	4.9	14.0	15.7	11.6	3.2	64.2	361	160	521	10.6	69.3	30.7
	0.8	6.6	14.8	16.5	16.5	4.4	66.9	512	221	733	11.0	69.8	30.2
	1.3	7.9	15.4	17.1	21.5	5.7	72.7	652	292	945	12.0	69.1	30.9
	1.8	8.7	15.8	17.5	26.5	7.0	80.9	781	373	1154	13.3	67.7	32.3
390	0.3	5.8	16.4	18.1	13.1	3.6	61.8	407	170	578	10.0	70.6	29.4
	0.8	7.5	17.2	18.9	18.4	5.0	66.2	563	230	793	10.6	71.0	29.0
	1.3	8.8	17.8	19.5	23.9	6.4	72.9	706	301	1006	11.5	70.1	29.9
	1.8	9.5	18.2	19.9	29.5	7.8	81.6	835	383	1218	12.8	68.6	31.4
450	0.3	6.6	18.7	20.4	14.5	4.0	60.1	450	177	628	9.5	71.7	28.3
	0.8	8.4	19.5	21.2	20.3	5.5	65.8	607	231	838	10.0	72.4	27.6
	1.3	9.6	20.1	21.8	26.3	7.0	73.1	749	298	1046	10.9	71.6	28.4
	1.8	10.4	20.5	22.2	32.3	8.5	82.3	875	377	1252	12.1	69.9	30.1
510	0.3	7.4	20.9	22.6	15.9	4.4	58.8	490	185	676	9.1	72.6	27.4
	0.8	9.2	21.7	23.4	22.2	6.0	65.5	648	234	882	9.6	73.5	26.5
	1.3	10.4	22.3	24.1	28.6	7.6	73.3	788	296	1085	10.4	72.7	27.3
	1.8	11.2	22.7	24.4	35.1	9.3	82.9	911	374	1284	11.5	70.9	29.1
570	0.3	8.2	23.0	24.8	17.3	4.8	57.9	528	194	722	8.8	73.2	26.8
	0.8	10.0	23.9	25.6	24.0	6.5	65.2	686	238	924	9.3	74.3	25.7
	1.3	11.2	24.5	26.2	30.9	8.2	73.6	824	297	1121	10.0	73.5	26.5
	1.8	12.0	24.9	26.6	37.9	10.0	83.4	942	373	1315	11.0	71.6	28.4
630	0.3	9.0	25.1	26.9	18.7	5.1	57.2	565	203	768	8.5	73.6	26.4
	0.8	10.7	26.0	27.7	25.8	7.0	65.1	722	242	964	9.0	74.9	25.1
	1.3	12.0	26.6	28.3	33.1	8.8	73.8	857	299	1157	9.7	74.1	25.9
	1.8	12.7	27.0	28.7	40.6	10.7	83.9	969	375	1344	10.6	72.1	27.9

*BW = body weight; ADG = average daily gain; DMI = dry matter intake; ME = metabolizable energy; TDN = total digestible nutrients; CP = crude protein; RDP = rumen degradable protein; RUP = rumen undegradable protein. [1]Winter = 22°C of maximum temperature and 65% of relative humidity; Summer = 29°C of maximum temperature and 79% of relative humidity.

Table 17.11b - Minerals requirements for **CROSSBRED** dairy cattle, **HEIFERS** in a **FEEDLOT** system

Average BW	ADG	Macrominerals, g							Microminerals, mg							
kg	kg	Ca	P	Ca:P	Mg	Na	K	S	Cu	Co	Cr	Fe	Mn	Mo	Se	Zn
210	0.3	10.62	7.10	1.50	3.74	4.69	11.25	3.93	29.98	3.28	8.09	855.63	91.29	1.40	2.04	147.31
	0.8	21.36	12.07	1.77	4.16	6.60	13.04	5.81	34.52	3.30	11.42	879.38	96.13	1.43	2.78	219.29
	1.3	32.21	17.10	1.88	4.58	8.53	14.84	7.70	39.10	3.32	14.79	903.37	101.03	1.46	3.53	292.01
	1.8	43.13	22.15	1.95	5.01	10.47	16.66	9.61	43.72	3.35	18.18	927.50	105.95	1.48	4.28	365.16
270	0.3	11.34	8.10	1.40	4.72	5.69	14.25	5.03	38.03	4.21	10.19	1097.05	117.24	1.80	2.49	188.31
	0.8	21.19	12.75	1.66	5.11	7.57	16.20	7.42	42.99	4.23	14.12	1122.38	123.25	1.83	3.21	279.00
	1.3	31.15	17.45	1.78	5.51	9.47	18.18	9.83	48.00	4.26	18.09	1147.97	129.32	1.86	3.95	370.63
	1.8	41.17	22.18	1.86	5.91	11.38	20.16	12.25	53.04	4.28	22.08	1173.71	135.42	1.89	4.69	462.80
330	0.3	12.19	9.15	1.33	5.70	6.69	17.25	6.13	46.04	5.15	12.26	1338.33	143.17	2.19	2.94	229.12
	0.8	21.39	13.56	1.58	6.08	8.55	19.34	9.02	51.37	5.17	16.74	1364.99	150.30	2.23	3.66	338.19
	1.3	30.69	18.02	1.70	6.46	10.43	21.45	11.94	56.75	5.19	21.27	1391.93	157.51	2.26	4.38	448.38
	1.8	40.04	22.50	1.78	6.84	12.32	23.57	14.88	62.16	5.21	25.82	1419.03	164.76	2.30	5.11	559.23
390	0.3	13.13	10.24	1.28	6.69	7.70	20.23	7.23	54.04	6.08	14.32	1579.50	169.08	2.59	3.39	269.76
	0.8	21.82	14.45	1.51	7.05	9.54	22.45	10.62	59.69	6.10	19.31	1607.34	177.31	2.63	4.10	396.95
	1.3	30.60	18.71	1.64	7.41	11.40	24.68	14.04	65.39	6.12	24.36	1635.46	185.62	2.66	4.81	525.43
	1.8	39.43	23.00	1.71	7.78	13.27	26.93	17.48	71.14	6.14	29.43	1663.74	193.99	2.70	5.53	654.68
450	0.3	14.12	11.34	1.25	7.68	8.71	23.21	8.33	62.01	7.01	16.36	1820.60	194.98	2.98	3.85	310.28
	0.8	22.39	15.40	1.45	8.03	10.53	25.53	12.21	67.95	7.03	21.84	1849.48	204.28	3.02	4.55	455.35
	1.3	30.75	19.49	1.58	8.38	12.37	27.88	16.13	73.96	7.06	27.38	1878.65	213.68	3.06	5.25	601.91
	1.8	39.16	23.62	1.66	8.73	14.23	30.24	20.07	80.00	7.08	32.95	1908.00	223.13	3.10	5.96	749.33
510	0.3	10.51	12.45	0.84	8.67	9.72	26.18	9.42	69.97	7.94	18.38	2061.64	220.87	3.38	4.30	350.69
	0.8	10.51	16.38	0.64	9.01	11.53	28.61	13.79	76.18	7.97	24.33	2091.46	231.22	3.42	4.99	513.45
	1.3	10.51	20.34	0.52	9.35	13.36	31.06	18.21	82.46	7.99	30.34	2121.59	241.68	3.46	5.69	677.88
	1.8	10.51	24.33	0.43	9.69	15.19	33.52	22.65	88.77	8.01	36.39	2151.89	252.20	3.51	6.40	843.29
570	0.3	11.74	11.35	1.03	9.66	10.73	29.15	10.52	77.92	8.88	20.40	2302.64	246.75	3.78	4.76	390.99
	0.8	11.74	11.35	1.03	9.99	12.53	31.67	15.38	84.38	8.90	26.80	2333.32	258.13	3.82	5.44	571.29
	1.3	11.74	11.35	1.03	10.32	14.34	34.22	20.28	90.91	8.92	33.26	2364.32	269.63	3.86	6.14	753.42
	1.8	11.74	11.35	1.03	10.65	16.17	36.78	25.22	97.47	8.94	39.76	2395.50	281.20	3.91	6.84	936.65
630	0.3	12.98	12.54	1.03	10.66	11.74	32.12	11.61	85.86	9.81	22.40	2543.60	272.61	4.17	5.21	431.22
	0.8	12.98	12.54	1.03	10.97	13.53	34.72	16.95	92.55	9.83	29.23	2575.08	285.01	4.22	5.89	628.89
	1.3	12.98	12.54	1.03	11.30	15.33	37.36	22.35	99.31	9.85	36.13	2606.88	297.54	4.26	6.58	828.58
	1.8	12.98	12.54	1.03	11.62	17.15	40.01	27.78	106.11	9.88	43.07	2638.87	310.14	4.31	7.28	1029.47

