NUTRIENT REQUIREMENTS OF ZEBU AND CROSSBRED CATTLE

BR-CORTE

3rd Edition - 2016

Editors
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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.

Chapter 1 is a new chapter that provides equations to empty 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.

Chapter 2 presents equations for estimating dry matter intake (DMI) of beef cattle, including intake of dairy crossbred, composed of Zebu, especially Gyr, crossed with dairy breeds, especially Holstein cattle. 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, new equations were developed to estimate the microbial protein synthesis, from crude protein and TDN intakes.

Chapter 4 presents new 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.

Chapter 5 presents prediction of carcass and empty body composition, with some equations published in the last edition of the BR-CORTE (2010), which were readjusted, and new equations to estimate body composition of dairy crossbred cattle. A new section included in this chapter discusses ways to estimate the composition of non-carcass components. Also, some alternative techniques to estimate body composition were suggested.

Chapter 6 is a new chapter that 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 ME concentration from the dietary digestible energy concentration. Also equations are presented for estimating methane production.

Chapter 7 provides an update of energy requirements for maintenance and weight gain of Zebu and crossbred cattle of different sexes. 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.

Chapter 8 provides an update of equations to estimate the metabolizable protein requirements for maintenance and gain of cattle from different genetic groups and sexes. Furthermore, the total requirements of protein predicted by the BR-CORTE (2010) were considered overestimated after they were tested. At the end of the chapter, results of two recently conducted experiments were presented comparing performance of cattle fed diets containing different levels of crude protein.

Chapter 9 presents the dietary mineral requirements. In this chapter, macromineral requirements have been re-evaluated, and it was included the sulfur and microminerals requirements. In the evaluation of minerals, the BR-CORTE

estimated net requirements and true retention coefficients for each mineral. Finally, this publication presents some informations not available in the international literature on micromineral requirements.

Chapter 10 is new and describes energy and protein requirements for maintenance and pregnancy of Zebu cows. The efficiency of utilization of metabolizable energy for pregnancy is presented. Furthermore, data regarding pregnancy requirements are scarce, mainly for Zebu cattle.

Chapter 11 presents energy, protein and mineral requirements for lactating Zebu cows and their calves. In this chapter, equations were included for estimating dry matter intake of cows and calves and one equation was obtained to estimate milk production of Zebu beef cows.

Chapter 12 is a new chapter that discusses regarding to environmental management. This issue has been much discussed recently. Initially, equations were tested as described in the literature for estimating excretion of nitrogenous compounds (N) and phosphorus (P). As these equations do not adequately estimate these excretions, new equations were obtained to estimate the excretion of N and P under tropical conditions.

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

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The committee wishes to thank the universities that provided individual data of experiments to BR-CORTE database, especially UNESP Jaboticabal and Dracena, UEM, and the Department of Animal Science of Veterinary School at UFMG.

The committee also thanks the postdoctoral researcher, Luiz Fernando Costa e Silva, for the great contribution to this publication, noting that without such contribution, possibly part of this work would not have been completed. We would like to thank the ex-postdoctoral and current professor, Polyana Pizzi Rotta, for the great contribution in the initial phase of this work. Finally, to the postdoctoral researcher, Laura Franco Prados, for the enormous contribution in the final phase of this work.

We also thanks all committee members and all co-authors of the chapters who kindly gave their time and knowledge to this project.

The committee wishes to thank the sponsors of the workshop for dissemination of this third edition: CRMV-MG, Trouw Nutrition, BR-NOVA, Exagro, Timac-agro, Phibro, Rehagro, and Intergado.

And the committee appreciates the support of the students that collaborated in organizing the workshop.

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1

Adjusting cattle body weight to physiological and feeding conditions

Mateus Pies Gionbelli, Sebastião de Campos Valadares Filho, Edenio Detmann

The result of weighting cattle does not represent the true weight of its body. Approximately 10–20% of the body weight of cattle as measured by a scale is the gastrointestinal tract content. This proportion can vary depending on whether the animal is fed or fasting. The ratio between the scale's weight and the true body weight of an animal can also vary as a function of age. In females, these ratios also vary because of the physiological stage (non-pregnant, lactation, and pregnant). To measure growth and performance or to 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 cattle 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, the 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 highest 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 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 also in other feeding systems. However, fasting animals are rarely weighed in beef cattle production systems in Brazil. Methods are necessary therefore 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 the feeding systems in use around the world.

This chapter was written aiming to establish the weighing ratios in beef cattle and also 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, usually people refer to the weight of an animal, in reality, 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 the 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 while 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, so as 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 weighing measurement used most in practice, in research, weighing in fasting is preferred to reduce the fill 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 fill. 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 to compare weight gain obtained by animals submitted to different treatments, the SBW has been considered the most adequate measurement to be taken at the start and end of the experiment. It is used to calculate the shrunk average daily gain (SADG) as the difference between the final and initial weighing in fasting, divided by the number of days of assessment. However, this measurement was always named average daily gain (ADG), even when taken from the differences between weightings 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 using the 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 empty body weight (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 nutritional 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. Weight at maturity represents the weight at which muscle mass growth practically stops, and from there onwards there is significant growth only through energy reserve accumulation, which can also be determined from 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 the energy requirements for growth, because animals of different sexes or genetic groups reach maturity at 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. 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

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

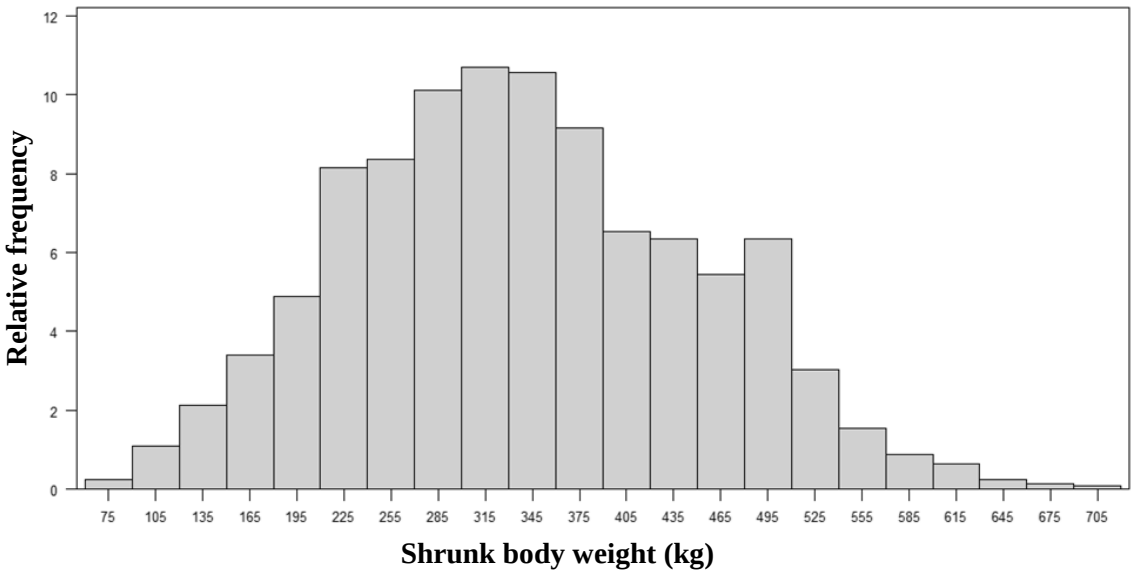

Figure 1.1 - Histogram of the frequency distribution of the SBW variable.

Table 1.2 - Description of the database used to establish the weight ratios in the BR-CORTE system

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 use in the BR-CORTE System was to assess the fit of models that best describe these statistical and biological relationships. In the previous edition of BR-CORTE (Valadares Filho et al., 2010) linear relationships between EBW and SBW and between EBG and SADG had been 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 suggesting that the proportions of weight lost in fasting in the BW and gastrointestinal tract content in the SBW are constant and do not vary with increase in animal weight. There is evidence, however, that these relationships are not linear

(Gionbelli et al., 2015). Therefore, 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 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 best 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 AIC values estimated 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 nonlinear model presents a better fit than the linear model.

In addition to better statistical fit, applying non-linear models to the weight ratios shown in Table 1.3 is also more adequate from the biological point of view, because it considers that the weight proportions 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 recently been observed. 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 the productive systems (BW).

Since 2010, BW and SBW data were collected from the same animals in a large part of the experiments carried out to make the BR-CORTE database. However, this measurement requires weightings on different days. 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 exactly 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 began recently, only data from Zebu and dairy crossbred genetic groups were available at the time of writing this chapter. The number of experiments carried out with animals of different sexes was also sufficient to assess the effect of sex on the meta-analysis carried out. Therefore, only the test of the possible difference between Zebu and dairy crossbred 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 in time 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). Two models were thus generated with independent parameters for Zebu and dairy crossbred, as follows:

Zebu cattle:

$$SBW = 0.8800 \times BW^{1.0175}$$

Eq. 1.1

Dairy crossbred cattle:

$$SBW = 0.9664 \times BW^{1.0017}$$

Eq. 1.2

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

An example of the use of the equations above 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 from solids was greater when the size of the animal was smaller and was 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

BW (kg)	SBW (kg)		SBW/BW		Difference in Weigh (kg)		Decrease in BW (%)	
	Zebu	Dairy Crossbred	Zebu	Dairy Crossbred	Zebu	Dairy crossbred	Zebu	Dairy crossbred
150	144	146	0.961	0.975	5.9	3.8	3.9	2.5
300	292	293	0.972	0.976	8.3	7.3	2.8	2.4
450	441	439	0.979	0.976	9.3	10.6	2.1	2.4
600	591	586	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, the use of Eq. 1.2 (Dairy crossbred) is 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.

For animals reared on pasture, although the equations here proposed were generated from animals on feedlot, it is considered more prudent to convert from BW to SBW using Eq. 1.1 (the experiments with

animals on pasture that are part of the BR-CORTE were carried out mostly with Zebu animals) than to not calculate or use the fixed 0.96 ratio. The EBW estimate for animals on pasture is obtained from SBW data of experiments carried out on pasture, where the animals were shut in a paddock with fasting from solids until SBW was measured, always in the morning.

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

The BR-CORTE System database contains 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 could be tested on the parameters of the linear model fitted to the ratio. The *F* test showed there was statistical improvement (P<0.04) in the fit of the models separated, according to the various classes of the tested fixed effects (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 Dairy crossbred cattle) and sexes (steers and bulls) raised on 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:

$$EBW = 0.8507 \times SBW^{1.0002} \quad \text{Eq. 1.3}$$

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

The Eq. 1.3 shows that the EBW-SBW ratio is practically linear in animals raised on pasture. Although the number of experiments has increased, the ratio is also fairly close to that proposed in the previous edition of the BR-CORTE (EBW = 0.863 × SBW).

For animals in a feedlot, a significant effect was observed for the sex and genetic group interaction 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), as follows:

Bulls	Zebu	$EBW = 0.8126 \times SBW^{1.0134}$	Eq. 1.4
	Crossbred	$EBW = 0.7248 \times SBW^{1.0314}$	Eq. 1.5
Steers	Zebu	$EBW = 0.6241 \times SBW^{1.0608}$	Eq. 1.6
	Crossbred	$EBW = 0.6586 \times SBW^{1.0499}$	Eq. 1.7
Heifers	Zebu	$EBW = 0.6110 \times SBW^{1.0667}$	Eq. 1.8
	Crossbred	$EBW = 0.6314 \times SBW^{1.0602}$	Eq. 1.9

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

In the previous edition of the BR-CORTE, a single linear ratio had been proposed to establish the ratio between EBW and SBW for feedlot animals (EBW = 0.895 × SBW). Considering the estimates of Eq. 1.4 to Eq. 1.9, 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 on feedlot in the previous edition of the BR-CORTE. 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 current edition, improves the accuracy and precision of the EBW estimates. Table 1.5 shows an example of applying Eq.1.3 (pasture) and Eq. 1.4 (feedlot) to estimate EBW for Zebu bulls. An example of the variability in the EBW and SBW ratios obtained from Eq. 1.4 to Eq. 1.9 is shown in Table 1.6.

Table 1.5 - Example of applying Eq. 1.3 and Eq.1.4 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	123	0.852	125	0.869
300	292	248	0.852	256	0.877
450	441	375	0.852	389	0.882
600	591	503	0.852	523	0.885

Table 1.6 - Ratio between empty body weight and shrunk body weight (EBW/SBW) in Zebu and their crosses, on feedlot, at different weights, estimated from Eq. 1.4 to Eq.1.9

SBW	Bulls		Steers		Heifers	
(kg)	Zebu	Crossbred	Zebu	Crossbred	Zebu	Crossbred
150	0.869	0.848	0.846	0.846	0.853	0.854
300	0.877	0.867	0.883	0.875	0.894	0.890
450	0.882	0.878	0.905	0.893	0.918	0.912
600	0.885	0.886	0.921	0.906	0.936	0.928

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

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 are not significant and the use of a single measurement, referenced only as ADG, can 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 nonlinear model was therefore fitted to describe the relationship between EBG and ADG, as follows:

$$EBG = 0.9630 \times ADG^{1.0151}$$

Eq. 1.10

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

An example of applying Eq. 1.10 is shown in Table 1.7. The EBG/ADG ratio ranged from 0.943–0.971, when considering gains of 0.25–1.75 kg/d. The previous edition of the BR-CORTE suggested using a fixed EBG/ADG ratio 0.955 for animals on pasture and 0.936 and 0.966 for Zebu and their crosses, respectively, on feedlot. The NRC (2000) uses a fixed relation of 0.951. The data in Table 1.7 show that the estimates proposed from Eq. 1.10 are in agreement with the data in the literature. Nevertheless, there is a gain in precision and accuracy with the use of a variable EBG/ADG ratio, obtained from the nonlinear model, as proposed for this edition of the BR-CORTE.

Table 1.7 - Ratio between the empty body gain and average daily gain (EBG/ADG) based on applying Eq. 1.10

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

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

The weight ratios presented until now are applicable to growing and finishing animals, in a condition of physiological homeostasis. That is, they are applicable to healthy animals, in a positive growth phase (intake > maintenance), that have not yet reached physiological maturity. 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 study by Gionbelli et al. (2015) is used as base for proposed weight adjustments for adult cows in this edition of the BR-CORTE, and the information described in this item was used from the referred study.

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

$$PREG = (UTpreg - UTnp) + (UDpreg - UDnp) \quad \text{Eq. 1.11}$$

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 allows to estimate portion of the weight of a pregnant cow that is function of pregnancy and the portion of the weight that is a function of the 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 10.

The equations used to estimate the fed, shrunk or empty body weight for non-pregnant and pregnant cows are described in Table 1.8. The detailed description of the abbreviations used in the equations presented in Table 1.8 is shown in Table 1.9. Because estimates of pregnant cow weight ratios require the use of several equations (Table 1.8), 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), using the link: <http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0112111>.

Table 1.8 - 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. 1.12
EBWnp	SBW	$EBWnp = 0.8424 \times SBWnp^{1.0122}$	Eq. 1.13
		Pregnant cows	
SBWpreg	BWpreg	$SBWpreg = 0.8084 \times BWpreg^{1.0303}$	Eq. 1.12
BWnp	BWpreg and PREG	$BWnp = BWpreg - PREG$	Eq. 1.14
SBWnp	SBWpreg and PREG	$SBWnp = SBWpreg - PREG$	Eq. 1.15
PREG	If $TG \leq 240$: UTfg If $TG > 240$: UTfg and UDfg	If $TG \leq 240$: PREG=UTfg If $TG > 240$: PREG = UTfg + UDfg	Eq. 1.16
UTfg	UTpreg and UTnp	UTfg = UTpreg -UTnp	Eq. 1.17
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. 1.18 Eq. 1.19
UTnp	SBWpreg and UTpreg	If $TG \leq 240$: $UTnp = 0.0012 \times (SBWpreg - UTpreg + 0.6)$ If $TG > 240$: $UTnp = 0.0012 \times (SBWpreg - UTpreg + 0.6 - 2)$	Eq. 1.20
UDnp	UTfg, SBWpreg and BCS	If $TG \leq 240$: $UDnp = (SBWpreg - UTfg) \times 0.00589 \times BCS^{0.2043}$ If $TG > 240$: $UDnp = (SBWpreg - UTfg - 2) \times 0.00589 \times BCS^{0.2043}$	Eq. 1.21
UDfg	UDnp and TG	If $TG \leq 240$: UDfg = 0 If $TG > 240$: $UDfg = UDnp \times \exp^{((TG - 238) \times 0.0109)} - UDnp$	Eq. 1.22
EBWpreg	EBWnp and PREG	EBWpreg = EBWnp + PREG	Eq. 1.23
EBWnp	SBWnp	$EBWnp = 0.8424 \times SBWnp^{1.0122}$	Eq. 1.13

Table 1.9 - List of abbreviations (in alphabetical order) used in the equations presented in Table 1.8 and the 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 1.8 (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 mean weight at birth of the calves from such herd would be 35 kg (CBW = 35 kg). The equations and ratios presented in Table 1.8 can be used to estimate the shrunk and empty body weight and maternal constituents weight along 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. 1.12) $SBWpreg = 0.8084 \times 450^{1.0303} = 437.76$ kg	$SBWpreg = 0.8084 \times BWpreg^{1.0303}$ (Eq. 1.12) $SBWpreg = 0.8084 \times 520^{1.0303} = 508.07$ kg
$UTpreg = 0.00801 \times CBW \times BCS^{0.3225} \times \exp^{((0.02544 - 0.0000286 \times TG) \times TG)}$ (Eq. 1.18) $UTpreg = 0.00801 \times 35 \times 4.5^{0.3225} \times \exp^{((0.02544 - 0.0000286 \times 150) \times 150)} = 10.87$ kg	$UTpreg = 0.00801 \times CBW \times BCS^{0.3225} \times \exp^{((0.02544 - 0.0000286 \times TG) \times TG)}$ (Eq. 1.18) $UTpreg = 0.00801 \times 35 \times 5^{0.3225} \times \exp^{((0.02544 - 0.0000286 \times 270) \times 270)} = 56.33$ kg
$UTnp = 0.0012 \times (SBWpreg - UTpreg + 0.6)$ (Eq. 1.20) $UTnp = 0.0012 \times (437.76 - 10.87 + 0.6) = 0.51$ kg	$UTnp = 0.0012 \times (SBWpreg - UTpreg + 0.6 - 2)$ (Eq. 1.20) $UTnp = 0.0012 \times (508.07 - 56.33 + 0.6 - 2) = 0.54$ kg
$UTfg = UTpreg - UTnp$ (Eq. 1.17) $UTfg = 10.87 - 0.51 = 10.36$ kg	$UTfg = UTpreg - UTnp$ (Eq. 1.17) $UTfg = 56.33 - 0.54 = 55.79$ kg
$UDnp = (SBWpreg - UTfg) \times 0.00589 \times BCS^{0.2043}$ (Eq. 1.21) $UDnp = (437.76 - 10.36) \times 0.00589 \times 4.5^{0.2043} = 3.42$ kg	$UDnp = (SBWpreg - UTfg) \times 0.00589 \times BCS^{0.2043}$ (Eq. 1.21) $UDnp = (508.07 - 55.79) \times 0.00589 \times 5^{0.2043} = 3.68$ kg
$UDfg = 0$ kg (Eq. 1.22)	$UDfg = UDnp \times \exp^{((TG-238) \times 0.0109)} - UDnp$ (Eq. 1.22) $UDfg = 3.68 \times \exp^{((TG-238) \times 0.0109)} - 3.68 = 1.54$ kg
PREG = UTfg (Eq. 1.16) PREG = 10.36 kg	PREG = UTfg + UDfg (Eq. 1.16) PREG = 55.79 + 1.54 = 57.33 kg
SBWnp = SBWpreg – PREG (Eq. 1.15) SBWnp = 437.76 – 10.36 = 427.40 kg	SBWnp = SBWpreg – PREG (Eq. 1.15) SBWnp = 508.07 – 57.33 = 450.75 kg
$EBWnp = 0.8424 \times SBWnp^{1.0122}$ (Eq. 1.13) $EBWnp = 0.8424 \times 427.40^{1.0122} = 387.66$ kg	$EBWnp = 0.8424 \times SBWnp^{1.0122}$ (Eq. 1.13) $EBWnp = 0.8424 \times 450.75^{1.0122} = 409.10$ kg
EBWpreg = EBWnp + PREG (Eq. 1.23) EBWpreg = 387.66 + 10.36 = 398.01 kg	EBWpreg = EBWnp + PREG (Eq. 1.23) 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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2

Regulation and prediction of dry matter intake

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INTRODUCTION

Dry matter intake (DMI) is the most important variable affecting animal performance (Waldo and Jorgensen, 1981), because it guarantees the organism adequate nutrients and energy substrates for biochemical reactions that contribute to oscillations in cell metabolism, especially in cattle for meat production. 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 are necessary 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 the majority of the nutrients of the beef cattle diet are used to meet maintenance requirements, a small alteration 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 indication that the solitary tract nucleus (STN), in the brain stem, works as 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 considered responsible for feeding disorders and inadequate energy storage or conservation. The arcuate nucleus (ARC) and the paraventricular nucleus (PVN) are also important centers in 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 of satiation 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 satiation (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 satiation center in the ventromedial hypothalamus (Konturek et al., 2005). Thus, feed intake could be stimulated by the absence of satiation signals (Allen et al., 2005).