*BW = body weight; ADG = average daily gain; Ca = calcium; P = phosphorus; Ca:P = ratio calcium/phosphorus; Mg = magnesium; Na = sodium; K = potassium; S = sulfur; Cu = copper; Co = cobalt; Cr = chromium; Fe = iron; Mn = manganese; Mo = molybdenum; Se = selenium; Zn = zinc.

Table 17.11c - Metabolizable amino acids requirements for **CROSSBRED** dairy cattle, **HEIFERS** in a **FEEDLOT** system

Average BW kg	ADG kg	Essentials, g										Non-Essentials, g							
		Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val	Ala	Asp	Cys	Glu	Gly	Pro	Ser	Tyr
330	0.3	6.20	2.31	6.33	11.57	9.38	1.69	5.75	5.51	0.96	5.92	9.54	12.60	8.04	9.37	8.04	7.87	6.24	5.29
	0.8	16.78	6.26	17.12	31.30	25.38	4.56	15.57	14.91	2.61	16.02	25.83	34.09	21.77	25.35	21.77	21.30	16.87	14.32
	1.3	27.47	10.25	28.03	51.24	41.54	7.47	25.49	24.40	4.27	26.23	42.28	55.80	35.63	41.50	35.63	34.86	27.62	23.44
	1.8	38.23	14.26	39.00	71.30	57.80	10.39	35.47	33.95	5.93	36.50	58.82	77.64	49.58	57.75	49.58	48.51	38.44	32.62
390	0.3	6.02	2.34	6.26	11.36	9.30	1.66	5.69	5.44	0.96	5.89	9.23	12.32	7.66	9.21	7.66	7.53	6.07	5.24
	0.8	16.30	6.32	16.93	30.75	25.17	4.50	15.40	14.73	2.59	15.95	24.97	33.34	20.74	24.93	20.74	20.39	16.43	14.19
	1.3	26.68	10.35	27.71	50.34	41.20	7.36	25.21	24.12	4.24	26.11	40.88	54.57	33.95	40.81	33.95	33.37	26.89	23.22
	1.8	37.13	14.40	38.56	70.04	57.32	10.25	35.07	33.56	5.90	36.33	56.88	75.93	47.24	56.79	47.24	46.43	37.41	32.31
450	0.3	5.87	2.36	6.20	11.19	9.23	1.64	5.64	5.39	0.95	5.87	8.96	12.08	7.35	9.08	7.35	7.25	5.93	5.20
	0.8	15.90	6.38	16.77	30.29	24.99	4.44	15.25	14.59	2.58	15.89	24.26	32.71	19.90	24.58	19.90	19.64	16.05	14.07
	1.3	26.03	10.44	27.45	49.58	40.91	7.27	24.97	23.88	4.22	26.01	39.71	53.54	32.57	40.23	32.57	32.14	26.27	23.04
	1.8	36.21	14.52	38.19	68.98	56.92	10.12	34.74	33.23	5.88	36.20	55.26	74.49	45.32	55.98	45.32	44.72	36.56	32.05
510	0.3	5.75	2.37	6.14	11.04	9.18	1.62	5.59	5.34	0.95	5.85	8.74	11.88	7.09	8.97	7.09	7.02	5.81	5.16
	0.8	15.56	6.42	16.63	29.88	24.83	4.40	15.12	14.46	2.57	15.84	23.66	32.16	19.19	24.27	19.19	19.00	15.73	13.97
	1.3	25.46	10.51	27.22	48.92	40.65	7.20	24.76	23.67	4.21	25.93	38.72	52.65	31.41	39.72	31.41	31.10	25.75	22.87
	1.8	35.43	14.63	37.87	68.07	56.57	10.01	34.45	32.94	5.85	36.07	53.88	73.26	43.71	55.27	43.71	43.28	35.83	31.83
570	0.3	5.64	2.39	6.10	10.91	9.13	1.61	5.55	5.30	0.95	5.83	8.55	11.71	6.87	8.87	6.87	6.82	5.71	5.13
	0.8	15.26	6.47	16.50	29.53	24.70	4.35	15.01	14.35	2.56	15.79	23.13	31.69	18.58	24.00	18.58	18.46	15.45	13.89
	1.3	24.98	10.58	27.01	48.34	40.43	7.13	24.57	23.49	4.19	25.85	37.87	51.87	30.41	39.28	30.41	30.21	25.29	22.73
	1.8	34.75	14.73	37.59	67.27	56.26	9.92	34.19	32.68	5.83	35.97	52.69	72.18	42.32	54.66	42.32	42.04	35.19	31.63
630	0.3	5.54	2.40	6.06	10.80	9.08	1.60	5.51	5.27	0.94	5.82	8.38	11.55	6.67	8.78	6.67	6.64	5.62	5.10
	0.8	14.99	6.50	16.39	29.22	24.58	4.32	14.91	14.25	2.55	15.75	22.67	31.27	18.05	23.76	18.05	17.98	15.20	13.81
	1.3	24.54	10.65	26.83	47.83	40.23	7.07	24.41	23.33	4.18	25.78	37.11	51.18	29.55	38.89	29.55	29.43	24.89	22.60
	1.8	34.15	14.81	37.33	66.55	55.98	9.83	33.96	32.46	5.81	35.87	51.64	71.22	41.11	54.11	41.11	40.95	34.63	31.45

*BW = body weight; ADG = average daily gain; Arg = Arginine; His = histidine; Ile = isoleucine; Leu = leucine; Lys = lysine; Met = methionine; Phe = phenylanine; Thr = threonine; Trp = tryptophan; Val = valine; Ala = alanine; Asp = aspartic acid; Cys = cystine; Glu = glutamic acid; Gly = glycine; Pro = proline; Ser = serine; Tyr = tyrosine.

Table 17.12a - Nutritional requirements of **ZEBU** beef cattle, **BULLS** in **PASTURE** system

Average BW kg	ADG kg	DMI, kg	Intake of water[1], L		Energy			Protein					
			Summer	Winter	ME, Mcal	TDN, kg	TDN, %	RDP, g	RUP, g	CP, g	CP,%	RDP, % CP	RUP, % CP
210	0.3	3.5	9.0	10.8	8.4	2.3	65.2	261	141	402	11.5	64.8	35.2
	0.8	5.0	9.8	11.5	11.4	3.1	62.6	374	199	573	11.5	65.3	34.7
	1.3	6.0	10.3	12.0	14.6	4.0	66.0	484	260	744	12.4	65.0	35.0
	1.8	6.6	10.5	12.3	17.9	4.8	73.1	589	326	916	14.0	64.4	35.6
270	0.3	4.5	11.7	13.4	9.9	2.7	60.9	315	160	475	10.6	66.4	33.6
	0.8	5.9	12.4	14.1	13.2	3.6	61.0	435	223	658	11.1	66.1	33.9
	1.3	6.9	12.9	14.6	16.7	4.5	65.3	551	291	842	12.1	65.4	34.6
	1.8	7.5	13.2	14.9	20.4	5.5	72.6	662	363	1025	13.6	64.5	35.5
330	0.3	5.4	14.2	15.9	11.4	3.1	58.2	366	179	546	10.2	67.1	32.9
	0.8	6.8	14.9	16.6	14.9	4.1	59.9	493	251	744	10.9	66.2	33.8
	1.3	7.8	15.4	17.1	18.8	5.1	64.8	615	328	943	12.0	65.2	34.8
	1.8	8.4	15.7	17.4	22.8	6.1	72.4	732	410	1141	13.6	64.1	35.9
390	0.3	6.2	16.6	18.3	12.7	3.5	56.4	414	200	614	9.9	67.5	32.5
	0.8	7.7	17.3	19.0	16.6	4.5	59.1	547	280	827	10.8	66.1	33.9
	1.3	8.7	17.8	19.5	20.7	5.6	64.5	675	366	1041	12.0	64.9	35.1
	1.8	9.3	18.1	19.8	25.1	6.7	72.2	797	457	1254	13.5	63.5	36.5
450	0.3	7.1	18.9	20.6	14.0	3.9	55.1	456	212	668	9.5	68.3	31.7
	0.8	8.5	19.6	21.3	18.1	5.0	58.5	589	288	877	10.3	67.1	32.9
	1.3	9.5	20.1	21.8	22.6	6.1	64.2	717	370	1087	11.4	66.0	34.0
	1.8	10.1	20.4	22.1	27.3	7.3	72.1	837	458	1295	12.8	64.6	35.4
510	0.3	7.9	21.1	22.8	15.3	4.2	54.1	496	225	720	9.2	68.8	31.2
	0.8	9.3	21.8	23.5	19.7	5.4	58.0	629	297	926	9.9	67.9	32.1
	1.3	10.3	22.3	24.0	24.4	6.6	64.0	756	375	1130	10.9	66.8	33.2
	1.8	10.9	22.6	24.3	29.4	7.9	72.1	874	460	1334	12.2	65.5	34.5
570	0.3	8.6	23.2	25.0	16.5	4.6	53.3	533	238	771	8.9	69.2	30.8
	0.8	10.1	24.0	25.7	21.2	5.8	57.6	666	306	972	9.6	68.5	31.5
	1.3	11.1	24.4	26.2	26.2	7.1	63.9	791	381	1173	10.5	67.5	32.5
	1.8	11.7	24.7	26.5	31.5	8.4	72.0	907	464	1371	11.7	66.2	33.8
630	0.3	9.4	25.3	27.1	17.7	4.9	52.6	569	251	821	8.7	69.4	30.6
	0.8	10.9	26.0	27.8	22.6	6.2	57.3	701	316	1018	9.4	68.9	31.1
	1.3	11.9	26.5	28.3	27.9	7.6	63.8	825	388	1213	10.2	68.0	32.0
	1.8	12.4	26.8	28.6	33.5	9.0	72.0	938	469	1407	11.3	66.7	33.3

*BW = body weight; ADG = average daily gain; DMI = dry matter intake; ME = metabolizable energy; TDN = total digestible nutrients; CP = crude protein; RDP = rumen degradable protein; RUP = rumen undegradable protein. [1]Winter = 22°C of maximum temperature and 65% of relative humidity; Summer = 29°C of maximum temperature and 79% of relative humidity.

Table 17.12b - Minerals requirements for **ZEBU** beef cattle **BULLS**, in **PASTURE** system

Average BW kg	ADG kg	Macrominerals, g							Microminerals, mg							
		Ca	P	Ca:P	Mg	Na	K	S	Cu	Co	Cr	Fe	Mn	Mo	Se	Zn
210	0.3	9.91	6.71	1.48	3.78	4.48	11.23	3.91	29.96	3.28	8.06	855.56	91.24	1.40	2.04	146.52
	0.8	19.44	11.02	1.76	4.28	6.04	13.01	5.75	34.46	3.30	11.35	879.18	96.00	1.43	2.78	217.15
	1.3	29.07	15.38	1.89	4.79	7.61	14.79	7.61	39.02	3.32	14.68	903.05	100.81	1.45	3.53	288.50
	1.8	38.75	19.76	1.96	5.30	9.19	16.59	9.48	43.60	3.35	18.02	927.05	105.65	1.48	4.28	360.28
270	0.3	10.48	7.68	1.36	4.78	5.43	14.18	4.99	37.99	4.21	10.14	1096.92	117.14	1.79	2.49	186.71
	0.8	18.87	11.62	1.62	5.28	6.87	16.01	7.30	42.90	4.23	13.99	1122.04	122.98	1.83	3.22	274.67
	1.3	27.34	15.59	1.75	5.79	8.33	17.85	9.64	47.85	4.26	17.87	1147.41	128.88	1.86	3.95	363.54
	1.8	35.87	19.59	1.83	6.30	9.80	19.71	11.99	52.83	4.28	21.78	1172.93	134.81	1.89	4.69	452.93
330	0.3	11.24	8.71	1.29	5.78	6.40	17.12	6.06	46.00	5.15	12.19	1338.15	143.02	2.19	2.94	226.62
	0.8	18.81	12.37	1.52	6.28	7.76	18.99	8.84	51.24	5.17	16.54	1364.52	149.89	2.23	3.66	331.43
	1.3	26.47	16.06	1.65	6.79	9.13	20.88	11.64	56.54	5.19	20.94	1391.17	156.83	2.26	4.39	437.31
	1.8	34.17	19.78	1.73	7.30	10.51	22.79	14.45	61.87	5.21	25.37	1417.97	163.82	2.29	5.12	543.82
390	0.3	12.11	9.78	1.24	6.78	7.38	20.06	7.14	53.98	6.08	14.22	1579.28	168.87	2.59	3.39	266.30
	0.8	19.07	13.22	1.44	7.28	8.67	21.97	10.36	59.52	6.10	19.05	1606.75	176.75	2.62	4.10	387.57
	1.3	26.10	16.70	1.56	7.79	9.97	23.90	13.62	65.13	6.12	23.93	1634.50	184.70	2.66	4.82	510.07
	1.8	33.18	20.19	1.64	8.30	11.28	25.84	16.89	70.77	6.15	28.84	1662.42	192.70	2.70	5.54	633.31
450	0.3	13.06	10.87	1.20	7.78	8.37	22.99	8.20	61.94	7.01	16.24	1820.35	194.71	2.98	3.85	305.79
	0.8	19.53	14.14	1.38	8.28	9.60	24.94	11.87	67.76	7.03	21.51	1848.79	203.56	3.02	4.55	443.20
	1.3	26.07	17.43	1.50	8.79	10.85	26.90	15.58	73.64	7.06	26.84	1877.52	212.49	3.06	5.26	582.01
	1.8	32.65	20.75	1.57	9.30	12.10	28.88	19.31	79.55	7.08	32.20	1906.43	221.47	3.10	5.98	721.65
510	0.3	14.06	11.98	1.17	8.77	9.36	25.92	9.27	69.89	7.94	18.24	2061.35	220.54	3.38	4.30	345.13
	0.8	20.14	15.10	1.33	9.28	10.55	27.90	13.38	75.96	7.97	23.94	2090.68	230.33	3.42	5.00	498.40
	1.3	26.27	18.25	1.44	9.79	11.75	29.89	17.53	82.09	7.99	29.70	2120.30	240.22	3.46	5.70	653.25
	1.8	32.45	21.42	1.51	10.30	12.96	31.90	21.70	88.26	8.01	35.49	2150.10	250.16	3.50	6.41	809.01
570	0.3	11.74	11.35	1.03	9.77	10.35	28.85	10.33	77.83	8.88	20.23	2302.32	246.35	3.78	4.76	384.32
	0.8	11.74	11.35	1.03	10.28	11.50	30.85	14.87	84.13	8.90	26.34	2332.44	257.07	3.82	5.45	553.23
	1.3	11.74	11.35	1.03	10.79	12.66	32.88	19.46	90.49	8.92	32.51	2362.88	267.89	3.86	6.15	723.87
	1.8	11.74	11.35	1.03	11.30	13.83	34.91	24.08	96.89	8.94	38.71	2393.50	278.78	3.90	6.85	895.52
630	0.3	12.98	12.54	1.03	10.77	11.35	31.78	11.39	85.76	9.81	22.21	2543.24	272.16	4.17	5.21	423.40
	0.8	12.98	12.54	1.03	11.28	12.47	33.81	16.36	92.27	9.83	28.71	2574.11	283.78	4.22	5.90	607.73
	1.3	12.98	12.54	1.03	11.79	13.59	35.85	21.38	98.85	9.85	35.27	2605.30	295.52	4.26	6.59	793.95
	1.8	12.98	12.54	1.03	12.30	14.73	37.92	26.44	105.47	9.88	41.88	2636.68	307.33	4.31	7.29	981.28