Therefore, the hypothalamic nucleus does not act separately in the context of energy homeostasis control but rather 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 in order to maintain the body weight and make sufficient energy available for all the metabolic processes

(Dietrich and Horvath, 2009). According to Forbes and Provenza (2000), 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 in 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).

In this way, the 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 to the hypothalamus via the ARC to mediate appetite stimuli (+), that are activated by neurons that secrete Y neuropeptide (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 satiation center in the PVN in the mid-hypothalamus (Currie et al., 2005).

In one study about the intake control center in ruminants, Miner (1992) suggested that YNP is a neurotransmitter involved in 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 increase in insulin plasma levels is stimulated by YNP;
- Ghrelin, is mostly produced (60%) by the stomach and stimulates the YNP / AgRP neurons through receptors that secrete the growth hormone (GH);
- YY 3-36 (PYY3-36) peptide is secreted in the distal gastrointestinal tract, and has an affinity with and bonds to the Y2 (Y2Rs) receptors, produces 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, that can be stimulated from 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 that also receive afferent modifications for signals from dopamine, serotonin and endocannabinoids; and
- These effector neurons express receptors that include the Y1 receptor (Y1R) and the melanocortin 4 receptor.

Among the anorexigenic peptides, the first recognized feed intake inhibitor was cholecystokinin (CCK), 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 digestive tract distension, and are transmitted to the brain by the afferent vagus nerve (Konturek et al., 2005).

However, in ruminants, there is a longer 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, 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 intake 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), in its DMI prediction model, 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 alterations 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 increase in BW. Body composition, specifically the body fat percentage, seems to be the main component that affects the DMI (NRC, 1987). According to Grant and Helferich (1991), this is due to the deceleration of the muscle growth and adipose tissue development, with the increase in BW. Fox et al. (1988) suggested altering the DMI when cattle presented empty body fat percentage higher than 21.3%. Jorge et al. (1997) observed higher body fat percentage (24.41) for Nellore animals compared to beef crossbred (21.62%) and dairy crossbred cattle (19.50%). Fox et al. (1988) suggested reducing the DMI by 3, 10, 18 and 27% when the empty body fat percentage was, respectively, 23.8, 26.5, 29.0 and 31.5%.

d) Sex

Marcondes et al. (2008), Véras et al. (2008) and Lage et al. (2012) did not report influence from the sexes: heifers, steers and bulls for DMI, but Paulino et al. (2008) observed that DMI was greater in heifers compared to bulls, while the steers DMI did not differ from either.

The NRC (1984) suggested that 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 for greater body fat accumulation at an earlier time-point in comparison to males. As fat indirectly influences DMI, by 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 increase in BW. Thus, the sex effect cannot be considered in isolation because the body condition or body

fat percentage is directly influenced by sex. According to Huuskonen et al. (2013), sex influence on the 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 the cattle herd distribution is concentrated mainly in the states of Mato Grosso, Minas Gerais, Mato Grosso do Sul and Goiás, that together represent more than 40% (Alvares et al., 2013; Teixeira and Hespanhol, 2015).

Regarding to 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 by 35%.

Ingvartsen et al. (1992) assessed the effect of day length on DMI capacity and observed that the expected DMI may be 1.5 to 2% larger on long days and 1.5 to 2% smaller 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 the 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 due mainly 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 located, mainly, 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 function in an integrated manner to create positive or negative signal on voluntary dry matter intake (Detmann et al., 2014).

NDF intake, or its diet concentration, is associated to 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 recommend qualitative discrimination of the NDF and lignin fractions for their efficacious use in DMI prediction models.

With regard to 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 the DMI is regulated

simultaneously by physical and physiological limitations.

The protein deficiency (<7–8% CP) is another diet characteristic that can decrease DMI, because it limits the 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 of these factors should be taken into account 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).

PREDICTION OF DRY MATTER INTAKE FOR FEEDLOT CATTLE

To plan an efficient feeding program capable to find the best feed management to meet nutrient requirements, it is necessary to predict with 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 was possible to include all the physiological, environmental, diet and management factors that interfere in the DMI, the model obtained might 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 commonly used prediction models in Brazil. However, the models proposed by the NRC (1984, 2000) were developed mainly with *Bos taurus taurus* animals. According to ANUALPEC (2015), 80% of the Brazilian herd consists of Zebu cattle, with an estimate of 150 million Zebu. The contribution of the 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 the Brazilian meat production systems. The Nellore breed is predominant in the beef production systems in Brazil.

Fox et al. (1988) observed that the genetic group is recognized as one of the factors that interferes in the 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 n^{o} 51 (Brasil, 1991) is in force that prohibits production, importation, commercialization and use of products for purposes of growth and weight gain in slaughter animals. Non-steroid compounds with anabolizing effect 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 beef crossbred database, 10 dissertations and/or theses were

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

where: BW = mean 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 efficient for DMI predictions by breed and for Zebu cattle overall.

Valadares Filho et al. (2006a) also observed 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 (2006).

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 ignoring 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 Valadares Filho 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 University of São Paulo. The BR-CORTE (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 $BW^{0.75}$ = mean metabolic body weight (kg) and ADG = average daily gain (kg/d).

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

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 pen collective, representing 632,306 animals on three commercial feedlot collected over a four-year period (2003 to 2006), they concluded that the equations proposed by the NRC (1996) were not useful to predict DMI of commercial feedlot cattle and suggested the need to develop new, and more exact 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) reported that it was disappointing to know that their research managed to improve only a little the prediction capacity for DMI, and recognized difficulty to develop precise DMI predictions for growing and finishing beef cattle. The influence of the complex factors that control DMI makes difficult to adequately explain DMI biological performance using regression mathematical models and some independent variables.

According to Anele et al. (2014), the BCNRM (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 mean metabolic body weight for the feeding period. For diets with NEm concentration ≤ 0.95 Mcal/kg MS, the BCNRM (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 BCNRM (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 = mean body weight (kg). The BCNRM suggests there is no reason to recommend a single equation to estimate DMI.

Based on the validation study by Galyean et al. (2011), the BCNRM (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:
$DMI\ (kg/d) = 3.83 + 0.0143 \times iSBW$;

- Heifers:
$DMI\ (kg/d) = 3.184 + 0.01536 \times iSBW$,

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 the production situations. 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 the productivity indexes. For these indexes to continue increasing to reduce production costs and make the end 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 took into account. Likewise, 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 the various production factors.

DESCRIPTION OF DATABASE USED TO PREDICT NEW MODELS FOR FEEDLOT CATTLE

Brazil is a country with continental dimensions. There is wide climatic diversity that permits raising cattle of predominantly Zebu breeds and also the use of different genetic groups specialized in meat production to obtain benefits from the hybrid vigor to increase the 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 as beef cattle. Faced by 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), beef crossbred cattle (animals derived from crosses of Zebu with breeds specialized in meat production, predominantly Angus x Nellore) and dairy crossbred cattle (animals derived from crosses of Zebu with breeds specialized in milk production, mainly Holstein).

An updated database is needed to generate DMI prediction models capable of being biologically representative and explaining the greater percentage in variation observed in the DMI of cattle under tropical conditions. For this, the database that was used to predict DMI in the BR-CORTE (2010) was increased from 360 to 649 experimental units (EU) with Zebu cattle and from 201 to 679 EU with beef or dairy crossbred cattle (Table 2.1). The database increased to 1,328 EU, derived from research on growing or finishing cattle, with recorded individual intake that also respected an adaptation period to minimize the impact of compensatory growth on DMI. The complete references of the origin of the database used to develop the equations can be accessed in appendix 2.1 in www.brcorte.com.br/en.

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 obtained, in the face of the universe of diets used for cattle for beef production under tropical conditions and their possible interactions with genetic group and interference in the DMI regulation patterns.

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

Variable	N	Mean	SD	Minimum	Maximum
Zebu cattle					
Feedlot, days	649	106	45.1	42.0	271
Initial body weight, kg	649	308	72.8	110	475
Final body weight, kg	649	400	84.4	125	580
ADG, kg/d	649	0.92	0.42	-0.36	1.84
Intake					
Dry matter, kg/d	649	7.39	2.12	1.29	13.2
NDF, kg/d	472	3.17	1.17	0.79	7.61
iNDF, kg/d	388	1.24	0.55	0.13	2.43
Crude protein, kg/d	472	0.98	0.28	0.29	1.74
TDN, kg/d	470	4.84	1.56	1.00	10.2
Beef crossbred 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
Dairy crossbred 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.

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 dairy crossbred genetic groups. In face of the results of the Pearson correlation, the $BW^{0.75}$ and ADG were adopted as variables to be used in the DMI prediction models.

According to St-Pierre (2001), the study effect need to be verified on the database. Study effect was observed ($P<0.0001$) and this was considered in the further analysis.

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

Zebu cattle:
DMI (kg/d) = – 1.7824 + 0.07765 × $BW^{0.75}$ + 4.0415 × ADG – 0.8973 × ADG^2
(R^2 = 0.821) (Equation 2.1)

Beef crossbred cattle:
DMI (kg/d) = – 0.6273 + 0.06453 × $BW^{0.75}$ + 3.871 × ADG – 0.614 × ADG^2
(R^2 = 0.626) (Equation 2.2)

Dairy crossbred cattle:
DMI (kg/d) = – 2.8836 + 0.08435 × $BW^{0.75}$ + 4.5145 × ADG – 0.9631 × ADG^2
(R^2 = 0.788) (Equation 2.3)

The negative coefficient for the ADG^2 (kg/d) variable for all the equations fitted 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 was to reach maximum ADG, the diet energy concentration must have been high, inhibiting DMI, that suggests the theory of energy intake regulation proposed by Mertens (1994).

Considering the importance of this effect, the NRC (2000) proposed equations that included the 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, DMI is represented in the form of a curve where the initial DMI increases gradually as a function of DOF due to increase in the body fat content of the feedlot animals. Fat starts to concentrate slowly in the carcass at the beginning of the feeding period, but accumulates rapidly at the end of the feeding period (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 (complete references can be accessed in Appendix 2.2 at www.brcorte.com.br/en) were compiled and used to construct a database to validate the DMI prediction equations for Zebu cattle and beef and dairy crossbred finishing on feedlot under tropical conditions (Table 2.2).

Table 2.2 shows 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 a large number of diets was used. It can be observed that the selection criterion used was efficacious, permitting good representativeness, 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, beef and dairy crossbred (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, on feedlot under tropical conditions.

Table 2.4 shows the dry matter intake estimated for Zebu, beef and dairy crossbred cattle finished on feedlot, obtained for different body weight and weight gains.

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

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
Beef crossbred 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
Dairy crossbred 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 beef and dairy crossbred cattle on feedlot

Variable	Zebu	Beef crossbred	Dairy crossbred
Intercept	-0.8375	-1.5386	0.6697
P-value[1] (H_0: a = 0)	0.5313	0.2022	0.0710
Slope	1.0759	1.1316	0.9449
P-value[2] (H_0: b = 1)	0.6108	0.3150	0.3112
r^2	0.4085	0.4087	0.8704
Mean bias	-0.1586	-0.3329	0.3189
CCC	0.5522	0.5262	0.9234
MSEP	0.6874	1.3306	0.7557
Decomposition of the MSEP			
Mean bias	0.0252 (3.66%)	0.1108 (8.33%)	0.1017 (13.46%)
Systemic error	0.0023 (0.33%)	0.0113 (0.85%)	0.0146 (1.93%)
Random error	0.6600 (96.01%)	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 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)

Table 2.4 - Dry matter intake estimated for Zebu, beef and dairy crossbred cattle finishing on 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)	Beef crossbred (Equation 2.2)	Dairy crossbred (Equation 2.3)
200	0.75	4.87	5.36	4.45
	1.00	5.49	6.06	5.15
	1.25	6.00	6.68	5.74
	1.50	6.39	7.23	6.21
	1.75	6.67	7.70	6.55
250	0.75	5.63	5.99	5.26
	1.00	6.24	6.69	5.97
	1.25	6.75	7.31	6.56
	1.50	7.14	7.85	7.02
	1.75	7.42	8.32	7.37
300	0.75	6.34	6.58	6.04
	1.00	6.96	7.28	6.75
	1.25	7.46	7.90	7.33
	1.50	7.86	8.45	7.80
	1.75	8.14	8.92	8.15
350	0.75	7.03	7.15	6.79
	1.00	7.65	7.85	7.49
	1.25	8.15	8.47	8.08
	1.50	8.54	9.02	8.55
	1.75	8.83	9.49	8.89
400	0.75	7.69	7.70	7.51
	1.00	8.31	8.40	8.21
	1.25	8.81	9.02	8.80
	1.50	9.21	9.57	9.27
	1.75	9.49	10.0	9.61
450	0.75	8.33	8.24	8.20
	1.00	8.95	8.93	8.91
	1.25	9.45	9.56	9.50
	1.50	9.85	10.10	9.96
	1.75	10.1	10.6	10.3
500	0.75	8.95	8.75	8.88
	1.00	9.57	9.45	9.59
	1.25	10.08	10.08	10.17
	1.50	10.5	10.6	10.6
	1.75	10.8	11.1	11.0

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

Diets with high concentrate levels have recently become economically viable because of the increase in roughage production costs, temporary reductions in concentrate prices and increased offers of by-products from industry (Cervieri et al., 2009). With the increasing use of diets with high concentrate levels for feedlot cattle in Brazil, adequate nutritional management has become necessary and for this to happen it is fundamental to predict the DMI.

Data considered valid for selection were those that included information regarding to: 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 complete references from the database used to develop the equations can be accessed in Appendix 2.3 (www.brcorte.com.br/en).

The descriptive statistic of the data used to validate DMI prediction of cattle fed a fixed concentrate level diet is shown in Table 2.5.

The following equations were obtained for the genetic groups:

Zebu cattle:

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

Beef crossbred cattle:

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

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

Table 2.5 - 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
Beef crossbred 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.

An independent database was used to validate the results with 106 experimental units for Zebu and 137 for beef crossbred (Table 2.6). 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 da Indústria Animal* and these references can be accessed in Appendix 2.4 (www.brcorte.com.br/en).

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 2.6).

Table 2.6 - Descriptive statistics of the variables used to validate dry matter intake prediction by cattle fed different concentrate level

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
Beef crossbred 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.

The results observed in Table 2.7 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.

Table 2.7 - Statistics for the ratio between the observed and predicted values by the DMI prediction equations for cattle fed with different concentrate level

Item	Zebu cattle	Beef crossbred cattle
Intercept	-1.3568	0.9373
P-value[1] (H_0: a = 0)	0.0623	0.2379
Slope	1.1577	0.9390
P-value[2] (H_0: b = 1)	0.0582	0.5064
r^2	0.6552	0.4377
Mean bias	0.0105	0.4144
Concordance correlation coefficient	0.7602	0.5920
Mean square prediction error	0.9254	1.3961
Decomposition of the mean square prediction error		
Bias square	0.0001 (0.01%)	0.1717 (12.30%)
Systemic bias	0.0315 (3.41%)	0.0040 (0.29%)
Random errors	0.8938 (96.58%)	1.2203 (87.41%)

[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 the parameter b = 1 (Neter et al., 1996)

Based on Equations 2.4 and 2.5, the Table 2.8 shows the estimated dry matter intake for Zebu and beef crossbred finishing on feedlot obtained for different body weights and weight gains, considering three concentrate contents (30, 60 and 90%) in the diet.

Table 2.8 - Dry matter intake for Zebu and beef crossbred cattle finishing on 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)	Beef crossbred (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

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 under pasture (IBGE, 2007). It also has 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 obtained with animals on pasture and only 11.1% were finished on feedlot (ABIEC, 2014) of the 42 million cattle slaughtered in Brazil in 2014 (Anualpec, 2015).

According to Paulino et al. (2005), sustainable pasture use for beef cattle production should be highlighted, because these resources are the main and 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 also 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 the DMI. Furthermore, animals on pasture are able to 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 on 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 do not usually 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 adjustment 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.

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 replacement, values lower than 1.0 g/g are assumed, and reduction is observed in pasture intake, but there is increase in total intake (Costa et al., 2011).

Considering the importance of the DMI estimate for pasture-raised cattle under tropical conditions receiving supplementation, the specific prediction model is recommended that takes into consideration the supplement intake (SI, kg/d). The database used to develop this equation and the complete references can be accessed in appendix 2.5 in www.brcorte.com.br/en.