*BW = body weight; ADG = average daily gain; Ca = calcium; P = phosphorus; Ca:P = ratio calcium/phosphorus; Mg = magnesium; Na = sodium; K = potassium; S = sulfur; Cu = copper; Co = cobalt; Cr = chromium; Fe = iron; Mn = manganese; Mo = molybdenum; Se = selenium; Zn = zinc.

Table 17.12c - Metabolizable amino acids requirements for **ZEBU** beef cattle, **BULLS** in **PASTURE** system

Average BW kg	ADG kg	Essentials, g										Non-Essentials, g							
		Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val	Ala	Asp	Cys	Glu	Gly	Pro	Ser	Tyr
330	0.3	6.25	2.31	6.34	11.62	9.40	1.69	5.77	5.52	0.96	5.93	9.63	12.67	8.14	9.41	8.14	7.96	6.28	5.30
	0.8	16.91	6.24	17.17	31.45	25.43	4.58	15.62	14.95	2.61	16.04	26.05	34.29	22.04	25.47	22.04	21.54	16.99	14.36
	1.3	27.68	10.22	28.11	51.48	41.63	7.50	25.57	24.47	4.27	26.26	42.65	56.13	36.08	41.69	36.08	35.26	27.82	23.50
	1.8	38.52	14.22	39.11	71.63	57.93	10.43	35.57	34.05	5.94	36.54	59.34	78.09	50.21	58.00	50.21	49.06	38.71	32.70
390	0.3	6.08	2.33	6.28	11.43	9.32	1.67	5.71	5.46	0.96	5.90	9.32	12.40	7.78	9.26	7.78	7.63	6.12	5.26
	0.8	16.45	6.30	16.99	30.92	25.23	4.52	15.45	14.79	2.60	15.97	25.23	33.57	21.05	25.06	21.05	20.66	16.56	14.23
	1.3	26.93	10.32	27.81	50.62	41.30	7.40	25.30	24.21	4.25	26.15	41.30	54.95	34.46	41.03	34.46	33.83	27.11	23.29
	1.8	37.47	14.35	38.70	70.43	57.47	10.29	35.20	33.68	5.91	36.38	57.47	76.46	47.95	57.08	47.95	47.07	37.73	32.41
450	0.3	5.94	2.35	6.22	11.26	9.26	1.65	5.66	5.41	0.95	5.88	9.07	12.18	7.48	9.13	7.48	7.37	5.99	5.22
	0.8	16.06	6.35	16.83	30.48	25.06	4.47	15.31	14.65	2.58	15.92	24.55	32.96	20.24	24.72	20.24	19.94	16.20	14.12
	1.3	26.30	10.40	27.56	49.89	41.03	7.31	25.06	23.98	4.23	26.05	40.19	53.96	33.13	40.47	33.13	32.64	26.53	23.11
	1.8	36.59	14.47	38.34	69.42	57.09	10.17	34.88	33.36	5.89	36.25	55.92	75.08	46.10	56.31	46.10	45.42	36.91	32.16
510	0.3	5.81	2.36	6.17	11.12	9.21	1.63	5.61	5.37	0.95	5.86	8.86	11.99	7.23	9.03	7.23	7.14	5.87	5.18
	0.8	15.73	6.40	16.70	30.09	24.92	4.42	15.19	14.53	2.57	15.87	23.97	32.44	19.55	24.43	19.55	19.33	15.90	14.03
	1.3	25.76	10.47	27.34	49.26	40.79	7.24	24.86	23.78	4.21	25.97	39.24	53.11	32.01	39.99	32.01	31.64	26.02	22.96
	1.8	35.84	14.57	38.04	68.54	56.75	10.07	34.60	33.09	5.86	36.14	54.60	73.90	44.54	55.64	44.54	44.03	36.21	31.95
570	0.3	5.71	2.38	6.13	10.99	9.16	1.62	5.57	5.33	0.95	5.85	8.67	11.82	7.01	8.93	7.01	6.95	5.77	5.15
	0.8	15.45	6.44	16.58	29.76	24.79	4.38	15.08	14.42	2.57	15.82	23.46	31.99	18.97	24.17	18.97	18.80	15.63	13.94
	1.3	25.29	10.54	27.14	48.71	40.57	7.17	24.69	23.61	4.20	25.90	38.41	52.37	31.05	39.56	31.05	30.78	25.58	22.82
	1.8	35.18	14.66	37.77	67.78	56.45	9.98	34.35	32.85	5.84	36.04	53.45	72.87	43.20	55.05	43.20	42.83	35.60	31.76
630	0.3	5.61	2.39	6.09	10.88	9.11	1.61	5.54	5.29	0.95	5.83	8.51	11.67	6.82	8.85	6.82	6.78	5.69	5.12
	0.8	15.19	6.47	16.48	29.46	24.67	4.35	14.99	14.33	2.56	15.78	23.02	31.59	18.45	23.94	18.45	18.34	15.39	13.87
	1.3	24.87	10.60	26.97	48.22	40.38	7.11	24.53	23.45	4.19	25.83	37.68	51.71	30.20	39.19	30.20	30.02	25.19	22.70
	1.8	34.61	14.75	37.53	67.09	56.19	9.90	34.13	32.63	5.83	35.94	52.43	71.95	42.03	54.53	42.03	41.77	35.06	31.59

*BW = body weight; ADG = average daily gain; Arg = Arginine; His = histidine; Ile = isoleucine; Leu = leucine; Lys = lysine; Met = methionine; Phe = phenylanine; Thr = threonine; Trp = tryptophan; Val = valine; Ala = alanine; Asp = aspartic acid; Cys = cystine; Glu = glutamic acid; Gly = glycine; Pro = proline; Ser = serine; Tyr = tyrosine.

Table 17.12d – Net **AMINO ACIDS** requirements for **MAINTENANCE** for beef cattle

Average BW kg	MPm	NPm	Essentials, g										Non-Essentials, g							
			Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val	Ala	Asp	Cys	Glu	Gly	Pro	Ser	Tyr
330	273.1	129.4	5.97	3.75	5.29	9.93	8.06	1.63	5.15	6.71	3.52	6.85	6.07	6.15	3.34	14.64	6.61	12.67	6.78	4.69
390	310.1	147.0	6.78	4.26	6.01	11.27	9.16	1.85	5.85	7.61	4.00	7.78	6.89	6.98	3.79	16.63	7.51	14.39	7.70	5.32
450	345.8	163.9	7.56	4.75	6.70	12.57	10.21	2.07	6.52	8.49	4.46	8.67	7.69	7.79	4.23	18.54	8.38	16.05	8.59	5.93
510	380.4	180.3	8.31	5.23	7.37	13.83	11.23	2.27	7.18	9.34	4.91	9.54	8.46	8.56	4.65	20.39	9.21	17.65	9.45	6.53
570	414.0	196.2	9.05	5.69	8.03	15.05	12.23	2.47	7.81	10.17	5.34	10.38	9.20	9.32	5.06	22.19	10.03	19.21	10.28	7.10
630	446.8	211.8	9.76	6.14	8.66	16.24	13.19	2.67	8.43	10.97	5.76	11.20	9.93	10.06	5.46	23.95	10.82	20.73	11.10	7.67

*BW = body weight; MPm = metabolizable protein for maintenance; NPm = net protein to maintain; Arg = Arginine; His = histidine; Ile = isoleucine; Leu = leucine; Lys = lysine; Met = methionine; Phe = phenylanine; Thr = threonine; Trp = tryptophan; Val = valine; Ala = alanine; Asp = aspartic acid; Cys = cystine; Glu = glutamic acid; Gly = glycine; Pro = proline; Ser = serine; Tyr = tyrosine

TABLES FOR LACTATING BEEF COWS AND THEIR CALVES

In Tables 17.13 to 17.16 are described the nutritional requirements for lactating beef cows and their calves according to the equations proposed in chapter 12. For cows, values for body weight, average daily gain and lactation week ranging from 400 to 500 kg, 0.10 to 0.20 kg/day and 2 to 18 weeks, respectively, were included. It should be noted that the values for multiparous and primiparous cows are presented in different Tables. The average composition of the milk considered was: 3.56% CP, 4.56% lactose and 4.76% fat.

The Tables for lactating calves were developed considering animals with average body weight, milk production of the dam and average daily gain ranging from 100 at 250 kg, 5 at 11 kg and 0.2 at 0.8 kg/day, respectively. Similar to what was presented in the previous section, the nutritional requirements described can be used directly for formulating diets according to category and performance levels.

The Tables of example calculations of calf requirements are important new tools in formulating diets for these animals. However, it is important to note that certain information regarding the requirements of calves with low or medium weight gain (0.2, 0.4 and 0.6 kg/day) and that are suckled by cows with higher milk production (7 and 9 kg) were removed from the Tables. This exclusion was made because these values did not represent biologically plausible examples. Appropriate selection of data is critical to ensure reliability of the Tables and to provide practical and realistic information for calf nutrition.

Table 17.13a - Nutritional requirements of lactating **PRIMIPAROUS COWS**

Average BW, kg	Week of lactation	Milk production, Kg	DMI, kg	ADG, kg	Energy			Protein					
					Met, Mcal	TDN, kg	TDN, %	RDP, g	RUP, g	CP, g	CP,%	RDP, % CP	RUP, % CP
400	2	6.21	6.0	0.10	18.4	4.9	80.6	612	362	974	16.1	62.8	37.2
				0.20	19.3	5.1	84.1	636	375	1011	16.7	62.9	37.1
	6	6.00	7.3	0.10	18.2	4.9	67.4	610	351	961	13.2	63.5	36.5
				0.20	19.1	5.1	70.3	634	364	998	13.7	63.5	36.5
	10	5.71	7.7	0.10	17.9	4.9	63.1	601	340	941	12.2	63.9	36.1
				0.20	18.7	5.1	65.9	625	353	978	12.7	63.9	36.1
	14	5.42	8.0	0.10	17.5	4.8	59.8	591	329	920	11.5	64.2	35.8
				0.20	18.4	5.0	62.5	615	342	958	11.9	64.2	35.8
	18	5.14	8.3	0.10	17.2	4.7	56.8	582	319	900	10.8	64.6	35.4
				0.20	18.1	5.0	59.3	606	332	938	11.2	64.6	35.4
450	2	6.21	6.8	0.10	19.4	5.2	76.0	644	376	1020	15.0	63.1	36.9
				0.20	20.3	5.4	79.2	667	389	1056	15.5	63.2	36.8
	6	6.00	8.2	0.10	19.2	5.2	63.7	642	364	1006	12.3	63.8	36.2
				0.20	20.1	5.4	66.3	666	377	1043	12.7	63.8	36.2
	10	5.71	8.6	0.10	18.9	5.2	59.8	633	353	987	11.4	64.2	35.8
				0.20	19.8	5.4	62.2	657	366	1023	11.8	64.2	35.8
	14	5.42	9.0	0.10	18.6	5.1	56.7	624	342	967	10.7	64.6	35.4
				0.20	19.4	5.3	59.1	648	355	1003	11.1	64.6	35.4
	18	5.14	9.4	0.10	18.2	5.1	53.9	615	331	947	10.1	65.0	35.0
				0.20	19.1	5.3	56.2	639	344	983	10.5	65.0	35.0
500	2	6.21	7.6	0.10	20.4	5.5	72.3	674	391	1064	14.1	63.3	36.7
				0.20	21.3	5.7	75.2	697	403	1100	14.6	63.4	36.6
	6	6.00	9.1	0.10	20.2	5.5	60.6	673	378	1051	11.6	64.0	36.0
				0.20	21.1	5.7	63.1	696	391	1087	11.9	64.1	35.9
	10	5.71	9.6	0.10	19.9	5.5	57.0	665	367	1031	10.7	64.4	35.6
				0.20	20.8	5.7	59.3	688	379	1067	11.1	64.5	35.5
	14	5.42	10.0	0.10	19.5	5.4	54.1	656	356	1011	10.1	64.8	35.2
				0.20	20.5	5.6	56.3	679	368	1047	10.4	64.9	35.1
	18	5.14	10.4	0.10	19.2	5.4	51.5	647	344	991	9.5	65.3	34.7
				0.20	20.1	5.6	53.6	670	357	1027	9.8	65.3	34.7

*BW = body weight; ADG = average daily gain; DMI = dry matter intake; MEt = total metabolizable energy; TDN = total digestible nutrients; CP = crude protein; RDP = rumen degradable protein; RUP = rumen undegradable protein.