Wide variation in the data was observed in the information regarding the descriptive statistics of the database (Table 2.9), so that prediction equations could be generated for more varied production systems.

Table 2.9 - Descriptive statistics of the variables used to predict dry matter intake for Zebu raised on pasture

Variable	N	Mean	SD	Minimum	Maximum
Mean body weight, kg	946	274	86.0	102	568
Metabolic body weight, kg	946	66.9	15.5	32.1	116
Average daily gain, kg/d	929	0.49	0.30	-0.39	1.14
Intake					
Dry matter, kg/d	944	5.20	2.08	1.21	14.6
Supplement, kg/d	948	0.78	0.61	0.00	4.42

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

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

Zebu cattle supplemented on pasture:

$$DMI\ (kg/d) = -1.912 + 0.900 \times SI + 0.094 \times BW^{0.75} + 1.070 \times ADG - 1.395 \times ADG^2 \quad (R^2 = 0.600)\ \text{(Equation 2.6)}$$

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

This equation was validated using an independent database from the following journals: *Revista Brasileira de Zootecnia*, *Arquivo Brasileiro de Medicina Veterinária e Zootecnia*, *Semina: Ciências Agrárias*, Asian-Australasian Journal of Animal Sciences, Bioscience Journal, Acta Scientiarum.Animal Sciences, *Enciclopédia Biosfera*, and *Pesquisa Agropecuária Brasileira*. The complete references can be accessed in Appendix 2.6 (www.brcorte.com.br/en).

The total size of the variables presented in the database for validating the intake prediction for Zebu cattle raised on pasture (Table 2.10) represents Brazilian characteristics of extensive beef cattle pasture and supplemented production systems and it is sufficiently representative to validate the equation.

Table 2.10 - Descriptive statistic of the variables used to validate the dry matter intake prediction equation for Zebu cattle raised on pasture

Variable	N	Mean	SD	Minimum	Maximum
Mean body weight, kg	135	335	80.3	133	474
Metabolic body weight, kg	135	77.9	14.6	39.2	102
Average daily gain, kg/d	135	0.59	0.27	-0.18	1.34
Intake					
Dry matter, kg/d	135	6.93	2.24	1.98	12.3
Supplement, kg/d	135	1.25	1.22	0.00	5.32

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

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 2.11), indicating that it could be applied to pasture-raised and supplemented animals.

Table 2.11 - Statistics for the ratio between observed and predicted values by the dry matter intake prediction equation for Zebu cattle raised on pasture

Item	Zebu cattle raised on pasture
Intercept	0.5336
P-value [1] (H_0: a = 0)	0.1675
Slope	0.9699
P-value [2] (H_0: b = 1)	0.5911
r^2	0.69
Mean bias	0.3348
Concordance correlation coefficient	0.8124
Mean square error of prediction	1.651
Decomposition of the mean square error of prediction	
Mean bias	0.1121 (6.79%)
Systematic error	0.0034 (0.20%)
Random error	1.5355 (93.01%)

[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 the parameter b = 1 (Neter et al., 1996).

Thereby, the Equation 2.6 should be used to predict the DMI in animals under stocking conditions and those that receive moderate concentrate levels (up to 4.5 kg/d) and present moderate weight gains (up to 1.15 kg/d). It should further be taken in mind that the majority of the data used to develop this equation were obtained in dry season periods.

The intake estimated by Equation 2.6 are shown in the Table 2.12 along with variations of combinations between body weight, daily gain and supplement intake.

Table 2.12 - Dry matter intake (DMI) estimated for grass-finishing cattle with different body weights, weight gains and supplement intake (SI)

Body weight (kg)	Weight gain (kg/d)	SI (kg/d)	DMI Eq. 2.6
200	0.00	0.00	3.09
		0.80	3.81
		1.60	4.53
	0.50	0.00	3.27
		0.80	3.99
		1.60	4.71
	1.00	0.00	2.76
		0.80	3.48
		1.60	4.20
300	0.00	0.00	4.86
		1.20	5.94
		2.40	7.02
	0.50	0.00	5.05
		1.20	6.13
		2.40	7.21
	1.00	0.00	4.54
		1.20	5.62
		2.40	6.70
400	0.00	0.00	6.50
		1.60	7.94
		3.20	9.38
	0.50	0.00	6.68
		1.60	8.12
		3.20	9.56
	1.00	0.00	6.17
		1.60	7.61
		3.20	9.05
500	0.00	0.00	8.03
		2.00	9.83
		4.00	11.6
	0.50	0.00	8.21
		2.00	10.0
		4.00	11.8
	1.00	0.00	7.70
		2.00	9.50
		4.00	11.3

DEVELOPMENT OF EQUATIONS TO PREDICT RESIDUAL FEED INTAKE AND RESIDUAL WEIGHT GAIN OF ZEBU IN BRAZIL

Brazil has an outstanding position as a supplier of animal protein to the world population. In recent years, it has been the biggest or second-biggest exporter of beef and has the biggest commercial cattle herd in the world (about 200 million head) (Anualpec, 2015).

Brazilian beef cattle system has gone through deep transformations in the domestic market, mainly from the moment when competitiveness and market demands increased for sustainable meat production, under all aspects (economic, social and environmental) and also for cheap high quality beef production, that are now

understood as nutritional and feed safety qualities.

To adapt to these changes, entrepreneurs in the agricultural sector have become increasingly required to use technologies coherent with the biological, social and economic environments, ensuring sustainable development, feed safety and production conciliated with environmental conservation.

To reach this aim, efficiency must be increased in the cattle production systems to ensure productivity increases and fewer environmental impacts, that is, there is no demand for just meat production but rather for feed with high aggregated value, produced at low costs and environmentally correct, with low greenhouse gas and residue emission, without needing to use areas currently occupied with native vegetation or destined for grain production.

Due to new challenges to increase efficiency in the sustainable meat production system, the efficiency of nutrient use in the diet is important. The efficient use of nutrients in the diet is one of the premises of sustainable animal production systems, because this approach could minimize or even prevent excessive nutrient losses that are damaging to the environment and affect the economic feasibility of raising cattle.

Therefore, selecting individuals that are genetically superior with regard to feed efficiency becomes urgent. Lastly, knowledge of DMI and the nutrient requirements of the cattle are the basis of precision nutrition because diets that are properly balanced with respect to daily energy, protein and mineral needs result in rational feed use and consequently contribute to minimizing environmental impacts and production costs. Thereby, optimizing the competiveness, profit and sustainability of raising beef cattle, and also knowing how to select the best individuals using these tools is a task that has been developed in a different way by many ranchers.

Information on residual feed intake (RFI) has been used as an alternative approach to identify more efficient animals in beef cattle genetic breeding programs in Brazil. However, according to Berry and Crowley (2012), RFI is not correlated with ADG, and although RFI may be a good indicator of feed efficiency, it cannot be accepted by all producers. The authors affirmed that selecting the best individuals based on RFI may result in the selection of slow-growing individuals that consume relatively small quantities of DM. Residual body weight gain (RG) (Crowley et al., 2010) is similar to the RFI but has the disadvantage of selecting individuals with fast growth rates that nonetheless consume large quantities of dry matter. Considering the inconveniences of each one of these factors, Berry and Crowley (2012) proposed an index named residual intake and body weight gain (RIG) that would consider the following equation: RIG = –RFI + RG.

For this proposal to impact the breeding of the Brazilian herd, DMI and ADG prediction models that can be used reliably by breeders are needed. Based on the database of Zebu animals (Table 2.1), Zebu DMI and ADG prediction models were developed in Brazil as follows:

$$DMI\ (kg/d) = -1.5187 + 0.07941 \times BW^{0.75} + 2.6519 \times ADG \quad (R^2 = 0.813) \qquad \text{(Equation 2.7)}$$

$$ADG\ (kg/d) = 0.3285 - 0.01113 \times BW^{0.75} + 0.2041 \times DMI \quad (R^2 = 0.598) \qquad \text{(Equation 2.8)}$$

To verify the RFI and RG value distribution in the database, ratios were established between RFI and weight gain (Figure 2.1) and between RG and weight gain (Figure 2.2).

Differences were observed when using RFI, RG or RIG values to select the 10% best animals present in the database (Table 2.13).

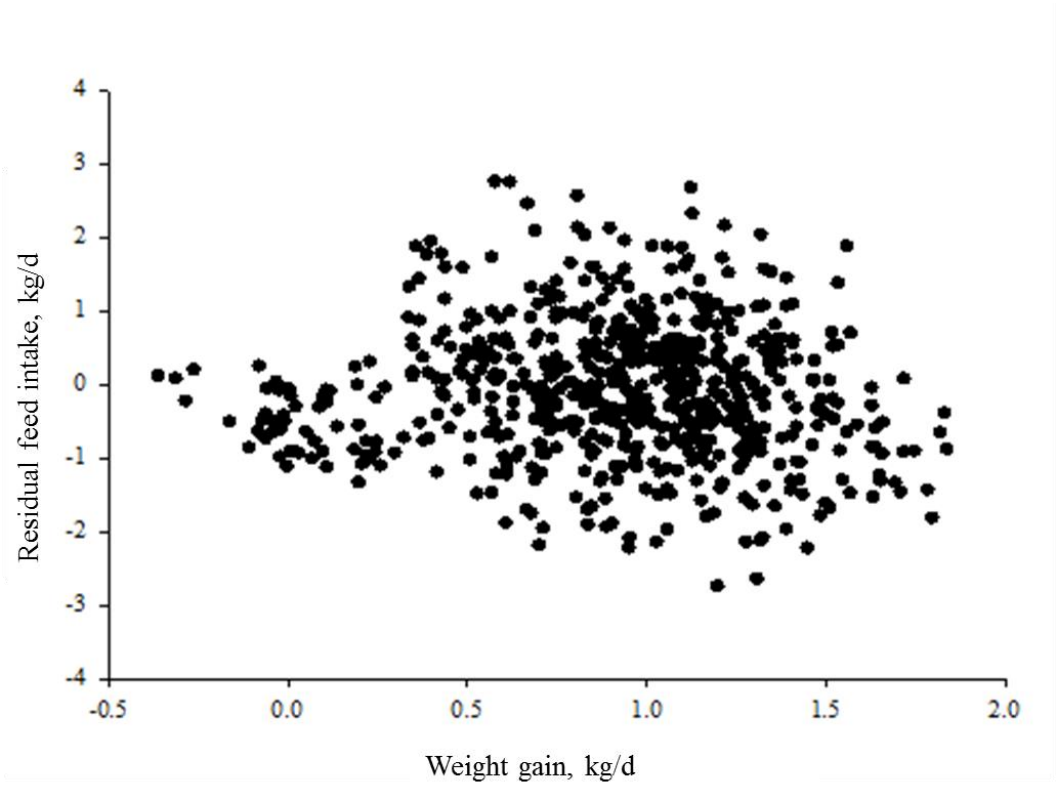

Figure 2.1 - Residual feed intake as a function of weight gain of Zebu cattle.

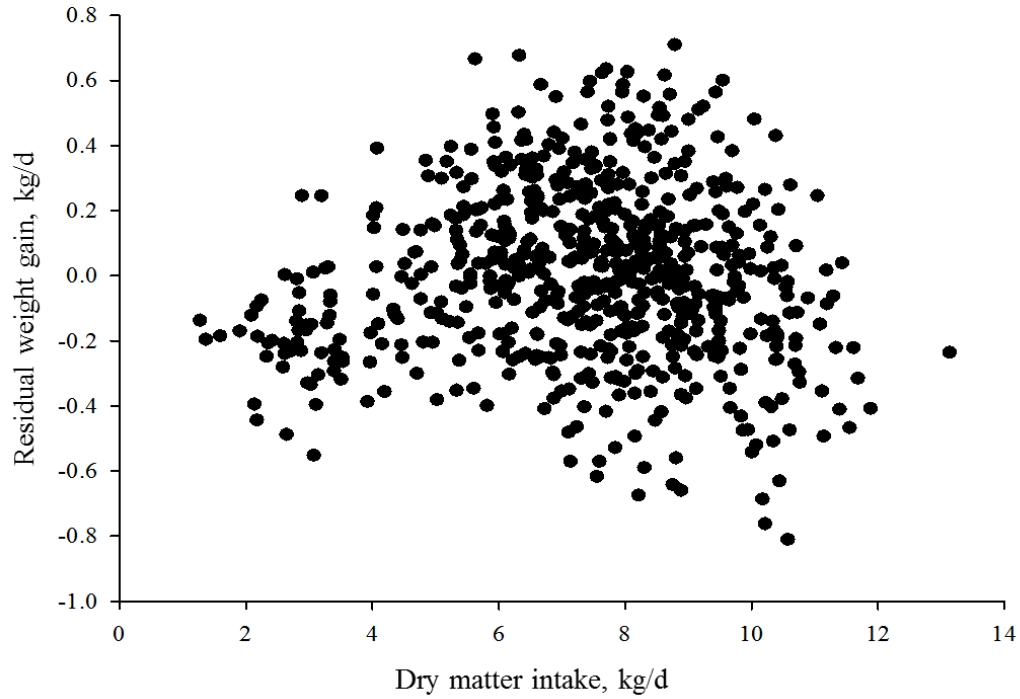

Figure 2.2 - Residual weight gain as a function of dry matter intake of Zebu cattle.

Table 2.13 - Descriptive statistics for the values of the 10% best individuals in the Zebu database for residual feed intake, residual body weight gain and, residual feed intake and body weight gain together

Variable	N	Mean	SD	Minimum	Maximum
Residual feed intake (RFI)					
Initial body weight, kg	64	327	60.7	199	448
Final body weight, kg	64	439	58.4	300	548
Mean body weight, kg	64	393	54.7	257	483
Average daily gain, kg/d	64	1.12	0.37	0.20	1.80
Dry matter intake, kg/d	64	6.96	1.25	4.03	9.56
Residual body weight gain (RG)					
Initial body weight, kg	64	308	61.5	158	446
Final body weight, kg	64	441	67.5	210	548
Mean body weight, kg	64	374	58.6	184	483
Average daily gain, kg/d	64	1.41	0.24	0.84	1.84
Dry matter intake, kg/d	64	7.62	1.32	4.09	10.4
Residual intake and body weight gain (RIG)					
Initial body weight, kg	64	325	60.8	199	448
Final body weight, kg	64	444	55.8	300	548
Mean body weight, kg	64	390	52.6	257	483
Average daily gain, kg/d	64	1.21	0.33	0.53	1.80
Dry matter intake, kg/d	64	7.11	1.21	4.09	9.56

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

Thereby, on average, the selection for RFI selects animals with lower DMI compared to selection for residual body weight gain. For residual body weight gain there was selection of animals for bigger ADG compared to selection for RFI. However, when the selection of the 10% best was carried out by RIG, the RFI and RG values converged to select the best individuals with intermediate DMI and ADG among the mean values observed for RFI and RG, so there were smaller variations between the minimum and maximum values.

An independent database based on the study by Zanetti et al. (2016, work in progress), using 42 Zebu with 8-month old bulls (from the Beef cattle sector at UFV), generated in the same mating season and on feedlot *ad libitum* receiving, in individual pens, diet with 60% concentrate, with data collection after the acclimation period, to prevent compensatory weight gain was used. The results of genetic selection work for weight gain in Nellore cattle, showed that if Equation 2.7 was used to obtain the RFI or Equation 2.8 to obtain the RG, 77.5% of the bulls would have negative RFI, and 50% would have 0 to -0.5 kg/d RFI. In selection for RG, it was observed that 80% of the bulls had positive RG varying from 0 to 0.5 kg/d.

Selecting the animals with the ten highest RIG values (Table 2.14) showed the efficiency of the equations that were developed to predict DMI and ADG in beef cattle genetic breeding programs, and the most efficient were in an intermediate situation between the best RFI and the best RG.

Table 2.14 - Values of residual intake and body weight gain (RIG), residual feed intake (RFI), residual body weight gain (RG), dry matter intake (DMI) and average daily gain (ADG) of the 10 best Zebu for RIG

Animal	RIG	RFI	RG	ADG	DMI
1	3.47	-0.77	0.33	1.33	7.81
2	3.46	-0.73	0.34	1.35	7.77
3	3.13	-0.85	0.27	1.17	7.37
4	2.80	-0.58	0.32	1.12	7.40
5	2.24	-0.53	0.27	1.35	8.36
6	2.25	-0.68	0.23	1.12	7.10
7	2.09	-0.43	0.29	1.38	8.18
8	1.84	-0.47	0.25	1.15	6.62
9	1.70	-0.59	0.20	1.07	6.92
10	1.24	-0.38	0.21	1.17	7.26

FINAL CONSIDERATIONS

The equations to predict dry matter intake for feedlot cattle under tropical conditions are:

Zebu cattle: $DMI\ (kg/d) = -1.7824 + 0.07765 \times BW^{0.75} + 4.0415 \times ADG - 0.8973 \times ADG^2$ (Equation 2.1)

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

Dairy crossbred cattle: $DMI\ (kg/d) = -2.8836 + 0.08435 \times BW^{0.75} + 4.5145 \times ADG - 0.9631 \times ADG^2$ (Equation 2.3)

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

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

Beef crossbred cattle: $DMI\ (kg/d) = -4.8196 + 0.0081 \times CL - 0.00011 \times CL^2 + 0.1239 \times BW^{0.75} + 2.8189 \times ADG - 0.775 \times ADG^2$ (Equation 2.5)

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

$DMI\ (kg/d) = -1.912 + 0.900 \times SI + 0.094 \times BW^{0.75} + 1.070 \times ADG - 1.395 \times ADG^2$ (Equation 2.6)

The following prediction equations are suggested for use in the **genetic improvement of Zebu cattle**:

$DMI\ (kg/d) = -1.5187 + 0.07941 \times BW^{0.75} + 2.6519 \times ADG$ (Equation 2.7)

$ADG\ (kg/d) = 0.3285 - 0.01113 \times BW^{0.75} + 0.2041 \times DMI$ (Equation 2.8)

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3

Protein ruminal degradation of feeds and microbial protein synthesis

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Ruminants are a group of animals characterized by intake of diets that are altered in rumen by anaerobic microorganisms. These microorganisms obtain 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 protein source for digestion in the small intestine of ruminants. Thus, to find an appropriate recommendation regarding protein requirements for cattle, we must characterize changes imposed by these microorganisms and the amount of microbial crude protein that arrives in small intestine with a specific diet.