Table 17.13b - Minerals requirements for lactating **PRIMIPAROUS COWS**

Average BW, kg	Week of lactation	Milk production, Kg	ADG kg	Macrominerals, g							Microminerals, mg					
				Ca	P	Ca:P	Mg	Na	K	S	Cu	Co	Cr	Fe	Mn	Zn
400	2	6.21	0.10	21.6	15.6	1.4	7.9	10.4	28.6	8.4	69.9	7.9	38.0	1863	190	553
			0.20	22.9	16.1	1.4	8.0	10.6	28.7	9.1	71.0	7.9	38.9	1871	192	577
	6	6.00	0.10	21.2	15.3	1.4	7.9	10.3	28.3	8.3	69.3	7.8	37.1	1855	189	542
			0.20	22.5	15.9	1.4	7.9	10.5	28.4	9.0	70.4	7.8	38.1	1862	191	566
	10	5.71	0.10	20.6	15.0	1.4	7.8	10.1	27.9	8.2	68.6	7.7	35.9	1843	188	527
			0.20	22.0	15.6	1.4	7.9	10.4	28.0	8.9	69.7	7.7	36.9	1850	190	551
	14	5.42	0.10	20.1	14.7	1.4	7.8	10.0	27.4	8.1	67.8	7.7	34.8	1831	187	511
			0.20	21.4	15.2	1.4	7.8	10.2	27.6	8.8	68.9	7.7	35.7	1839	189	536
	18	5.14	0.10	19.5	14.3	1.4	7.7	9.8	27.0	8.0	67.0	7.6	33.6	1820	187	496
			0.20	20.9	14.9	1.4	7.8	10.1	27.2	8.7	68.1	7.6	34.5	1827	188	521
450	2	6.21	0.10	22.5	16.5	1.4	8.8	11.2	31.0	9.2	76.5	8.6	39.5	2064	211	581
			0.20	23.8	17.1	1.4	8.8	11.5	31.2	9.9	77.6	8.7	40.5	2071	213	608
	6	6.00	0.10	22.1	16.3	1.4	8.7	11.1	30.7	9.1	75.9	8.6	38.6	2055	210	570
			0.20	23.4	16.8	1.4	8.8	11.4	30.9	9.8	77.0	8.6	39.7	2063	212	597
	10	5.71	0.10	21.6	16.0	1.4	8.7	11.0	30.3	9.0	75.1	8.5	37.5	2044	210	554
			0.20	22.8	16.5	1.4	8.7	11.2	30.4	9.7	76.3	8.5	38.5	2051	211	581
	14	5.42	0.10	21.0	15.6	1.3	8.6	10.8	29.9	8.9	74.3	8.4	36.3	2032	209	539
			0.20	22.3	16.2	1.4	8.7	11.1	30.0	9.6	75.5	8.4	37.3	2039	210	566
	18	5.14	0.10	20.5	15.3	1.3	8.5	10.7	29.4	8.8	73.6	8.4	35.1	2020	208	524
			0.20	21.7	15.8	1.4	8.6	10.9	29.6	9.5	74.7	8.4	36.2	2028	209	551
500	2	6.21	0.10	23.5	17.5	1.3	9.6	12.1	33.4	9.9	83.0	9.4	41.0	2264	232	608
			0.20	24.7	18.0	1.4	9.6	12.3	33.6	10.7	84.2	9.4	42.1	2272	234	638
	6	6.00	0.10	23.1	17.3	1.3	9.5	12.0	33.1	9.8	82.4	9.4	40.2	2256	232	597
			0.20	24.3	17.8	1.4	9.6	12.2	33.3	10.6	83.6	9.4	41.3	2264	234	627
	10	5.71	0.10	22.5	16.9	1.3	9.5	11.8	32.7	9.7	81.7	9.3	39.0	2244	231	582
			0.20	23.7	17.4	1.4	9.5	12.1	32.9	10.5	82.8	9.3	40.1	2252	233	611
	14	5.42	0.10	22.0	16.6	1.3	9.4	11.7	32.3	9.6	80.9	9.2	37.8	2233	230	567
			0.20	23.2	17.1	1.4	9.5	11.9	32.5	10.4	82.1	9.2	38.9	2240	232	596
	18	5.14	0.10	21.4	16.3	1.3	9.4	11.5	31.9	9.5	80.1	9.1	36.6	2221	229	551
			0.20	22.6	16.8	1.3	9.4	11.8	32.0	10.3	81.3	9.1	37.8	2229	231	581

*BW = body weight; ADG = average daily gain; Ca = calcium; P = phosphorus; Ca:P = ratio calcium/phosphorus; Mg = magnesium; Na = sodium; K = potassium; S = sulfur; Cu = copper; Co = cobalt; Cr = chromium; Fe = iron; Mn = manganese; Mo = molybdenum; Se = selenium; Zn = zinc.

Table 17.14a - Nutritional requirements of lactating **MULTIPAROUS COWS**

Average BW, kg	Week of lactation	Milk production, Kg	DMI, kg	ADG, kg	Energy			Protein					
					MEt, Mcal	TDN, kg	TDN, %	RDP, g	RUP, g	CP, g	CP,%	RDP, % CP	RUP, % CP
400	2	7.35	6.8	0.10	19.7	5.2	77.0	659	397	1056	15.5	62.4	37.6
				0.20	20.6	5.4	80.1	682	411	1093	16.1	62.4	37.6
	6	7.39	8.2	0.10	19.8	5.4	65.3	666	393	1060	12.9	62.9	37.1
				0.20	20.6	5.6	67.8	689	407	1097	13.4	62.9	37.1
	10	6.99	8.5	0.10	19.3	5.3	61.7	653	379	1031	12.1	63.3	36.7
				0.20	20.2	5.5	64.2	676	392	1068	12.5	63.3	36.7
	14	6.58	8.8	0.10	18.9	5.2	58.9	639	364	1003	11.4	63.7	36.3
				0.20	19.7	5.4	61.2	662	378	1040	11.8	63.7	36.3
	18	6.18	9.0	0.10	18.4	5.1	56.2	625	350	975	10.8	64.1	35.9
				0.20	19.3	5.3	58.5	648	364	1012	11.2	64.1	35.9
450	2	7.35	7.7	0.10	20.7	5.5	72.5	690	411	1101	14.4	62.6	37.4
				0.20	21.6	5.8	75.3	713	425	1138	14.9	62.7	37.3
	6	7.39	9.2	0.10	20.8	5.7	61.5	698	407	1105	12.0	63.2	36.8
				0.20	21.7	5.9	63.8	721	421	1142	12.4	63.1	36.9
	10	6.99	9.6	0.10	20.3	5.6	58.2	685	392	1077	11.2	63.6	36.4
				0.20	21.2	5.8	60.4	708	406	1114	11.6	63.6	36.4
	14	6.58	9.9	0.10	19.9	5.5	55.6	671	378	1049	10.6	64.0	36.0
				0.20	20.8	5.7	57.8	694	391	1085	11.0	64.0	36.0
	18	6.18	10.2	0.10	19.4	5.4	53.2	658	363	1021	10.0	64.4	35.6
				0.20	20.3	5.6	55.3	681	376	1057	10.4	64.4	35.6
500	2	7.35	8.5	0.10	21.7	5.8	68.7	720	426	1146	13.5	62.8	37.2
				0.20	22.6	6.1	71.3	743	439	1182	13.9	62.9	37.1
	6	7.39	10.3	0.10	21.8	6.0	58.3	729	421	1150	11.2	63.4	36.6
				0.20	22.7	6.2	60.5	751	434	1186	11.6	63.4	36.6
	10	6.99	10.7	0.10	21.3	5.9	55.3	716	406	1122	10.5	63.8	36.2
				0.20	22.2	6.1	57.4	738	419	1158	10.8	63.8	36.2
	14	6.58	11.0	0.10	20.9	5.8	52.9	702	391	1094	10.0	64.2	35.8
				0.20	21.8	6.0	54.9	725	404	1129	10.3	64.2	35.8
	18	6.18	11.3	0.10	20.4	5.7	50.7	689	377	1066	9.4	64.7	35.3
				0.20	21.3	5.9	52.6	712	389	1101	9.7	64.6	35.4

*BW = body weight; ADG = average daily gain; DMI = dry matter intake; MEt = total metabolizable energy; TDN = total digestible nutrients; CP = crude protein; RDP = rumen degradable protein; RUP = rumen undegradable protein.

Table 17.14b - Minerals requirements of lactating **MULTIPAROUS COWS**

Average BW, kg	Week of lactation	Milk production, Kg	ADG kg	Macrominerals, g							Microminerals, mg					
				Ca	P	Ca:P	Mg	Na	K	S	Cu	Co	Cr	Fe	Mn	Zn
400	2	7.35	0.10	23.8	16.9	1.4	8.2	11.0	30.2	8.9	73.0	8.2	42.6	1910	194	614
			0.20	25.1	17.4	1.4	8.2	11.3	30.4	9.5	74.1	8.2	43.6	1917	195	638
	6	7.39	0.10	23.9	16.9	1.4	8.2	11.0	30.3	8.9	73.1	8.2	42.8	1911	194	616
			0.20	25.2	17.5	1.4	8.2	11.3	30.5	9.5	74.2	8.2	43.7	1919	195	640
	10	6.99	0.10	23.1	16.5	1.4	8.1	10.8	29.7	8.7	72.0	8.1	41.1	1895	192	594
			0.20	24.4	17.0	1.4	8.1	11.1	29.9	9.4	73.1	8.1	42.1	1902	194	619
	14	6.58	0.10	22.3	16.0	1.4	8.0	10.6	29.1	8.6	70.9	8.0	39.5	1879	191	573
			0.20	23.7	16.6	1.4	8.1	10.8	29.3	9.2	72.0	8.0	40.5	1886	193	597
	18	6.18	0.10	21.5	15.5	1.4	7.9	10.4	28.5	8.4	69.8	7.9	37.8	1862	190	551
			0.20	22.9	16.1	1.4	8.0	10.6	28.7	9.1	70.9	7.9	38.8	1869	191	576
450	2	7.35	0.10	24.7	17.8	1.4	9.0	11.9	32.6	9.6	79.6	9.0	44.2	2110	215	641
			0.20	26.0	18.4	1.4	9.0	12.1	32.8	10.3	80.7	9.0	45.2	2118	217	668
	6	7.39	0.10	24.8	17.9	1.4	9.0	11.9	32.7	9.6	79.7	9.0	44.3	2112	215	643
			0.20	26.1	18.4	1.4	9.0	12.1	32.9	10.3	80.8	9.0	45.4	2120	217	670
	10	6.99	0.10	24.0	17.4	1.4	8.9	11.7	32.1	9.5	78.6	8.9	42.7	2096	214	622
			0.20	25.3	18.0	1.4	9.0	11.9	32.3	10.2	79.7	8.9	43.7	2103	215	649
	14	6.58	0.10	23.3	17.0	1.4	8.8	11.4	31.5	9.3	77.5	8.7	41.0	2079	212	600
			0.20	24.5	17.5	1.4	8.9	11.7	31.7	10.0	78.6	8.8	42.1	2087	214	627
	18	6.18	0.10	22.5	16.5	1.4	8.8	11.2	31.0	9.2	76.4	8.6	39.4	2063	211	579
			0.20	23.7	17.0	1.4	8.8	11.5	31.1	9.9	77.5	8.6	40.4	2070	213	606
500	2	7.35	0.10	25.7	18.8	1.4	9.8	12.7	35.1	10.4	86.1	9.7	45.7	2311	236	669
			0.20	26.9	19.3	1.4	9.9	13.0	35.2	11.1	87.3	9.7	46.8	2319	238	698
	6	7.39	0.10	25.8	18.8	1.4	9.8	12.7	35.1	10.4	86.2	9.7	45.8	2313	236	671
			0.20	27.0	19.4	1.4	9.9	13.0	35.3	11.2	87.4	9.7	46.9	2320	238	700
	10	6.99	0.10	25.0	18.4	1.4	9.7	12.5	34.5	10.2	85.1	9.6	44.2	2296	235	649
			0.20	26.2	18.9	1.4	9.8	12.8	34.7	11.0	86.3	9.6	45.3	2304	237	679
	14	6.58	0.10	24.2	17.9	1.4	9.7	12.3	34.0	10.1	84.0	9.5	42.6	2280	234	628
			0.20	25.4	18.4	1.4	9.7	12.5	34.1	10.8	85.2	9.5	43.7	2287	235	658
	18	6.18	0.10	23.4	17.5	1.3	9.6	12.1	33.4	9.9	82.9	9.4	40.9	2263	232	607
			0.20	24.6	18.0	1.4	9.6	12.3	33.5	10.7	84.1	9.4	42.0	2271	234	636

*BW = body weight; ADG = average daily gain; Ca = calcium; P = phosphorus; Ca:P = ratio calcium/phosphorus; Mg = magnesium; Na = sodium; K = potassium; S = sulfur; Cu = copper; Co = cobalt; Cr = chromium; Fe = iron; Mn = manganese; Mo = molybdenum; Se = selenium; Zn = zinc.

Table 17.15a - Nutritional requirements for suckling beef **CALVES** at **100** and **150 kg BW**

Average BW, kg	Milk Production, Kg	ADG kg	DMI milk, kg	DMI solids, kg	DMI total. kg	Energy			Protein					
						MEt, Mcal	TDN, kg	TDN, %	RDP, g	RUP, g	CP, g	CP,%	RDP, %CP	RUP, %CP
100	5.0	0.2	0.70	1.12	1.81	4.7	1.1	60.9	25	188	213	11.7	11.6	88.4
		0.4	0.70	1.19	1.88	5.6	1.3	70.1	51	221	271	14.4	18.6	81.4
		0.6	0.70	1.26	1.95	6.5	1.5	78.3	75	254	330	16.9	22.9	77.1
		0.8	0.70	1.33	2.02	7.3	1.7	85.6	100	289	388	19.2	25.7	74.3
	7.0	0.4	0.97	1.04	2.01	5.5	1.3	65.1	6	256	263	13.0	2.3	97.7
		0.6	0.97	1.11	2.08	6.4	1.5	72.7	31	290	321	15.4	9.5	90.5
		0.8	0.97	1.18	2.15	7.2	1.7	79.6	54	325	379	17.6	14.3	85.7
	9.0	0.8	1.25	1.03	2.28	7.2	1.7	74.4	9	361	370	16.2	2.5	97.5
150	5.0	0.2	0.70	1.65	2.35	6.3	1.5	64.1	30	244	274	11.7	10.9	89.1
		0.4	0.70	1.72	2.42	7.6	1.8	74.5	76	266	342	14.2	22.3	77.7
		0.6	0.70	1.79	2.49	8.8	2.1	83.9	121	289	410	16.5	29.5	70.5
		0.8	0.70	1.86	2.56	10.0	2.4	92.5	164	313	477	18.7	34.4	65.6
	7.0	0.4	0.97	1.57	2.55	7.6	1.8	70.3	19	312	330	13.0	5.7	94.3
		0.6	0.97	1.64	2.62	8.7	2.1	79.1	64	335	398	15.2	16.0	84.0
		0.8	0.97	1.71	2.69	9.9	2.3	87.2	108	358	466	17.4	23.1	76.9
	9.0	0.6	1.25	1.49	2.75	8.7	2.1	74.8	6	381	387	14.1	1.6	98.4
		0.8	1.25	1.56	2.82	9.8	2.3	82.5	50	404	455	16.1	11.0	89.0

*BW = body weight; ADG = average daily gain; DMI = dry matter intake; MEt = total metabolizable energy; TDN = total digestible nutrients; CP = crude protein; RDP = rumen degradable protein; RUP = rumen undegradable protein.