INTRODUCTION

The potentially fermentable protein pool in rumen includes the nitrogenous compounds from the diet, besides the endogenous protein from saliva, and scurf and lysed rumen microorganisms in the rumen (NRC, 2001). This protein pool that undergoes significant changes in this compartment is named rumen degradable protein (RDP). Thus, the protein nutrition of ruminants is dependent on the magnitude and profile of that pool that reaches small intestine for absorption as amino acids plus the dietary protein which does not suffer degradation in the rumen, also named rumen undegradable protein (RUP). The set of all amino acids that are available for intestinal absorption is denoted as metabolizable protein (MP). Thus, to obtain the values of nutritional requirements of MP and crude protein (CP) for beef cattle, it is assumed that one should know the changes that the rumen requires to the nitrogenous compounds from the diet. For this, it is necessary to know the microbial crude protein (MCP) that is produced in the rumen when providing certain diet, as well as the factors that affect the production efficiency of this protein and, to understand digestion and absorption of the protein in the gastrointestinal tract.

The literature shows different methods to estimate the nitrogen partitioning of diet into RDP and RUP and their intestinal digestibility. These methods include reviews *in vivo*, *in situ* and a variety of *in vitro* methods (Schwab et al., 2003). Taking into account the accuracy of these methods, *in vivo* method presents a characteristic to provide reliable estimates of what happens in the digestion of nutrients. However, *in vivo* techniques require a lot of feed, great number of replicates to avoid variations related to animal and it does not allow generating results for concentrated feed alone. Furthermore, the majority of the *in vivo* assay protocols need cannulated animals, not only in the rumen, but also in other compartments, such as abomasum and ileum. This represents a source of stress that may alter animal performance (Harmon and Richards, 1997). Thus, the cost to obtain an adequate number of replicates plus the cost of maintenance of animals, and the number of samples can make *in vivo* studies costly; this has led to increase the interest of using *in vitro* and *in situ* techniques (Broderick and Cochran, 2000).

The validation of protocols that allow the use of *in vitro* and *in situ* techniques in an accurately and precisely manner is an alternative to obtain estimates for ruminal protein degradation. The estimated total microbial nitrogen synthesis can also be performed using *in vivo* techniques with the use of microbial markers also associated with the operational disadvantages and conflicting with the principles of animal welfare. Thus,

alternative techniques, such as the use of urinary purine derivatives (PD), can be used to quantify the microbial nitrogen that leaves the rumen and reaches small intestine for absorption as amino acid. The microbial crude protein synthesized in the rumen can meet most of the amino acids required for the maintenance and growth for cattle (Titgemeyer and Merchen, 1990); taking into account that diet can affect efficiency which occurs the microbial growth and thereby the amino acid supply. Moreover, the ability to measure the microbial production and efficiency as a function of offered diet is an essential tool to estimate the MP requirements. Also, intestinal digestibility of the microbial true crude protein can be estimated, since the nucleic acids are not used in the synthesis of body tissues and milk proteins (AFRC, 1993). So, these nucleic acids should be discounted to estimate the MP requirements for beef cattle. The objective of this chapter is to discuss the main techniques involved in estimating RDP and RUP, including effects of microbial contamination in the ruminal incubation residue, to assess the techniques used to quantify microbial crude protein production, to evaluate factors that affect microbial crude protein production, and to develop equations to estimate microbial crude protein synthesis.

PROTEIN RUMINAL DEGRADATION

In situ techniques

The major differences found in estimation of ruminal protein degradation are the technique's choice to be used. The *in situ* technique consists on measurement of the ruminal disappearance of feed through the addition of ingredients to bags of known porosity, where the rumen microorganisms access feed and degrade it. It allows the quantification of non-degraded residue. 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 rumen. In the case of CP, it can be degraded and converted into microbial crude protein. In rumen digestibility studies, dietary protein may give a negative digestibility, close to zero or positive, depending on the efficiency of microbial crude protein. The study of degradability is essential to understand changes imposed on nutrient in the rumen.

According to Nocek (1988), using *in situ* technique allows for intimate contact between 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. According to López (2005), other limitations may be reported, as not all the material that leaves the bag can be regarded as degradable, and also not all the remaining material is considered undegradable. Furthermore, the author reports that the bag can be considered an independent compartment in the rumen, wherein the nylon is a barrier that, on the one hand, enables feed decay unless the same is lost in the rumen, and secondly, imposes an obstacle to simulates ruminal conditions inside the bag. According to Nocek (1988), this technique has been used for several years and it is the basis to predict digestion at various feeding systems and their comparison. This technique went through several phases until a standardization technique making it accurate and reproducible. Just over 20 years many authors have described the critical points and some standardizations that made the most credible method possible, which will be discussed below.

a) Non-degraded material losses

According to Stala (1983), the loss of material inside the incubation bag is critical. According to the author, particles lower 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 2 mm particle size 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 lower 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 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 by means of 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 the loss of particles may be accomplished 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 finishing a rumen *in situ* incubation, the bags should pass through 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 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 protein fraction of low protein content forages, microbial contamination implies greater impact on estimates of degradable fractions.

However, the procedures to estimate microbial contamination require the use of microbial markers, which are costly and timely to raise the final chemical analysis, discouraging most of researchers to perform such a procedure in their incubations. The current techniques used to correct residues for microbial contamination are based on eliminating bacterial cells (Michalet-Doreau and Ould-Bah, 1992) or making the microbial cells for subsequent isolation and quantification of adhering microorganisms waste (Nocek, 1988). Several microbial markers may be used in this procedure, such as diaminopimelic acid, RNA, ^{35}S and ^{15}N. The ^{15}N has been widely used as a marker to

quantify the microbial production, since it is a stable isotope, presents a low environmental risk, low cost relative to other isotopes, marks all microbial N pools and does not check the animal protein until microbial labeled amino acids are incorporated in their tissues (Merchen and Broderick, 1992). However, one should emphasize the high cost and the difficulty of this technique to estimate microbial contamination in all assays involving *in situ* incubation. 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 also 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 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.

Thus, to correct the non-degradable residues of incubated feeds before calculating the fractions of the model, the authors suggested the following model:

$$cDR = AIR \times \left(\frac{100 - \%C}{100} \right)$$

where cDR = corrected degradable residue (g); AIR = apparent incubation residue (g), and %C = microbial contamination percentage in relation to initially incubated sample.

Thus, we suggest that for *in situ* technique, the estimates for ruminal degradation of CP in tropical forages must be corrected for microbial contamination to estimate accurate values for soluble and potentially degradable fractions, and for the degradation rates.

To estimate the impact of microbial contamination on *in situ* incubation residues of concentrate feeds, Menezes (2016) conducted a study using ^{15}N as microbial marker and evaluated 12 concentrate feeds, including six protein and six energetic. Although there was microbial contamination in incubation residues (Figure 3.1), this study found no significant difference ($P>0.05$) among degradation fractions A, B, and kd, when values were corrected for microbial contamination after 72 hours of ruminal incubation or not corrected as such (Table 3.1). The author observed that the greatest contaminations were obtained for corn straw and corncobs, sunflower meal and wheat

bran, which are feeds with high NDF content. This study suggested that for concentrate feeds the microbial contamination presents irrelevant contribution to residues of incubation, suggesting that for these feeds it is not necessary to correct for microbial contamination due to lack of interference in RDP and RUP.

However, Beckers et al. (1995) observed effects for microbial contamination on protein degradability of concentrate feeds. These authors reported that for wheat bran, meat and bone meal, and soybean meal the microbial contamination was responsible for 5% of residues and that this percentage increases according to the incubation time. Alexandrov (1998) reported that microbial adhesion in feed residues with low cell wall and low CP percentages is lower than in residues with high NDF levels, suggesting an important role of microbial adherence and thus microbial contamination of the residues.

These results are clear in studies that evaluated the microbial contamination in forages such in Krawielitzki et al. (2006), Dixon and Chanchai (2000), and Machado et al. (2013), where residues were proportionally more contaminated with microbial crude protein when they stayed more time in rumen. However, contamination increasing is not linear. Krawielitzki et al. (2006) evaluated 20 feeds (forages and concentrates) and observed that microbial contamination presented an exponential pattern as a function of time. These authors also concluded that microbial contamination is positively correlated with NDF content in feed, which is in agreement with the fact that fiber feeds facilitate microbial adherence when inside of incubation bags and thus need to be studied more carefully.

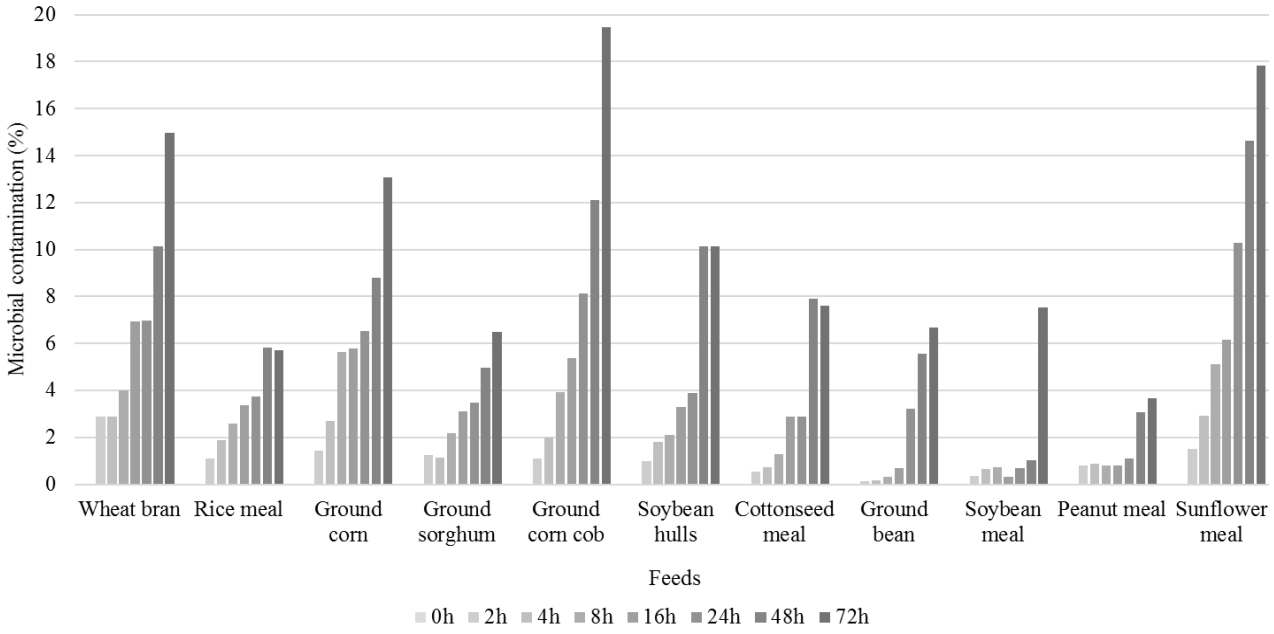

Figure 3.1 - Microbial contamination in residues obtained in different times of *in situ* incubation of protein and energetic concentrates in cattle. (Adapted from Menezes, 2016).

Table 3.1 - Soluble (A) and potentially degradable (B) fractions from crude protein and degradation rate of B fraction (kd) corrected and non-corrected for microbial contamination in protein and energy concentrates

Feedstuffs	Parameters[1]	Non-corrected	Corrected	*P*-value[2]
Wheat bran	A	31.2 ± 2.02	31.1 ± 2.02	0.993
	B	63.7 ± 2.21	63.3 ± 2.21	
	kd	0.332 ± 0.0260	0.324 ± 0.0250	
Rice bran	A	36.9 ± 2.63	36.9 ± 2.63	0.995
	B	44.8 ± 2.87	44.0 ± 2.87	
	kd	0.336 ± 0.0490	0.335 ± 0.0500	
Ground corn	A	30.9 ± 1.60	30.3 ± 1.58	0.910
	B	68.8 ± 3.39	69.7 ± 5.77	
	kd	0.037 ± 0.0050	0.033 ± 0.0030	
Ground sorghum	A	35.1 ± 1.48	34.6 ± 1.46	0.973
	B	64.3 ± 2.29	64.7 ± 2.49	
	kd	0.021 ± 0.0020	0.020 ± 0.0020	
CSC[3]	A	24.3 ± 2.51	24.2 ± 2.47	0.958
	B	70.1 ± 4.41	69.9 ± 4.88	
	kd	0.043 ± 0.0070	0.039 ± 0.0070	
Soybean hulls	A	17.3 ± 3.87	17.2 ± 3.87	0.997
	B	67.3 ± 4.27	66.4 ± 4.27	
	kd	0.200 ± 0.0300	0.200 ± 0.0310	
Cottonseed meal	A	27.3 ± 2.07	27.2 ± 2.07	0.997
	B	62.2 ± 2.31	61.6 ± 2.31	
	kd	0.154 ± 0.0150	0.154 ± 0.0150	
Soybean meal	A	27.0 ± 2.25	27.0 ± 2.25	0.999
	B	70.6 ± 2.51	70.5 ± 2.51	
	kd	0.152 ± 0.0140	0.152 ± 0.0140	
Ground bean	A	23.8 ± 2.82	23.7 ± 2.82	0.999
	B	73.4 ± 3.43	73.6 ± 3.43	
	kd	0.092 ± 0.0120	0.091 ± 0.0120	
Peanut meal	A	26.8 ± 3.35	26.7 ± 3.34	0.999
	B	65.0 ± 3.79	64.9 ± 3.79	
	kd	0.134 ± 0.0210	0.132 ± 0.0200	
Sunflower meal	A	18.0 ± 4.61	30.1 ± 3.67	0.738
	B	63.8 ± 4.95	50.2 ± 4.44	
	kd	0.145 ± 0.0280	0.121 ± 0.0290	

[1]Parameters estimated by Orskov and McDonald (1979) method. [2]P-value – Identity test of the models (Regazzi, 1993). [3]CSC – corn straw and corncobs. Adapted from Menezes (2016).

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 to measure feed's degradation and removing the confounding animal's effect. The Latin square design may be used to control sources of variation and to avoid experimental errors from animals. Machado et al. (2013) reported that Latin square design does not need to be used to estimate variability or to account for sources of variation on experimental error, but to conduct an 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 (2016) should be used. This author conducted a cluster analysis and estimated that, for protein concentrate feeds, the time of incubation to estimate RDP should be 9.9 ± 2.9 h, considering kp = 0.05 h^{-1} and 7.5 ± 2.1 h for ruminal incubation when kp = 0.08 h^{-1}. However, for energetic concentrate feeds, the author observed two different clusters. The first one, which included corn meal, sorghum meal, and corn straw and corncobs, presented 15.4 ± 3.9 h when using a kp = 0.05 h^{-1} and 10.4 ± 2.8 h of ruminal incubation when using a kp = 0.08 h^{-1} to estimate the RDP. On the other hand, for wheat bran, rice bran and soybean hulls, the author have suggested 6.8 ± 2.2 h with a kp = 0.05 h^{-1} and 5.4 ± 1.7 hours when using a kp = 0.08 h^{-1} to estimate the RDP. Thus, the literature recommendations of 16 h (Calsamiglia et al., 1995) to obtain feed RDP may not be useful for all feed types (Table 3.2).

Table 3.2 - Incubation period needed (hours) to estimate rumen degradable protein (RDP) from concentrate feedstuffs, considering two passage rates

	Feedstuffs[4]	Ruminal passage rate									
		0.05 h^{-1}					0.08 h^{-1}				
					Confidence interval					Confidence interval	
		IIT[1]	AIT[2]	SEM[3]	Lower	Upper	IIT[1]	AIT[2]	SEM[3]	Lower	Upper
	Ground corn	15.2					10.3				
1	Ground sorghum	16.3	15.4	0.46	13.4	17.4	10.6	10.4	0.12	9.80	10.9
	CSC[5]	14.8					10.2				
	Wheat bran	6.20					5.00				
2	Rice bran	6.10	6.80	0.60	4.20	9.30	4.90	5.40	0.41	3.60	7.10
	Soybean hulls	7.90					6.20				
	Cottonseed meal	9.10					7.00				
	Soybean meal	9.20					7.00				
3	Ground bean	11.4	9.90	0.41	8.80	11.1	8.30	7.50	0.25	6.80	8.20
	Peanut meal	9.80					7.40				
	Sunflower meal	10.2					7.60				

[1]IIT = individual incubation time; [2]AIT = average incubation time; [3]SEM = Standard error of the mean; [4]Feedstuffs grouped in Cluster; [5]Corn straw and corncobs. Adapted from Menezes (2016).

However, it is important to highlight that these times may be not 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 time to estimate *in situ* degradation for concentrate feeds and 72 hours for forages. Detmann et al. (2008) reported a difference in ruminal degradation for tropical and temperate roughages, which leads us to infer that these differences affect incubation time necessary to obtain asymptotic values for ruminal incubation residue. Despite of several studies evaluating the time necessary to estimate fiber fractions for *in situ* incubation (Casali et al., 2008), few studies have evaluated the time necessary to estimate RDP from forages.

d) Conditions inside the incubation bags

According to López (2005), conditions inside the incubation bags should be similar to the rumen. Thereat, the choice of the adequate fabric to produce bags is very important. The material should be synthetic and absolutely refractory to microbial degradation. Also, according to Nocek (1997), the porosity of an adequate bag constitutes the adjustment between the limit to ruminal content influx without associating to feeds evaluated, allowing therefore, the entrance of microbial populations for degradation; while, at the same time, to limit the exiting of non-degraded feed particles. For many years, nylon bags, with variation from 40 to 60 μm of porosity as recommended by Nocek (1997), have been used as 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 ranged between 30

and 50 μm in studies evaluating *in situ* CP degradation. Nevertheless, studies comparing protein degradation in bags with different porosity were not found. Thus, until studies conducted to evaluate the ideal porosity of nylon bags to obtain better RDP estimates of feeds will be conducted, we recommend the use of nylon bags with porosity of 40-60 μm.

The surface area of incubated bags relative to the amount of sample is also an important variable to be considered in the internal conditions of the *in situ* degradation. According to Nocek (1988), the optimum amount of sample is that which provides enough amount for chemical analysis at the end of the degradation process without excessive filling the bags that delays microbial adhesion, increasing latency phase, and underestimating digestion rates. After a literature review, the author recommended a sample from 10 to 20 mg/cm^2 of bags for the majority of feedstuffs, highlighting that for concentrate feeds, the greater value can be critical due to high density and rapid degradation, causing intense gas production per unit of time. Therefore, despite of appearing in the 80´s, the study of Nocek (1988) was not refuted yet, being currently used as reference for *in situ* incubation studies.