Table 17.15b - Minerals requirements for suckling beef **CALVES** at **100** and **150 kg BW**

Average BW, kg	Milk production, Kg	ADG, kg	Macrominerals, g					
			Ca	P	Ca:P	Mg	Na	K
100	5.0	0.4	5.1	4.0	1.3	1.8	2.3	5.3
		0.6	8.1	6.1	1.3	2.0	2.8	5.8
		0.8	11.1	8.1	1.4	2.2	3.4	6.2
		1.0	14.1	10.2	1.4	2.4	3.9	6.7
	7.0	0.6	8.1	6.1	1.3	2.0	2.8	5.8
		0.8	11.1	8.1	1.4	2.2	3.4	6.2
		1.0	14.1	10.2	1.4	2.4	3.9	6.7
	9.0	1.0	14.1	10.2	1.4	2.4	3.9	6.7
150	5.0	0.4	5.6	5.0	1.1	2.7	3.1	7.8
		0.6	8.2	7.0	1.2	2.8	3.7	8.2
		0.8	10.8	9.0	1.2	3.0	4.2	8.7
		1.0	13.3	11.1	1.2	3.2	4.8	9.1
	7.0	0.6	8.2	7.0	1.2	2.8	3.7	8.2
		0.8	10.8	9.0	1.2	3.0	4.2	8.7
		1.0	13.3	11.1	1.2	3.2	4.8	9.1
	9.0	0.8	10.8	9.0	1.2	3.0	4.2	8.7
		1.0	13.3	11.1	1.2	3.2	4.8	9.1

*BW = body weight; ADG = average daily gain; Ca = calcium; P = phosphorus; Ca:P = ratio calcium/phosphorus; Mg = magnesium; Na = sodium; K = potassium.

Table 17.16a - Nutritional requirements for suckling beef **CALVES** at **200** and **250 kg BW**

Average BW, kg	Milk production, Kg	ADG kg	DMI milk, kg	DMI solids, kg	DMI kg	Energy			Protein					
						MEt, Mcal	TDN, kg	TDN, %	RDP, g	RUP, g	CP, g	CP,%	RDP, %CP	RUP, %CP
200	5.0	0.2	0.70	2.18	2.88	7.9	1.9	65.0	82	259	341	11.8	24.0	76.0
		0.4	0.70	2.25	2.95	9.5	2.2	76.0	136	280	416	14.1	32.6	67.4
		0.6	0.70	2.32	3.02	11.0	2.6	86.1	320	198	518	17.2	61.7	38.3
		0.8	0.70	2.39	3.09	12.4	2.9	95.4	238	328	567	18.3	42.0	58.0
	7.0	0.2	0.97	2.04	3.01	7.9	1.9	61.9	25	304	329	10.9	7.6	92.4
		0.4	0.97	2.11	3.08	9.4	2.2	72.4	80	326	405	13.2	19.6	80.4
		0.6	0.97	2.18	3.15	10.9	2.6	82.0	213	284	497	15.8	42.9	57.1
		0.8	0.97	2.25	3.22	12.4	2.9	90.9	183	373	556	17.3	32.9	67.1
	9.0	0.4	1.25	1.96	3.21	9.4	2.2	69.1	22	371	394	12.3	5.7	94.3
		0.6	1.25	2.03	3.28	10.8	2.6	78.3	75	394	469	14.3	16.1	83.9
		0.8	1.25	2.10	3.35	12.3	2.9	86.7	127	418	544	16.3	23.3	76.7
	11.0	0.6	1.53	1.88	3.41	10.8	2.6	74.8	18	440	458	13.4	3.9	96.1
		0.8	1.53	1.95	3.48	12.2	2.9	82.9	70	463	533	15.3	13.1	86.9
250	5.0	0.2	0.70	2.72	3.41	9.4	2.2	64.9	130	275	405	11.9	32.1	67.9
		0.4	0.70	2.79	3.48	11.2	2.7	76.3	192	297	489	14.0	39.2	60.8
		0.6	0.70	2.86	3.55	13.0	3.1	86.8	250	322	573	16.1	43.7	56.3
		0.8	0.70	2.93	3.62	14.8	3.5	96.6	307	349	656	18.1	46.8	53.2
	7.0	0.2	0.97	2.57	3.54	9.3	2.2	62.3	74	319	393	11.1	18.8	81.2
		0.4	0.97	2.64	3.61	11.2	2.6	73.2	136	342	478	13.2	28.5	71.5
		0.6	0.97	2.71	3.68	12.9	3.1	83.2	196	366	562	15.3	34.9	65.1
		0.8	0.97	2.78	3.75	14.7	3.5	92.6	253	392	645	17.2	39.2	60.8
	9.0	0.2	1.25	2.42	3.67	9.3	2.2	59.9	17	365	382	10.4	4.5	95.5
		0.4	1.25	2.49	3.74	11.1	2.6	70.4	80	386	467	12.5	17.2	82.8
		0.6	1.25	2.56	3.81	12.9	3.0	79.9	140	410	551	14.4	25.5	74.5
		0.8	1.25	2.63	3.88	14.6	3.4	88.9	198	436	634	16.3	31.3	68.7
	11.0	0.4	1.53	2.34	3.87	11.1	2.6	67.7	23	432	455	11.8	5.1	94.9
		0.6	1.53	2.41	3.94	12.8	3.0	76.9	84	455	539	13.7	15.6	84.4
		0.8	1.53	2.48	4.01	14.5	3.4	85.5	143	481	623	15.5	22.9	77.1

*BW = body weight; ADG = average daily gain; DMI = dry matter intake; MEt = total metabolizable energy; TDN = total digestible nutrients; CP = crude protein; RDP = rumen degradable protein; RUP = rumen undegradable protein.

Table 17.16b - Minerals requirements for suckling beef **CALVES** at **200** and **250 kg BW**

Average BW, kg	Milk production, Kg	ADG, kg	Macrominerals, g					
			Ca	P	Ca:P	Mg	Na	K
200	5.0	0.2	6.4	0.1	56.3	3.5	4.0	10.1
		0.4	8.7	0.1	58.8	3.7	4.5	10.6
		0.6	11.0	0.2	61.0	3.8	5.1	11.1
		0.8	13.2	0.2	63.0	4.0	5.6	11.5
	7.0	0.2	6.4	0.1	62.6	3.5	4.0	10.2
		0.4	8.7	0.1	65.2	3.7	4.5	10.6
		0.6	11.0	0.2	67.5	3.8	5.1	11.1
		0.8	13.2	0.2	69.5	4.0	5.6	11.5
	9.0	0.4	8.7	0.1	71.6	3.7	4.5	10.6
		0.6	11.0	0.1	73.9	3.8	5.1	11.1
		0.8	13.2	0.2	76.0	4.0	5.6	11.5
	11.0	0.6	11.0	0.1	80.4	3.8	5.1	11.1
		0.8	13.2	0.2	82.5	4.0	5.6	11.5
250	5.0	0.2	7.2	0.1	79.2	4.3	4.8	12.7
		0.4	9.3	0.1	80.9	4.5	5.3	13.1
		0.6	11.4	0.1	82.6	4.7	5.9	13.5
		0.8	13.5	0.2	84.2	4.8	6.5	13.9
	7.0	0.2	7.2	0.1	85.3	4.3	4.8	12.7
		0.4	9.3	0.1	87.1	4.5	5.3	13.1
		0.6	11.4	0.1	88.8	4.7	5.9	13.5
		0.8	13.5	0.1	90.4	4.8	6.5	13.9
	9.0	0.2	7.2	0.1	91.5	4.3	4.8	12.7
		0.4	9.3	0.1	93.2	4.5	5.3	13.1
		0.6	11.4	0.1	94.9	4.7	5.9	13.5
		0.8	13.5	0.1	96.6	4.8	6.5	13.9
	11.0	0.4	9.3	0.1	99.4	4.5	5.3	13.1
		0.6	11.4	0.1	101.1	4.7	5.9	13.5
		0.8	13.5	0.1	102.7	4.8	6.5	13.9

*BW = body weight; ADG = average daily gain; Ca = calcium; P = phosphorus; Ca:P = ratio calcium/phosphorus; Mg = magnesium; Na = sodium; K = potassium.