In vitro techniques

The *in vitro* technique has been used in ruminant nutrition for many years and according to Hungate (1966), the first studies were in 20´s. Calsamiglia et al. (2000) reported that alternative procedures are necessary to *in situ* technique that suffer extensive variability as a function of diet or animal, and among different assays. These authors reported that the evaluation of forage using *in situ* technique presents additional difficulties such as high levels of water-soluble constituents, which are lost as degradable material, and greater microbial contamination in residues due to high adhesion of microorganisms to fiber particles. Several *in vitro* techniques can be found in the literature to estimate protein degradation, as follows: cultures in closed anaerobic system (Batch culture) and the use of chemical-enzymatic methods that simulate the gastrointestinal tract digestion whose will be discussed.

a) Inhibitor in vitro method

Specifically, for the CP degradation, a common technique is the measurement of ammonia production in the rumen inoculum (Broderick, 1982; NRC, 1985). The advantage of this procedure is the simplicity; however, it presents several disadvantages. The microbial growth and ammonia capture occur simultaneously to protein degradation and ammonia release; if so, ammonia concentration in the inoculum is the result of the balance between protein degradation and ammonia capture for microbial crude protein synthesis. Broderick (1987), considering these limitations, described a method that has as principle to inhibit amino acid deamination and capture by microorganisms (hydrazine sulfate and chloramphenicol), allowing the real measurement of net ammonia production from protein degradation. The method recommends the measurement of ammonia and amino acid concentration before any capture by microorganisms. This procedure was named *in vitro* inhibitor method (Broderick and Cochran, 2000). According to Calsamiglia et al. (2000), this method is the most indicated to estimate CP degradation rate and its other fractions due to data are compatible with first order kinetic models.

Stern et al. (1997) reported that hydrazine sulfate is a non-competitive inhibitor of phosphoenolpyruvate carboxykinase, blocking gluconeogenesis and avoiding microorganisms to utilize carbon skeletons from amino acids as glucose source. The chloramphenicol is an antibiotic that interrupts microbial crude protein synthesis by blocking the translation phase. The advantage of these compounds is that they do not inhibit proteolytic reactions, allowing to evaluate protein degradation dynamics. The *in vitro* inhibitor method, recommended initially by Broderick et al. (1987) had several standardizations. Broderick et al. (2004) described several adaptations to this technique aiming to increase the accuracy of the results. Thus, these authors suggested modifications in several steps of the method such as a pre-treatment of ruminal liquid by dialysis, which would increase number of microorganisms associated to particles, increasing culture

feasibility and reducing variability among analytical analysis. Broderick et al. (2004) reported that pre-incubation improves precision of the protein degradation estimated due to the increase of viable microbial biomass. Otherwise, other procedures tested with the inclusion of vitamins and volatile fatty acids did not provide improvement in the original technique and they were not recommended.

b) Enzymatic methods

The ruminal protein hydrolysis occurs by microbial enzymes that reduce the size of these compounds or even transforming chemical nature of these molecules. The main enzymes, such as proteases, peptidases, and deaminases, as well as protein three-dimensional structure and the accessibility of their links will determine ruminal protein degradation, extension and rate (Calsamiglia et al., 2000). Furthermore, the interaction among different types of enzymes produced by microorganisms is an important factor in protein degradation efficiency. Kohn and Allen (1995a) reported the importance of enzymes that act on other compounds such as carbohydrates. According to these authors, the presence of starch and NDF interfere on protein degradation causing a physical barrier which allow us to infer that the addition of enzymes such as cellulases and amylases to *in vitro* cultures can increase the degradation efficiency of proteolytic enzymes. According to Stern et al. (1997), enzymatic techniques present the complete independence of the animal use as the main advantage, which results in lower variability, simplifying its standardization. In contrast, these authors highlight that the biological validity can be limited and present incomplete enzymatic activity when compared to ruminal activity.

The two basic approaches to estimate ruminal *in vitro* digestion involve incubation with ruminal microorganisms (ruminal *in vitro* methods) or free cell enzymes (non-ruminal *in vitro* methods). The first technique uses ruminal digesta, generally obtained from cannulated animals while the second technique is based on the use of enzymes commercially available, intending similar results to those found with ruminal liquid (Broderick and Cochran, 2000). In both cases, protein degradation rate is measured by accumulation rate of amino acids and ammonia that represents the end-products from protein degradation (Schwab et al., 2003).

Thus, there is the need of discussing advantages and disadvantages of utilizing enzymes commercially extracted or preparations of ruminal microbial cells. According to Calsamiglia et al. (2000), proteolytic enzymatic extracts from ruminal liquids can be physiologically more efficient on *in vitro* protein degradation. Mahadevan et al. (1987) proposed an enzymatic extraction using different compounds such as acetone, butanol or even washing by cold water. Mahadevan et al. (1987) reported recovery efficiency between 30 and 35% of proteolytic activity from integral ruminal liquid and it can be stored at -20^{o}C for at least a year without losing proteolytic activity. Kohn and Allen (1995a) stated that main limitation of the method initially proposed is that non-enzymatic proteins present significant interference on enzymatic preparations from ruminal liquid. Probably they compete for protein from feeds by enzymes. However, an advantage of the use of proteases extracted from ruminal liquid is that these enzymes are more adequate for inferences in respect to CP degradation rate, and its fractions than commercial enzymes, once commercial enzymes do not produce data that adjust to first order kinetic models (Calsamiglia et al., 2000).

Then, Kohn and Allen (1995a) proposed modification in the model originally proposed and increased activity efficiency for up to 62%. Utilizing azocasein as a marker for enzymatic activity, these authors concluded that greater proteolytic activities were observed using only acetone or detergent in the enzymatic extraction and described all extraction protocol and *in vitro* incubation. Kohn and Allen (1995b) evaluated feasibility of enzyme activity extracted with acetone and verified enzymatic action for up to 16 hours. However, feed degradation becomes slower with more incubation time. The authors also concluded that there is the need of inclusion

of cellulases that can improve degradation efficiency of structural components.

Nevertheless, beyond enzymatic preparations from ruminal liquid, commercial enzymes are extensively used in the evaluation of protein degradation of feedstuffs. Krishnamoorthy et al. (1983) proposed the use of proteases extracted from *Streptomyces griseus*, due to its endo and exopeptidases are similar to those found for the majority of ruminal microorganisms. Krishnamoorthy et al. (1983) performed *in vitro* proteolysis using an enzymatic concentration of 0.066 unit/ml, which was correlated with ruminal proteolytic activity. An *in vivo* method was used to that comparison, the results indicated that proteases from *S. griseus* can be utilized to estimate ruminal content of non-degraded protein.

Calsamiglia et al. (2000) performed a compilation data of 11 studies using proteases from *S. griseus*, five studies using ficin (extracted from *Ficus glabatra*), seven studies using bromelain, three studies using papain and eight studies evaluating another enzymes. In this compilation, the authors verified that protein degradation with ficin for 4 hours is highly correlated with *in vivo* protein degradation and *in situ* protein degradation after 24 hours. Satisfactory results were not found for fromase, alcalase, chymosin, trypsin, pepsin, pancreatin, and protease type XIV, both in isolated and associated ways. Two other vegetable proteases like bromelain and papain presented distinct results. While bromelain provided moderate correlation with *in vivo* degradation, papain provided greater correlations; although, it was not greater than those found for ficin (Calsamiglia et al., 2000). Also, we highlight the study of Aufrère et al. (1991) that evaluated *in vitro* incubation with proteases of *S. griseus* from 97 feeds during 24 hours compared to *in situ* incubation. Aufrère et al. (1991) observed high correlated estimates (r = 0.89), suggesting that this enzyme could be used to estimate non-degraded nitrogen concentrations in feedstuffs.

Licitra et al. (1999) evaluated different protease concentrations of *S. griseus* using *in vitro* incubations and concluded that the concentration of 1.5 unit/ml represents the optimum value of use, differing of value of 3.3 unit/ml recommended in the older literature. Other studies evaluating ideal pH (Stern et al., 1997) reported that protein conformation is altered as a function of pH. Notably, pH equal to 6.5 increased the correlation between *in situ* and *in vitro* methods, while maximum enzyme activity was observed at pH 8.0.

c) Protein solubilizing method

The most widely method used to estimate the fractions of nitrogen compounds of feeds is the subdivision protocol utilized 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), constituted by non-protein nitrogen compounds (NPN); B1, true protein fastly degraded in rumen, soluble in BFB, with precipitation in TCA; B2, true protein and large peptides, moderately degraded in rumen, calculated by difference between total CP of feeds and other fractions; B3, true protein slowly degraded in rumen, calculated by difference between neutral detergent insoluble protein content (NDIP) and acid detergent insoluble protein (ADIP), and fraction C, or unavailable protein, equals to ADIP.

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

The CNCPS also recognize that the ruminal CP disappearance is a simultaneous function of degradation rate (kd) and passage rate (kp), and kp varies with intake, feedstuff, and diet characteristics. Thereby, two equations can be used to predict kp of undegraded feeds, one for forages ($kp = 0.388 + 22.0 \times [DMI/BW^{0.75}] + 0.0002 \times [\%$ roughage on DM basis]) and another one for concentrate ($kp = -0.424 + [1.45 \times kp$ for

roughage]). The passage rates are adjusted for individual feeds, using a multiplicative adjustment factor for particle size, utilizing physically effective neutral detergent fiber (peNDF). Two equations are used to estimate the adjustment factor (AF), one for forages (AF = 100/[peNDF + 70]) and another one for concentrates (AF = 100/[peNDF + 90]).

The values of RDP and RUP can be directly calculated by the association of CP fractions with their respective passage and digestion rates. Then, RDP (% CP) can be calculated as follows: A + B1 (kdB1/[kdB1 + kp]) + B2 (kdB2/[kdB2 + kp]) + B3 (kdB3/[kdB3 + kp]) and RUP = 1 − RDP. An interesting aspect of the approach used by CNCPS is that the analyses (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 updated recently, when Higgs et al. (2015) presented new nomenclature for CP fractions adopted in the current CNCPS. A few changes have been made to the methods of analysis used by the authors, as follows:

PA1 = ammonia × (SP/100) × (CP/100)

PA2 = [SP × (CP/100)] – PA1

CP1 = CP – (PA1 – PA2 – CP2 – IP)

CP2 = (NDIP – ADIP) × (CP/100)

IP = ADIP × (CP/100)

where: PA1 = ammonia; PA2 = soluble true protein; CP1 = insoluble true protein; CP2 = 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

Correlation among in vivo, in situ, and in vitro estimates

Hvelplund and Weisbjerg (2000) reported the difficulty of validating *in situ* protocol using *in vivo* methods for protein degradability. According to the authors, the greatest difficulty of knowing *in vivo* protein degradability is to estimate the separation of duodenal protein flow for RUP, microbial crude protein and endogenous protein. Furthermore, measurement of the feed degradation profile is difficult because it is typically applied to studies evaluating complete diets. Hvelplund and Weisbjerg (2000) reported some important details that might be considered in the comparison, such as passage rate and feeding level, which can directly influence the flow of protein to the small intestine.

Vanzant et al. (1996) studied the estimates of *in vivo* and *in situ* protein degradation of three types of temperate hays. Using ruminal and duodenum cannulated animals, the authors have used indigestible ADF (iADF) as marker for duodenum flow of organic matter (OM) aiming to estimate the total amount of nitrogen that escapes from ruminal degradation. The microbial nitrogen (MN) flow was estimated through purine concentrations in the duodenum sample and total N flow in the duodenum (duodN). The endogenous N (EN) was estimated by mathematical approaches using data of three distinct studies: Orskov et al. (1986), Hart and Leibholz (1990) and Lintzenich et al. (1995). Vanzant et al. (1996) also measured ammonia N (AN) flow in the duodenum and total N intake. After estimating these values, N degradability of the diet was estimated as follows:

RUN = duodN – AN – MN – EN

RDN = 1 – RUN

Comparing values of rumen degradable nitrogen (RDN) obtained using *in vivo* and *in situ* methods, Vanzant et al. (1996) did not observe significant differences among estimates. The authors attributed this fact to high variability of *in vivo* values due to the difficulty of this technique in measuring duodenal flow and the amount of microbial nitrogen that reaches this compartment. Another limitation involves estimates of the endogenous N level that would present substantial variation, which depends on the method used for estimation (Table 3.3).

Table 3.3 - Sensitivity of *in vivo* degradability of CP (CPdeg) of two roughages in function of different estimates of duodenal flow of endogenous nitrogen

	Reference		
	Orskov et al. (1986)	Hart and Leibholz (1990)	Lintzenich et al. (1995)
Estimated N endogenous, g/d	19.4	38.4	27.8
Alfalfa – CPdeg (%)	78.8	89.7	83.4
Prairie hay – CPdeg (%)	41.2	72.3	55.5

Gosselink et al. (2004a) compared the estimates of *in situ*, *in vivo*, and *in vitro* CP degradation of 11 temperate forages. To estimate MN, the authors used both ^{15}N and PD. The *in situ* measurements were performed in the rumen of cows and sheep using nylon bags at incubation times up to 72 hours, with data fitted in exponential models.

The *in vitro* degradation was performed from subdivision of dietary N as recommended by CNCPS (Sniffen et al., 1992) in the fractions A, B1, B2, B3, and C while degradation and passage rates were calculated by the CPM-Dairy Program (CPM-Dairy, 2003). The undegradable N was estimated by incubation with protease of *S. Griseus* during 24 hours (Aufrère and Cartailler, 1988). The authors did not find significant correlation ($P>0.05$) among CP degradability obtained from *in situ* method using cows and sheep comparing to *in vivo* estimates, independent of technique used to obtained MN. The same occurred for the *in vitro* estimates; otherwise, the authors found significant correlation ($P<0.05$) of ADIN with RUN calculated with ^{15}N (RUN_{15N}), and with non-ammonia N flow in the duodenum calculated by both ^{15}N (NAN_{15N}) and PD (NAN_{PD}). Therefore, the authors recommended the following equations:

$$RUN_{15N} = 3.08 \times ADIN + 1.6 \ (r^2 = 0.87)$$

$$NAN_{15N} = 3.72 \times ADIN + 0.7 \ (r^2 = 0.83)$$

$$NAN_{PD} = 2.74 \times ADIN + 29.4 \ (r^2 = 0.83)$$

Moreover, Gosselink et al. (2004b) suggested that there is a potential use of ADIN to predict RUN using *in vivo* method; however, they recognize that these data need to be validated and more studies to prove this relationship need to be conduct. Edmunds et al. (2012) studied the relationship between the RUP measured by *in situ* and *in vitro* methods using 25 concentrates and roughage. The *in situ* procedure was performed using nylon bags at incubation times up to 96 hours, corrected for microbial contamination according to method of Krawielitzki et al. (2006) and adjusted in exponential model. The *in vitro* procedure was performed through enzymatic incubation in protease of *S. Griseus* during 24 hours following protocol of Licitra et al. (1998). The authors found a high correlation between *in situ* and *in vitro* estimates showing equivalence between methods.

Madsen and Hvelplund (1985) utilized the marker diaminopimelic acid (DAPA) to estimate MCP yield in 12 different diets; correlating these data with others obtained by *in situ* method, they observed a linear correlation among methods, considering both 0.05 and 0.08 h^{-1} as passage rates of the digesta. The authors also compared *in vivo* degradation with data obtained from *in vitro* method using ruminal inoculum and they did not find satisfactory relationship between these two techniques. Roe et al. (1991) compared three *in vitro* enzymatic techniques with *in situ* technique to estimate ruminal CP degradation of four soybean by-products. The enzymes were the protease of *S. griseus,* ficin, and neutral protease with amylase and *in vitro* incubations were conducted for 48 hours. The results were not satisfactory because the authors did not verify a significant relationship for degradation curves obtained from *in situ* and *in vitro* methods.

Then, we noticed from data exposed that *in situ* and *in vitro* techniques present greater precision in their estimates while *in vivo* technique present high variability, and

therefore little correlation with *in situ* and *in vitro* techniques. Hvelplund and Weisbjerg (2000) reported that in comparison to the extensive use of *in situ* technique, its validation from *in vivo* experiments is scare and doubtful due to the lack of data and trustful estimates of duodenum flow of endogenous nitrogen.

Mathematical models to estimate ruminal protein degradation from data obtained through in situ or in vitro methods

The traditional mathematical methods used to describe ruminal degradation generally calculate this variable based on substrate mass retained in the compartment evaluated. Some of these models are of first order (Waldo et al., 1972) that consider only the substrate to be digested, and others from second order because they also consider the pool of substrates studied and the microbial mass present in the system (France et al., 1990). The first order model of Mitscherlich proposed by Ørskov and McDonald (1979) is utilized with a greater frequency for the evaluation of CP residues obtained from *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 kinetic, 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. Otherwise, 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 which consider that the fractional degradation rate of nutrients is not a constant value, but variable; and that some degradation models based on microbial growth kinetic are from sigmoidal pattern, indicating alternative solution to 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 CP degradation curves, for both exponential and sigmoidal pattern 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 the CP disappearance expressed as a percentage; *a* represents the water soluble fraction in the time zero; *b* represents the water insoluble fraction but potentially degradable in the rumen in a determined time; *c* represents lag time and degradation rates (h^{-1}); kd is the degradation rate of the *b* fraction; and *t* is the incubation time (hours).

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

Beyond the models cited above, López et al. (1999) described several non-linear models that can be used for the same aim of those described. However, these models consider that degradation rate (kd) is not a static parameter, but dynamics, presenting variations throughout incubation time. Among these models, France et al. (1990) used two-compartment model, adding more one parameter referring to inhibition imposed by undegradable substrate as follows:

$$(3)\ DEG\ (t) = a + b \times (1 - e^{-ct - d \times \sqrt{t}})$$

where: DEG (t) represents the CP disappearance expressed as a percentage; *a* represents the water soluble fraction in time zero; *b* represents the water insoluble fraction but potentially degradable in the rumen in a determined time; *c* is a parameter related to fractional degradation rate (h^{-1}); *t* is the incubation time (hours); *d* is a parameter

related to fractional degradation rate ($h^{-1/2}$) related to diffusion of a disappearance catalyst (e.g. microbial enzymes) after latency phase until the point of inflexion. The variable degradation rate (kd) can be calculated by:

$$kd = c + \left[\frac{d}{2 \times \sqrt{t}} \right]$$

France et al. (2000) estimated the degradation fractions of feeds adapting the generalized model of Michaelis–Menten. In this model, the fractional degradation rate decreases continuously ($c \leq 1$) or increases in the first moment and decreases thereafter ($c > 1$). This initial increase in the degradation rate might be basically the substrate accessibility due to particle hydration, microbial adhesion, and increase of microbial population of colony while the immediate decreasing reflects chemical and structural restriction of particles from feedstuffs (Groot et al., 1996).

$$(4)\ DEG(t) = a + b \times \left[\frac{(t-T)^c}{K^c + (t-T)^c} \right]$$

where: DEG (t) represents the CP disappearance expressed as a percentage; *a* represents the water soluble fraction in time zero; *b* represents the water insoluble fraction but potentially degradable in the rumen in a determined time; *c* is a parameter related to fractional degradation rate (h^{-1}); *t* is the incubation time (hours); and *K* is the total degradation time after lag time T (optional parameter). The variable degradation rate (kd) can be calculated by:

$$kd = \left[\frac{ct^{c-1}}{(t^c + K^c)} \right]$$

The functions of standard growth as the Logistic and Gompertz function were also adapted by Robinson et al. (1986) and France et al. (1990) for the same target. These models assume that microorganisms can utilize incubation substrate for their growth only when maintenance requirements are satisfactory until a determined point of inflexion. After the point of inflexion, the degradation rate of substrate is reduced and the maintenance requirements are responsible by greater part of spent of substrate per time unit, reducing fractional microbial growth rate and consequently reducing microbial production. Thus, the CP degradation rate (kd) obtained by these two models increases throughout incubation time. This increase can be interpreted as an increase of microbial activity per unit of substrate mass.

$$(5)\ DEG(t) = a + b \times \left[\frac{\left(1 - e^{-ct}\right)}{(1 + Ke^{-ct})} \right]$$

$$(6)\ DEG(t) = a + b \times \left(1 - e^{(K/c)(1-e^{ct})} \right)$$

where: DEG (t) represents the CP disappearance expressed as a percentage; *a* represents the water soluble fraction in the time zero; *b* represents the water insoluble fraction but potentially degradable in the rumen in a determined time; *c* is a parameter related to fractional degradation rate (h^{-1}); *t* is the incubation time (hours); and *K* is a parameter related to fractional degradation rate (h^{-1}) for a given point of inflexion. The variable degradation rate (kd) of these two models are calculated by the following sentences:

$$(7)\ kd = c/(1 + Ke^{-ct})$$

$$(8)\ kd = b \times e^{ct}$$

Generally, the rusticity of a degradation equation reduces as increases the number of phases, characteristics inherent to non-linear models. An increase of the number of parameters used in the model can also reduce the probability of mathematical fitting which increases the probability of the use of simpler models as Ørskov and McDonald (1979). These authors presented a model with static values for degradation rate, with lower number of parameters to be estimated. Therefore, we recommend the model of Ørskov and McDonald (1979), because it is simple and works relatively well to evaluate protein degradation of feedstuffs. For any model used, from soluble fraction (a),

potentially degradable fraction (b), and degradation rate (kd) measured for CP and using an estimated passage (kp), we will be able to calculate the effective degradability that will correspond to RDP:

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

The measurement of the microbial crude protein supply has been an important area of study inside of protein nutrition of ruminants. The microbial crude protein flow for duodenum can be considered one of the most important and sensible indicators of optimization the protein metabolism in ruminants (Tas and Susenbeth, 2007). Otherwise, the direct measurement of microbial crude protein flow in the intestine requires cannulated animals which represent high cost, demand more care in animal use and it can affect DM intake and consequently animal performance.

The estimate of microbial crude protein flow for intestine is important to estimate protein content of the diet and type of total N contribution. Depending of N source in the diet, the microbial N can contribute from 50 to 90% N that reaches duodenum (Miller et al., 1982). This quantification can be performed by different methods that will be further discussed.

Therefore, one of the important factors that directly interfere the RDP values is the passage rate adopted in the calculations of effective CP degradability. The NRC (2001) previously adopted three different functions to estimate passage rate of humid forage, dry forage and concentrates. However, Seo et al. (2006) highlighted that data compiled to generate these three equations were obtained in experiments that used rare earth element as main markers, which limits 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, whose were capable to predict 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 × FiBW + 0.0734 × CiBW + 0.069 × Fi) / 100

kp concentrate = (1.169 + 0.1375 × FiBW + 0.1721 × CiBW) / 100

kp liquids = (4.524 + 0.0223 × FiBW + 0.2046 × CiBW + 0.344 × 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.

MICROBIAL CRUDE PROTEIN SYNTHESIS

Considering ruminal microorganisms, the major modifiers of dietary protein, not only the CP requirement of the animal should be considered, as well as the quantification of N required for synthesis of ruminal microbial crude protein. According to Puchala and Kulasek (1992), to obtain the required total N by ruminant, the 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 crude protein synthesized in the rumen and the protein of diet that escapes from ruminal degradation. The nutritional requirement of RUP is calculated as the total of MP required minus the amount of digestible true microbial crude protein that reaches the duodenum, thus there is a need to obtain accurate estimates of this variable to quantify the MP nutritional requirements for ruminants (Firkins, 1996).

Microbial crude protein may fill 50–100% of the MP required for beef cattle, with approximately 80% intestinal digestibility and an amino acid profile compatible with the need for muscle deposition (NRC, 2000). Amino acid composition of the microbial crude protein is similar to that of animal tissue. Compared to the composition of protein concentrates and plant proteins, microbial crude protein contains a greater proportion of methionine and lysine. Thus, after the ban on the use of animal byproducts in ruminants diets in Brazil, there are no sources that best meet the amino acids requirements than microbial

crude protein (Verbic, 2002).

According to Broderick and Merchen (1992), microbial markers are necessary to quantify rumen microbial crude protein. These can be classified as internal and external markers. The internal markers are those inherent to the microorganisms, or are already chemical components of the microorganisms themselves such as DAPA. This compound is an amino acid present in bacteria, and was identified in oligopeptides bound to the peptidoglycan of the bacterial cell wall. Other compounds, such as D-alanine amino acid, aminoethyl phosphonic acid, and odd-chain fatty acids can also be classified as internal microbial markers. In addition to those mentioned methods, the most widely used microbial compound as an internal marker is set to microbial nucleic acids. The high content of RNA in microbial cells becomes these compound of great interest in the quantification of microbial crude protein pool synthesized in the rumen. The external markers are those added to the rumen and they are able to adhere to microorganisms, as is the case of heavier isotopes such as ^{15}N. An ideal microbial marker should include features such as easy to quantify, not present or present in small amounts in feeds, present at a constant ratio even under experimental conditions and be biologically stable. The use of each of these markers is a different technique to estimate the microbial crude protein, which will be discussed below.

Techniques to estimate ruminal microbial crude protein

a) Comparing ^{15}N and RNA

The ^{15}N have been widely used as marker to estimate the microbial crude protein, even it is a stable isotope, with low environment risk, lower cost in relation to other isotopes due to mark all microbial N pools; also, it cannot be naturally found in the protein from feedstuffs and it does not mark animal protein until marked microbial amino acids are incorporated to their tissues (Broderick and Merchen, 1992). The ^{15}N is well distributed in the microbial cell; then, in cell lysis during bacteria isolation, the loss of protoplasm that underestimate nucleic acids causes little damage to the estimate of ^{15}N concentration.

With the infusion of marked ammonium sulfate salts, $(^{15}NH_4)_2SO_4$, in the rumen, there is gradually microbial amino acid synthesis using the $^{15}NH_3$ as precursor and, thereby, the isotope becomes to be the microbial crude protein constituent. Furthermore, the protozoa are marked mainly after ^{15}N incorporation contained in the predatory bacteria. Broderick and Merchen (1992) recommended continuous infusion, via ruminal cannula, of $(^{15}NH_4)_2SO_4$ over the course of 48 hours and estimating ^{15}N as proposed by Siddons et al. (1985).

Normally, the marker: microbial N ratio have been obtained in bacteria isolated from liquid phase of ruminal digesta, considering that it is similar to mixed ruminal microbial ratio, although 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 to particle phase is 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 PAB phase to estimate a more representative marker: total N ratio.

Martín et al. (1994) observed different ^{15}N contents between LAB (0.164% total N) and PAB (0.111% total N), possibly due to greater growth rate and protein synthesis of LAB. Although the contribution of PAB is little studied, its presence on the estimation of marker: microbial total N ratio have a huge impact on the estimate of microbial crude protein flow. Carro and Miller (2002) found greater contents of ^{15}N and purine bases (PB) in relation to total N in LAB when compared to PAB and intermediate contents in mixed pellets, containing both bacteria. Then, methods capable to isolate mixed bacteria are recommended. The ^{15}N:^{14}N ratio and microbial N content, generally, can be obtained from the average in samples of LAB and PAB, once in several cases, differences are not found among these two protocols of bacteria isolation (Machado et al., 2013, Rotta et al., 2014a, Prates, 2015; Menezes, 2016; Table 3.4).

Table 3.4 - Descriptive statistics of the $^{15}N:^{14}N$ ratio and 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)[4]	341[2]	7.07	358[2]	7.20
Rotta et al. (2014a)	0.093[3]	7.80	0.092[3]	8.20
Menezes (2016)	304[2]	5.89	322[2]	5.46
Mariz (2016)	454[2]	7.17	463[2]	7.51
Prates (2015)	0.076[3]	7.27	0.068[3]	7.35

[1]Means of the $^{15}N:^{14}N$ ratio and microbial N content did not differ by F test ($P>0.05$), except microbial N in Mariz (2016) 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.

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

The majority of feedstuffs has low RNA concentration and, according to McAllan and Smith (1973), there is extensive exogenous RNA degradation in the rumen. Thus, duodenal RNA flow is mainly from microbial origin. However, in protein of animal byproducts, the RNA concentration is similar to microorganisms and, then, the use of RNA as marker is not appropriate for animals receiving this type of feeds. Although, these feedstuffs are not allowed in Brazil, this does not cause problems with the use of this technique.

According to Rotta et al. (2014b), the most the studies that evaluated different markers to estimate ruminal microbial crude protein utilized samples from abomasum and duodenum and the maintenance of cannulated animals in abomasum and duodenum is difficult and it has high operational costs, causing trouble in animal handling. Reynal et al. (2005) and Ipharraguerre et al. (2007) recommended that the calculation of microbial crude protein flow using ^{15}N as marker should be performed utilizing samples from omasum. However, using ^{15}N and PB as markers, these authors found differences in values obtained for microbial crude protein flow from duodenum samples. Moreover, Krizsan et al. (2010) suggested that samples of reticulum can replace omasum samples. Mariz (2016) studied possible differences between microbial markers ^{15}N and PB to estimate ruminal microbial synthesis and efficiency when provided different CP content in diets of Nellore and crossbred cattle, and did not find difference in the estimates presented.

Table 3.5 - 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 (SS)				P-value
Markers	Reticulum	Omasum	Abomasum	SEM[1]	SS × 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/FOM[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]Standard error of the mean; [2]Interaction between sampling 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. (2014).

The similarity among microbial markers indicated that both ^{15}N and PB are adequate to estimate microbial crude 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 in different sampling sites (Table 3.5). Rotta et al. (2014b) reported that samples obtained in the omasum and abomasum provided similar results for microbial nitrogen yield as well as for microbial efficiency when they used ^{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 crude protein obtained from assays with single and double marker systems for values compatible to triple markers system, being them as follow:

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

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

where MNcor is the microbial nitrogen production per day corrected for the use of single or double marker, MNsingle is the microbial nitrogen obtained from single marker system, and MNdouble is the microbial nitrogen obtained from double marker system.

b) Urinary purine derivatives

The discovery that urinary purine derivatives (PD) in ruminants are quantitatively important as final products of N metabolism leaded to the deepening of researches 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 base of the knowledge that originate the use of urinary PD as non-invasive method to estimate the supply of microbial crude protein for intestine in ruminants (Chen and Gomes, 1992).

The principle of the method is that nucleic acids coming out the rumen are essentially from microbial origin (McAllan and Smith, 1973). This occurs because feedstuffs commonly used in ruminant diets have low purine contents and the majority of diets suffer extensive degradation in the rumen as result of microbial fermentation (McAllan and Smith, 1973). The nucleic acids from bacteria origin that reaches the intestine are, in the majority, digested and absorbed in the small intestine. The 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 previous discussed, these methods present difficulties for the extensive use because they are extremely invasive and require the use of cannulated animals for the estimation of DM flow by abomasum or duodenum. These methods based on the estimate of microbial crude protein flow have been used mainly to calibrate some factors of the calculation utilizing PD method (Tas and Susenbeth, 2007; Barbosa et al., 2011; Prates et al., 2012).

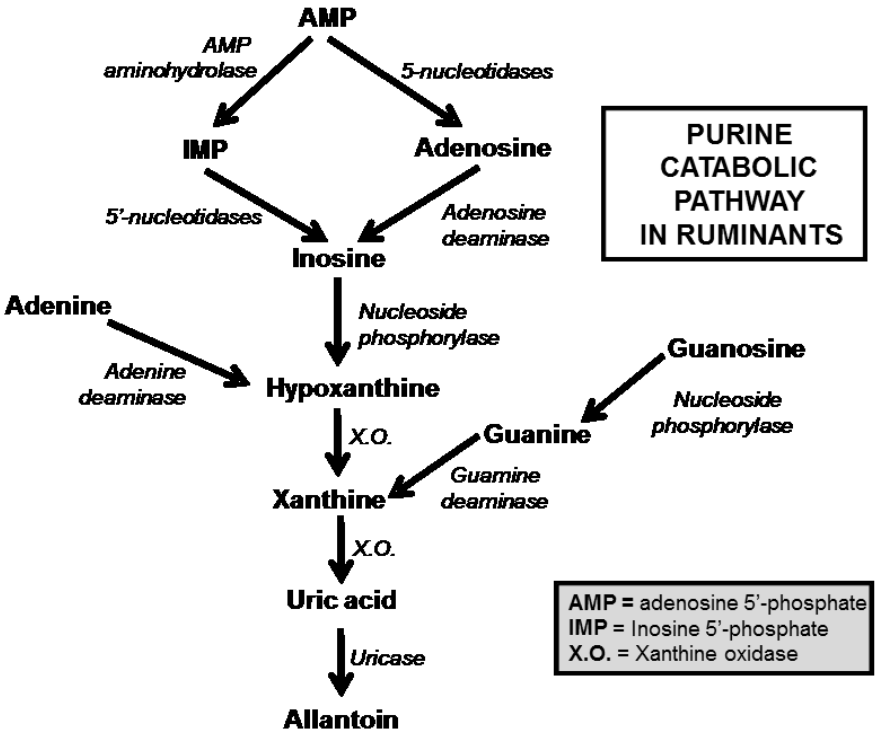

Figure 3.2 - Pathways of purine catabolism in ruminants. Adapted from Chen and Gomes (1992).

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 near-constant revision and updating. One graphic representation of these factors is presented in Figure 3.3, as follows: (a) collection and sampling, (b) urinary recovery of absorbed purines, (c) intestinal digestion and absorption of microbial purines, and (d) urinary endogenous purine fraction. The most recent results of researches related to these factors, emphasizing the use of this method to estimate microbial crude protein synthesis of cattle raised in tropical conditions, especially on grazing conditions, are discussed in the following items. An example of application (represented by item "e" in the Figure 3.3) using the most updated information is also presented.

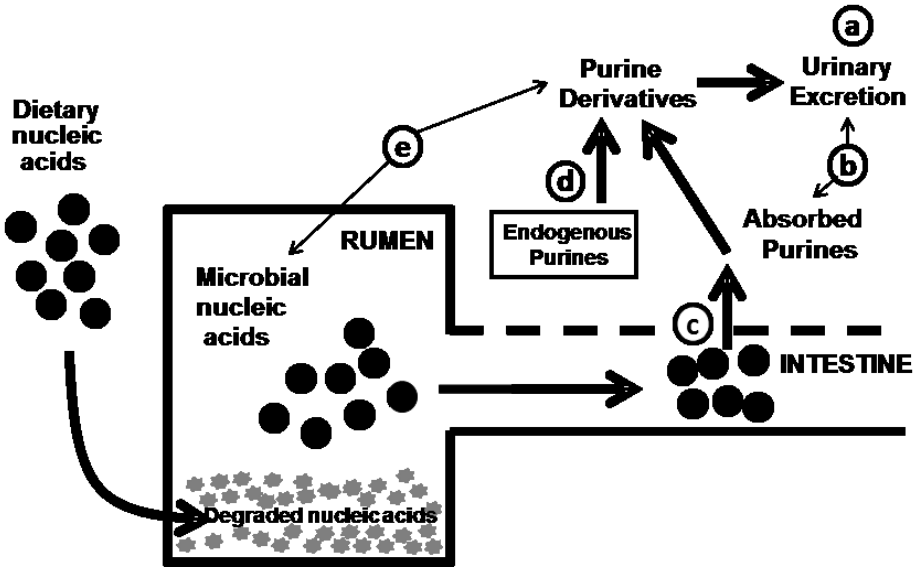

Figure 3.3 - Schematic representation of the purine derivative method to estimate microbial crude protein in ruminants. The main points of the method are: (a) collection, sampling and urinary estimation, (b) urinary recovery of absorbed purines, (c) intestine digestion and absorption of microbial purines, and (d) endogenous purine fractions in the urine. The point (e) represents an example of application to estimate microbial yield from purine derivatives in the urine. Adapted from Chen and Gomes (1992).

c) Collection and sampling

The method to estimate microbial N flow in cattle is based on the quantification of daily excretion of urinary PD (allantoin and uric acid). Therefore, the 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 allow total urine collection during 24 hours. In females, normally Foley-type probes are used which urine is 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 by periods from 3 to 7 days with daily quantification and sampling. However, methods of total collection are often labor which can affect animal behavior and welfare and there are difficulties to apply this technique in grazing animals. In dairy cows, the large amount of urine and the handling of collection system during milking contribute to become the use of total collection unfeasible and difficulty to conduct. Thus, an alternative technique will be further discussed.

d) Urinary recovery of absorbed purines

The relationship between urinary recovery of PD and purine duodenum flow (item "b", Figure 3.3) is an important factor of adjustment in the method to estimate microbial yield from urinary PD. Several studies aimed to measure the urinary recovery of purines post-rumen infused from microbial extracts. The urinary excretion of PD was linearly correlated with abomasum infusion of nucleic acids, nucleosides, purines from brewery 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 in the duodenum. In this type of study, the value of PD excretion is linearly related to value of infused purines (abomasum or duodenum). The slope of the equation provides the value of recovery 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 suggested for practical use of 0.80 which it will be adopted as standard in the edition of the BR-CORTE for both Zebu and Holstein cattle. Prates et al. (2012) did not observe differences on recovery rate of absorbed purines between Nellore and Holstein heifers, which there is no need of different values for each genetic group.

e) Intestinal digestion and absorption of microbial purines

The nucleic acids from bacteria, 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 could be observed on true digestibility of ruminal microorganism 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 the use in Zebu cattle raised under Brazilian conditions (item "c", Figure 3.3), being therefore considered as the standard value in this edition of the BR-CORTE.

In the small intestine, nucleotides from purines are hydrolyzed to nucleosides (adenosine, guanosine, and inosine) and free bases (adenine and guanine) (Figure 3.3), that are almost completely absorbed by sodium and potassium-depending pump (McAllan, 1980). In cattle, the high activity of the xanthine-oxidase enzyme was observed in the intestinal mucosa and blood plasma (Chen et al., 1990c), making that hypoxanthine and xanthine are virtually degraded completely until uric acid, differently from sheep. In the liver, uric acid is oxidized up to allantoin by uricase enzyme (Tas and Susenbeth, 2007). Allantoin and uric acid cannot be used by tissues and are excreted mainly in the urine but also in the milk and saliva (Tas and Susenbeth, 2007). In cattle, allantoin is the main PD (more than 80% of total) while the remain is composed by 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 microbial crude protein yield. Thus, the BR-CORTE does not recommend performing analysis of xanthine and hypoxanthine in cattle.

f) Endogenous fraction of urinary purine derivatives

Represented by the item "d" in the Figure 3.3, the endogenous fraction of urinary PD includes the portion of PD from nucleic acids that were 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 feeding restriction to evaluate endogenous losses of PD using the following scheme: feeding at 1% BW in the first eight days, 0.5% BW from ninth to eleventh day, and complete fasting from twelfth to sixteenth experimental day, totalizing 5 days of absolute fasting whose total collection of urine was performed. Braga et al. (2012) found endogenous contribution of 0.332 mmol/$BW^{0.75}$ and 0.384 g N/$BW^{0.75}$ for growing Nellore heifers.

Alternatively, the endogenous fraction has been estimated as the intercept of the linear regression between urinary excretion of PD and post-rumen infused PB. Some studies have shown that the endogenous fraction is similar between *Bos taurus indicus* and *Bos taurus taurus* cattle (Pimpa et al., 2001; Prates et al., 2012), while other studies suggest differences (Chen and Gomes, 1992; Osuji et al., 1996; Bowen et al., 2006). The endogenous fraction in *Bos taurus indicus* cattle was less of the half than those observed for *Bos taurus taurus* cattle in the study of Bowen et al. (2006). In a study conducted in

Brazil, Prates et al. (2012) did not observe difference on endogenous fractions of PD between Nellore and Holstein heifers. Studies conducted under Brazilian 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.

g) The use of urinary allantoin as the unique estimator of ruminal microbial crude protein synthesis

Allantoin is the most abundant purine derivative which the other components such as uric acid, xanthine, and hypoxanthine. In cattle, due to high activity of xanthine-oxidase enzyme that converts xanthine and hypoxanthine to uric acid, the excretions of allantoin and uric acid contribute as approximately 98% of urinary PD; therefore, the contribution of xanthine and hypoxanthine are irrelevant to estimate total excretion of PD (Rennó et al., 2000). However, when the proportion of uric acid is considered in relation to allantoin, observed in some studies in the last ten years, we highlight a relationship from 8 to 15% uric acid in relation to allantoin in the urine (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, we believe that it becomes interesting for the scientific community, the knowledge of the real relationship between these metabolites and the adjustment of a mathematical model capable to predict the uric acid content in the urine.

Thus, using a statistical toll such as meta-analysis, we estimated the proportion of allantoin and uric acid in the urine which allowed us to estimate the uric acid from allantoin content in the urine. The meta-analysis (St-Pierre, 2001) have been the most adequate procedure to evaluate data from several studies aiming to develop quantitative models whose can explain the effect of one or more independent variables on dependent variable. As normally there is differences among studies and if they are not considered during data analysis, they can provide in biased estimations for the parameters evaluated. Thereby, during the procedure of analysis, the effects of experiment and its interaction with the independent variables were considered as random component in a mixed linear model (St-Pierre, 2001), which the solution for the model was estimated by PROC MIXED of SAS (9.1, SAS Institute Inc., Cary, NC).

From a meta-analysis involving 38 experiments (Appendix 3.1) conducted in the Animal Science Department at *Universidade Federal de Viçosa* (Table 3.6), we verified that the daily excretion of uric acid in the urine can be estimated from daily excretion of allantoin in the urine ($P<0.05$), as follows:

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

where UA is the total uric acid excreted in the urine and ALA is the total allantoin excreted in the urine (mmol/d). 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 intercept.

These results (Figure 3.4) suggest that allantoin can be used as the unique estimator of microbial crude protein yield in cattle without the need of uric acid analysis, having, thus, an economy of reagents for analysis and lower time spent with chemical analysis to estimate ruminal microbial crude protein yield.

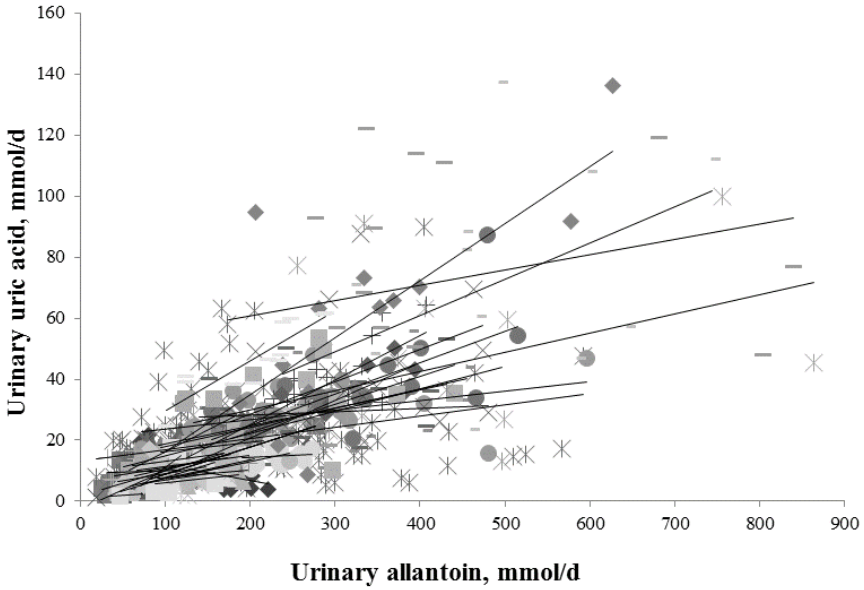

Figure 3.4 - Relationship between total urinary acid and total urinary allantoin (mmol/d) in cattle. Data from 38 studies.

h) Auxiliary technique – Estimation of urinary volume from urinary creatinine concentration

Creatinine is formed in the muscle by the removal of water in the creatinine-phosphate from muscle tissue metabolism (Harper et al., 2013). The molecule of creatinine-phosphate is spontaneously degraded at constant rates, producing creatinine. Creatinine is then the metabolic product, where the body does not need; therefore, it is not utilized for the formation of new molecules, being excreted by kidneys. The daily production of creatinine and consequently creatinine excretion depends on muscle mass and, thus, it is proportional to body weight of the animal (Koren, 2000). Then, once estimated, the daily creatinine excretion in relation to body weight of the animal and considering a constant concentration through the day, it is possible to estimate the excreted urinary volume from creatinine excretion in urine spot sample collected from an animal with a known body weight (Leal et al., 2007).

Currently, the profile of urinary creatinine excretion is known and the creatinine presents a constant excretion throughout 24-h period from constant degradation rates of muscle tissue. The creatinine excretion is little affected by the dietary contents of CP, non-fiber carbohydrates or NPN (Susmel et al., 1994; Vagnoni et al., 1997; Valadares et al., 1999; Oliveira et al., 2001; Rennó et al., 2000), thus, variations are not expected due to different diets.

Also, some studies are responsible by the adjustment of equations capable to predict creatinine excretion for determined animal category. Chizzotti et al. (2006) proposed an equation to estimate urinary creatinine excretion (UCE) for growing Holstein heifers, as follows:

$$UCE\ (mg/BW) = 32.27 - 0.01093 \times BW.$$

Then, linear equations are utilized to estimate creatinine excretion as a function of body weight. However, once the animals present different proportions of tissues in each development phase, variations can occur for daily creatinine excretions throughout animal life due to it is synthesized in the muscle tissue.

Table 3.6 - Descriptive statistics of data used to adjust the models for linear regression to estimate the relation between uric acid and allantoin in urine of cattle

	Alantoin (mmol/d)	Uric acid (mmol/d)	ALA:PD
Mean	169	20.2	89.0
Median	129	13.5	90.4
Standard deviation	123	22.9	4.97
Minimum	18.8	0.30	66.2
Maximum	864	322	99.8
n	1100	1100	1100
Experiments	38	38	38

[1]Total allantoin percentage relating to total purine derivatives excreted in urine.

According to Hammond (1968), growth can be understanding as the increase of body weight until the animal becomes adult. This definition, despite of simple, does not take the complexity off the theme because from the allometric model proposed by Huxley (1932), all variables are reduced to value of growth coefficient (Pereira Filho et al., 2008). The body development can be measured by some non-linear models as those proposed by Huxley (1932) and Callow (1948). Nevertheless, the allometric model of Huxley (1932), defined as $Y = aX^b$, allows performing an adequate quantitative description of growth from regions and tissues in relation to others and the whole body, describing a curve relationship between growth of the majority of tissues.

Then, aiming to study a possible allometric patter of urinary creatinine excretion as a function of body weight of cattle, a meta-analysis was performed with results of 32 experiments (Table 3.7) conducted in the Animal Science Department at *Universidade Federal de Viçosa* (Appendix 3.2), which the following equation was used to estimate urinary creatinine excretion for cattle:

$$UCE\ (mg/d) = 37.88 \times SBW^{0.9316};\ r^2 = 0.98$$

where UCE is the urinary creatinine excretion (mg/d) and SBW is the shrunk body weight (kg, Figure 3.5).

Table 3.7 - Descriptive statistics of data used to adjust the allometric models to estimate the relation between the body weight and the creatinine daily excretion in urine

	Creatinine (mg/d)	Creatinine (mg/BW)	Shrunk body weight (kg)
Mean	8,975	24.8	358
Median	8,298	25.2	310
Standard deviation	3,258	5.21	119
Minimum	1,266	13.3	96.5
Maximum	33,593	68.7	743
n	746	746	746
Experiments	32	32	32

The estimates of model's parameters were statistically significant ($P<0.05$) and data adjusted satisfactorily to allometric model. Thus, we recommend the urinary creatinine excretion should be estimated through allometric model according to body weight for different ages and genetic groups.

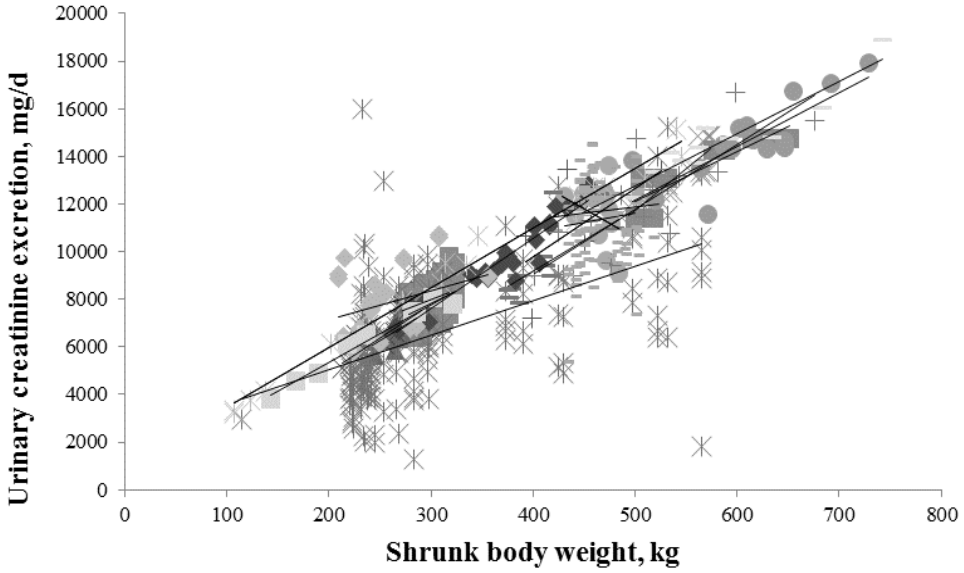

Figure 3.5 - Relationship between the shrunk body weight and the urinary creatinine excretion in cattle. Data from 38 studies.

The use of creatinine as a precise tool to estimate urinary volume, in different animal categories, becomes practical the process of estimation of ruminal microbial crude protein synthesis by the use of PD excreted in the urine. In Brazil, Pereira (2009) evaluated the relationship between body weight, the amount of muscle in the carcass, ribeye area, and subcutaneous fat thickness with urinary creatinine excretion of Nellore heifers in different body weights. Also, this author evaluated total creatinine excretion in intervals from 4 to 24 hours and the relationships of PD, urea, and total N compounds with creatinine obtained from 2-h urinary spot collections. The relationship between PD and creatinine did not range ($P>0.05$) through 24-h period from 2-h urinary spot collections, suggesting that the calculation of daily excretion of PD could be effective in collections obtained in any time of the day. However, effect of collection time was observed on relationship between urea:creatinine and total N compounds:creatinine. These relationships were close to the means in two points at the day when the animals received the feeding (8 and 16 hours). Pereira (2009) suggested that the estimate of N compounds in growing animals can be performed without the need of total collection, using only two urinary spot collections immediately after the feeding supply. However, we highlight that more studies are necessary to confirm this statement.

Silva Jr. (2014) studied the relationship between PD and N compounds with creatinine in grazing beef cattle to evaluate the possibility to perform collections each 4-h periods to measure microbial crude protein synthesis, N balance, and urea N excretion. This author performed collections each 4 hours during 5 consecutive days and did not find differences between collection day and time for the relationship between PD and creatinine which allows inferring about the possibility of performing urine collections in any time only to estimate the microbial crude protein synthesis for grazing cattle through technique of urinary PD. However, based on the variation observed for the relationships between creatinine and urea N and total N, respectively, over a 24-h period, Silva Jr. (2014) did not recommend the use of a sample to estimate the urinary excretion of N compounds.

i) Validation of proposed models

The following equations, that were previously proposed, were evaluated as quality of fitting and equality between predicted and observed values (Table 3.8).

Table 3.8 - Hypothesis test to evaluate the proposed model adjustment to estimate the uric acid excretion (mmol/d) as a function of allantoin excretion and creatinine in function of body weight

	P-value to hypothesis test	
Model evaluated	$\beta_0 = 0$	$\beta_1 = 1$
$^1Y = 0.1104X$	0.6700	0.9972
$^2Y = 37.88Z^{0.9316}$	0.5977	0.3357

^1Y = uric acid excreted in urine (mmol/d) and X = allantoin excreted in urine (mmol/d); ^2Y = creatinine excretion in urine (mg/d) and Z = body weight (kg).

For the statistical evaluation of the equations, data were submitted to adjustment by a regression test (Mayer et al., 1994), independently of effects of experiment and treatment, being evaluated by the linear regression equation of observed values (dependent variable) on predicted values (independent variable). For the non-rejection of null hypothesis ($\beta_0 = 0$ and $\beta_1 = 1$), we concluded that there is a similarity between predicted and observed values using the program SAS (version 9.1), adopting 0.05 as critical level of probability for error type I. We verified that predicted and observed values did not differ (Table 3.8), which supports use of the equations proposed here.

Microbial crude protein synthesis

The microbial efficiency can be conceptualized as the amount of microbial crude protein obtained from a determined energy unit, or so, it is the amount of protein produced by ruminal microorganisms from energy substrate that is available in the rumen, having therefore the interference of a series of factors. According to Clark et al. (1992), the availability of energy and N are the greatest determining of the amount of microbial crude protein synthetized in the rumen and, according to these authors, a mixed of structural and non-structural carbohydrates is the best energy source for microbial growth. Fermentable carbohydrates provide greater energy yield per unit of weight than proteins and lipids, although lipids can be captured by microorganisms and they cannot provide the energy required for protein synthesis (Clark et al., 1992). Thus, the main factors that might be considered to evaluate microbial efficiency are those that interfere with the degradation of carbohydrates and proteins and their availability. Effects such as voluntary intake, relationship between forage and concentrate, source and amount of non-structural carbohydrates, CP, presence of lipids in the diet, feeding frequency, grain and forage processing, methods for forage conservation, supply of microminerals, additives, and ruminal environment affect microbial efficiency (Clark et al., 1992). However, the majority of reports in the literature suggest that the levels of fermentable carbohydrates and N compounds have the strongest effect on ruminal microbial efficiency.

a) Energy availability

A simple increase in OM intake increases the passage rate of ruminal microbial nitrogen, while an increase in digested true OM intake creates a quadratic pattern for the rate of microbial N passage through the small intestine (Clark et al., 1992). This shows that high levels of rapidly fermentable carbohydrate can also be deleterious to microbial crude protein synthesis. Nevertheless, generally, the increase of DM intake is the most important mechanism to increase amino acid availability in the small intestine which increase both microbial crude protein synthesis and RUP scape for small intestine (Clark et al., 1992).

According to Detmann et al. (2014a), under grazing conditions, low-quality tropical forage is typically deficient in N. This reality is widespread in tropical countries such as Brazil. Supplementation with rapidly degradable carbohydrate isolately does not provide positive nutritional effects. The supply of non-fiber carbohydrates can increase competition between fibrolytic and non-fibrolytic microorganisms by N compounds that are not present in sufficient amounts in low-quality

forage (Detmann et al., 2014a). Also, according to these authors, the low nitrogen availability for enzyme synthesis and the increase of non-fiber carbohydrates availability can contribute for the increase of futile cycles by non-fibrolytic microorganisms which will reduce microbial efficiency in these conditions.

According to Clark et al. (1992), under feedlot conditions, the use of concentrate level ranging from 30–70% increases the energy efficiency of ruminal microbial synthesis. The supply exclusively of forage or the great part of concentrate cause certain modification in ruminal fermentation, once energy is more rapidly released than it could be utilized for microbial growth. The addition of structural carbohydrates to a diet with high concentrate levels will allow the use of energy by bacteria more efficiently due to it will be released slowly throughout the day. On the other hand, the deficiency of non-structural carbohydrates decreases microbial growth and increases microbial cell lysis due to the reduction on passage rate of the digesta. This slow passage rate will occur because microorganisms will adhere to large particles of forage, increasing retention time of these microorganisms and prioritizing their maintenance requirements with consequent losses of nitrogen compounds and energy.

Dewhurst et al. (2000) asserted that in different production systems, distinct points should be clarified with regard to alterations in microbial efficiency. In grazing conditions, there is abundance of fermentable organic matter in the rumen and reduced content of nitrogen compounds need to be supplemented to increase microbial efficiency, while animals fed silage-based diets can receive abundance of peptides and amino acids from protein degradation.

Evaluating the effect of various fractions (pectin, sucrose, and starch) from non-fiber carbohydrates and NDF on microbial crude protein synthesis using *in vitro* fermentation systems, with pH maintained above 6.49 in the fermentation tubes, Hall and Herejk (2001) observed greater microbial production in animals fed with starch, pectin, sucrose and NDF. Also, they observed that peaks of microbial crude protein synthesis were achieved at 15.6, 13.5, 12.6, and 19.3 hours after the beginning of the fermentation, respectively, for starch, pectin, sucrose, and NDF.

An interesting aspect of the use of sugars in ruminant diets is related to its effect on nitrogen metabolism and microbial growth. A reduction on ruminal ammonia concentration have been noticed in almost all studies where sugars were added to diets. This reduction suggests an increase of microbial growth and the efficiency of the use of ruminal rapidly degradation protein compounds. Chamberlain et al. (1993) showed that soluble sugars (sucrose, lactose, and fructose) are superior to starch as energy source for microbial nitrogen fixation in the rumen. These observations suggest the existence of an optimum relationship between available sugars and soluble nitrogen. Hoover and Miller-Webster (1998) obtained an average increase of 25% of microbial growth when the ratio protein/soluble sugar varied from 1:1 to 2 or 3:1.

As sugars represent less than 10% of total NFC, starch becomes the main source of carbohydrates for microbial growth (Hoover and Miller-Webster, 1998). The fermentation source of all carbohydrates determines its destiny on gastrointestinal tract and the efficiency that microorganisms can utilize them (Van Soest et al., 1991). The knowledge of the variation on effective degradability (ED) of several sources of starch whose can be utilized as ingredients, to synchronize energy and protein availability to maximize ruminal fermentation is an interesting strategy on diet formulation for ruminants.

b) Nitrogen compounds

The extent and rate of protein degradation directly affect microbial crude protein synthesis and estimates of the amount of RUP that will reach the duodenum. The dietary protein degradation becomes the most important factor that estimates the amount of absorbed amino acids, altering thus RUP requirements (Stern et al., 1994). Hoover and Stokes (1991) reported that large peptides are more rapidly caught than the majority of amino acids and small peptides, being more efficiently utilized for microbial synthesis. According to Russell et al. (1992), non-structural carbohydrates fermenter microorganisms caught peptides at a rate of 0.07 g of peptides per gram of

microorganisms per hour and this nitrogen is utilized for microbial crude protein synthesis or ammonia production. The diversity of nitrogen compounds varies as a function of fermentable carbohydrate availability. When there are carbohydrates available for microbial growth, peptides become the main source of nitrogen for non-structural carbohydrates fermenter microorganisms. When there is reduction on carbohydrate availability, all peptides are conducted for ammonia production (Russel et al., 1992).

According to Detmann et al. (2014a), the ammonia nitrogen content needed to maximize DM intake is at least 8 mg/dL; however, the authors reported that levels of 15 mg/dL are necessary to increase NDF intake. This, in turn, maximizes the degradation of fiber carbohydrates, which increases microbial efficiency and the ruminal passage of low-quality forage under tropical pasture conditions. Then, Detmann et al. (2014a) asserted that the maintenance of ammonia nitrogen levels of approximately 15 mg/dL is necessary to increase microbial crude protein synthesis, which contributes to the increased MP intended for the host. The discrepancy among ammonia nitrogen levels enough to increase DM intake than those needed to increase NDF degradation and NDF intake suggest a multifactorial intake control pattern (Detmann et al., 2014b) and they are not only regulated by dietary NDF levels or ruminal repletion as previously preconized for grazing ruminants.

Considering the CP levels that maximize microbial yield, Detmann et al. (2014a) observed that 8% CP is the minimum level required so that ruminal microorganisms do not utilize endogenous sources of nitrogen compounds. Under such conditions, there is a positive balance in the use of ammonia nitrogen. Below this value, we believe that nitrogen recycling is a source necessary for maintenance of microbial growth which can reduce body protein retention of cattle. Above of this value, the efficiency of conversion from nitrogen to microbial crude protein is not maximum; however, the positive balance was obtained for nitrogen compounds in the ruminal environment. Detmann et al. (2014a) also reported that 10% CP is the maximum level for extraction of basal energy resources and above this value the levels of ammonia nitrogen can be deleterious to intake when there is not enough energy in the diet. These factors characterize the importance of the maintenance of an adequate relationship between metabolizable protein and energy in order to maximize microbial efficiency.

Ammonia is the primary source of protein for ruminal bacteria growth; however, some *in vitro* studies showed that several other bacteria present absolute requirements or they are stimulated by addition of amino acids and peptides (Cotta and Russell, 1982). According to Cotta and Russell (1982), *Bacteroides ruminicola, Selenomonas ruminantium, Streptococcus bovis, Megasphaera elsdenii* and *Butyrivibrio fibrissolvens,* abundant in the ruminal environment, are amino acid users. Some are not exclusively amino acid users, such as *Bacteroides ruminicola* that is relatively little affected in low amino acid environments. On the other hand, *in vitro* cultures of *Butirivibrio fibrissolvens* do not maintain themselves viable in the lack of amino acids and peptides as source of nitrogen compounds. The authors reported that these microorganisms present requirements for some specific amino acids.

c) Effect of pH

According to Dewhurst et al. (2000), microbial efficiency is directly affected by the meeting of requirements for maintenance of the microorganisms, including the nutrients needed for motility, cell turnover, production of extra-cellular molecules, active transport, phosphorylation, futile cycles and cell lysis. According to these authors, with the increase of intake, there is reduction of costs with maintenance of the microorganisms, because they will remain less time in the rumen. Other factors, such as pH, when low, increases energy losses to maintain pH inside of microbial cell. According to Strobel and Russell (1986), in low ruminal pH, the energy available for microbial growth is diverted for the maintenance of internal pH from microorganisms, reducing the efficiency of energy use for microbial synthesis.

Generally, in pH below 6.0, there is inhibition of cellulose degradation. Under normal conditions, cellulolytic microorganisms

grow well in pH 6.7 and substantial detours to increase or decrease this value are inhibitory. A variation of pH which activity maintains close to normal would be 0.5 units. Values of pH below to 6.2 inhibit digestion rate and increase lag time for cell wall degradation (Van Soest, 1994). The increase of latency increases costs for maintenance reducing microbial efficiency.

Strobel and Russell (1986) highlighted that microbial efficiency is highly influenced by detour of functions in low pH. The use of energy to maintain cell processes is prioritized, which reduces microbial growth. This energy is subsequently dissipated as heat. The maintenance of membrane potential is a priority function, as lower external pH, more energy will be required to put out protons.

d) Prediction of microbial crude protein flow of the diet

To know the variables that effectively influence microbial crude protein synthesis in beef cattle raised under tropical conditions, we proceeded a meta-analysis aiming to evaluate the effect of animal and diet characteristics on this variable. In this study, 69 studies published in Brazil and abroad were used, as well as thesis and dissertations concluded in the Animal Science Department at the Universidade Federal de Viçosa (Appendix 3.3), totalizing 2,676 observations, which different variables that could interfere on ruminal microbial crude protein synthesis were evaluated. The database was divided in two distinct groups. The first group was designed to the generation of mathematical equations where 32 studies (n = 2,102) were used while the second group was designed for the evaluation of quality of equations generated. Other 37 studies (n = 191) were used, which the means of treatments were utilized, totalizing 1,285 animals.

Moreover, the database was used separately to evaluate four types of energy attributes initially associated with CP intake for each model. We also evaluated the effects of total digestible nutrients intake (TDNI), metabolizable energy intake (MEI), total digested organic matter intake (tdMOI), and TDNI corrected for EE (ceeTDNI). Thus, the complete database comprised all effects evaluated, with variables classified according to experiment, genetic group (Zebu, beef crossbred, dairy crossbred, and Holstein cattle), sex (bulls, steers, heifers, and cows) and method (RNA, PD and ^{15}N) (Table 3.9). The random effect related to experiments was considered in the generation of the parameters of the equations.

Table 3.9 - Descriptive statistics of data used to generate the multiple regression models to estimate the microbial crude protein synthesis in cattle under tropical conditions

Item[1]	n	Mean	SD[2]	Maximum	Minimum
MCP	2,102	775	547	3,008	66.8
CPI	2,102	1.22	0.87	4.39	0.59
DMI	2,102	8.52	5.31	23.8	1.76
TDNI	2,102	6.22	3.74	16.8	0.83
MEI	2,102	22.3	13.3	60.9	3.00
tdOMI	1,454	5.70	2.98	15.5	0.62
CP (%)	2,102	13.2	2.61	28.9	8.89
BW (kg)	1,563	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.

From the variables cited, the procedure started with the selection of significant variables that influenced microbial CP (MCP). Initially, the correlation among variables was studied using the PROC CORR of SAS (version 9.3, SAS Inst. Inc., Cary, NC). The significant variables were added to model using PROC REG of SAS through STEPWISE tool (version

9.3, SAS Inst. Inc., Cary, NC) that selected the significant variables. Further, the variables were evaluated by meta-analysis (St-Pierre, 2001) to estimate the main effect using the following mathematical model:

$$Yij = \beta_0 + Si + \beta_1 \times Xij + bi \times Xij + \varepsilon ij,$$

where, Yij = the dependent variable, in this case MCP; β0 = general intercept considered as random effect; Si = random effect of ith experiment; β1 = general regression coefficients of response variable as a function of X (fixed effect); Xij = predictor variable; bi = random effect of experiment on the regression of response variable as a function of X; ij = residual error, assuming ij, bi, and Si as independent variables. From this model, beyond experiment, other variables were considered: genetic group (Zebu, beef crossbred, dairy crossbred, and Holstein cattle), sex (bulls, steers, heifers, and cows), and method (RNA, PD, and ^{15}N), as well as all interactions between them.

The random effects as genetic group, sex, and analytical method were not significantly for any equation proposed (P>0.05) and for each genetic attribute to evaluate MCP, the following parameters were obtained: TDNI (CPI: P<0.0001, CPI^2 = 0.2242, TDNI: P<0.0001, and $TDNI^2$ = 0.0283), MEI (CPI: P<0.0001, CPI^2 = 0.9977, MEI: P<0.0001, and MEI^2 = 0.0002), and tdMOI (CPI: P<0.0001, CPI^2 = 0.4814, tdMOI: P=0.004, and $tdMOI^2$ = 0.0273). Once all effects were evaluated and the variables that composed the models were verified, the procedure Cross Validation (Duchesne and MacGregor, 2001) was used to estimate regression parameters, that the linear and quadratic behaviors were tested. We chose this polynomial due to microbial synthesis does not follows a linear behavior and, in theory, it will reach a plateau (Figures 3.6-3.8). Then, the following equations were obtained:

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

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

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

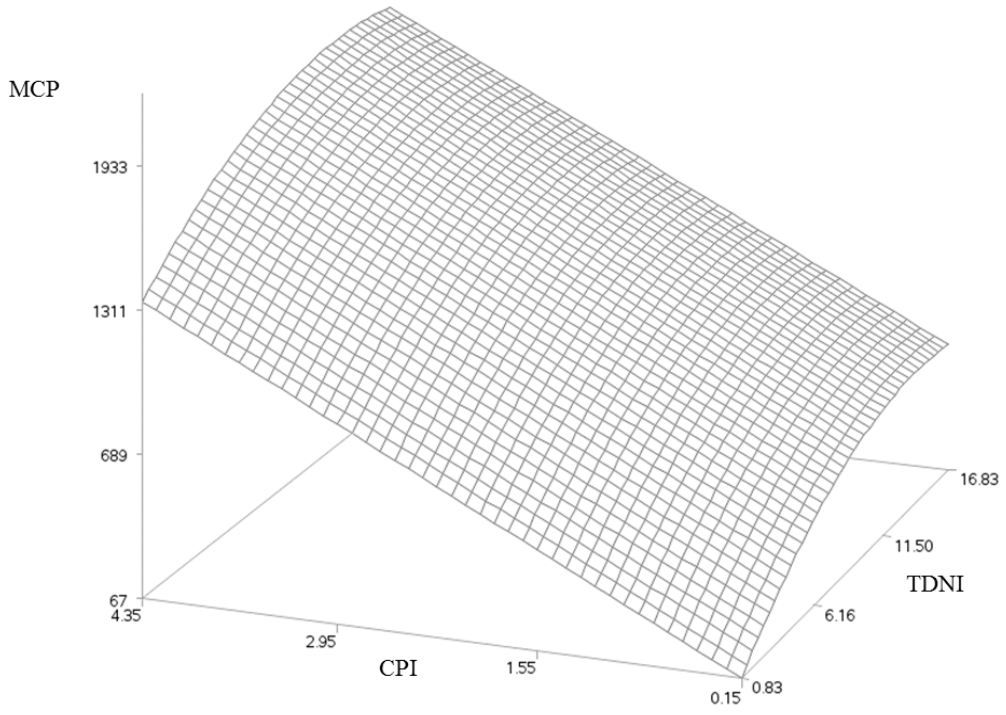

Figure 3.6 - Microbial crude protein estimated by the equation: MCP = - 53.07 + 304.9 × CPI + 90.8 × TDNI – 3.13 × $TDNI^2$, where MCP in g/d, TDNI and CPI in kg/d.

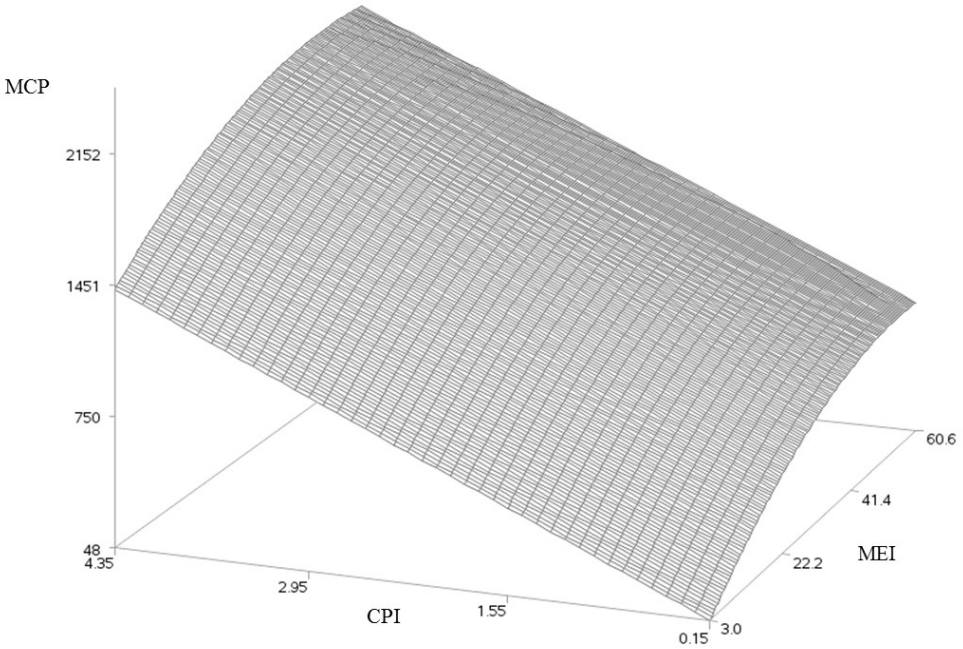

Figure 3.7 - Microbial crude protein estimated by the equation: MCP = - 84.87 + 328.7 × CPI + 28.3 × MEI – 0.25 × MEI^2, where MCP in g/d, MEI in Mcal/d and CPI in kg/d.

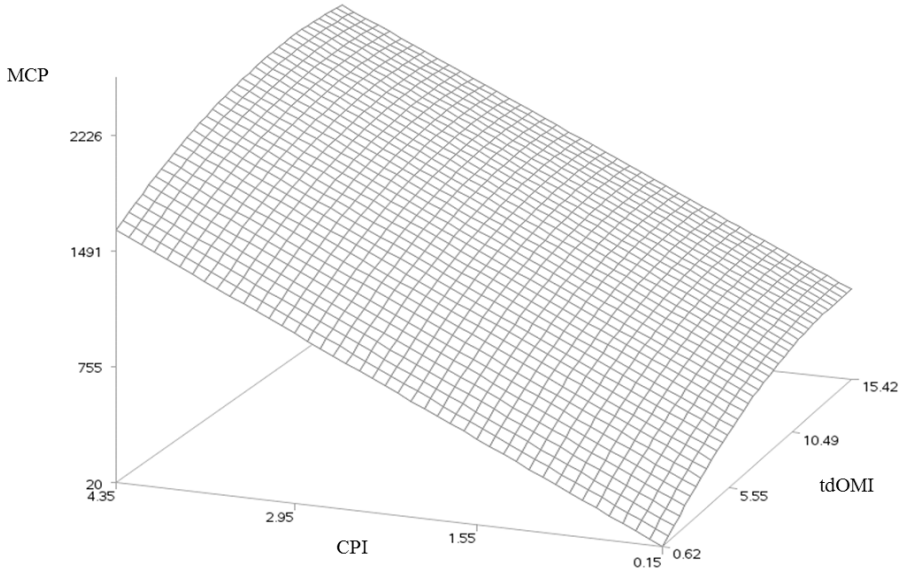

Figure 3.8 - Microbial crude protein estimated by the equation: MCP = - 93.62 + 381.7 × CPI + 90.7 × tdOMI – 3.13 × tdOMI^2, where MCP in g/d, tdOMI and CPI in kg/d.

When each equation evaluated was submitted to validation (Table 3.10), the null hypothesis was accepted, which proves that the equations were adequate to predict MCP flow. The high values for the concordance correlation coefficient (CCC) and determination coefficient of the regression tested (r^2) for all equations indicate high adjustment degree of equations to observed values. The mean square error of prediction (MSEP) was lower for TDNI which indicates greater accuracy of these equations in comparison to MEI and dtMOI. Decomposing MSEP, we highlight that TDNI and dtOMI were the equations that presented greater values for

random error that for a desirable situation, this value might be close to 100%, indicating greater precision to obtain the estimates. The greater MSEP and greater mean and systematic bias for MEI equation indicates lower suitability of this equation to predict MCP flow; although, this equation had presented adequate.

Table 3.10 - Regression analysis, correlation and concordance coefficient (CCC) and decomposition of mean square error of prediction (MSEP) among the predicted and observed values for microbial crude protein as a function of TDNI, MEI, and tdOMI

	MCP prediction equation		
	TDNI[1]	MEI[2]	tdOMI[3]
AR[4]			
r^2	0.9531	0.9670	0.9418
H_0: a=0 (P-value)	0.069	0.067	0.5371
H_0: b=1 (P-value)	0.202	0.152	0.0546
CCC	0.9691	0.9697	0.9687
MSEP	8,548	11,454	10,187
Mean bias (%)	1.09	15.67	1.76
Systematic error (%)	0.87	0.93	1.99
Random error (%)	98.04	83.40	96.25

[1]Total digestible nutrients intake; [2]Metabolizable energy intake; [3]Total digestible organic matter intake; [4]Regression analysis between the values of MCP predicted and observed by three regression equations using different energy basis;

The database utilized to estimate the previously equations was developed by data with, on average, 2.83% (± 1.03) EE in the diet. However, as BCNRM (2016), an equation was developed to estimate microbial crude protein synthesis for high values of ether extract (EE). The BR-CORTE (2016) suggested the equation below for diets with high EE content:

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

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

The BCNRM (2016) also suggests an equation with which to estimate microbial crude protein synthesis that corrects for EE when diets with EE content above 3.9% are used. In Brazil, a lot of diets for beef cattle are formulated to contain EE contents that are lower than 3.9%. However, if the aim is to formulate diets with high EE content, we recommend use of the equation proposed by the BR-CORTE that was generated from a database containing 1,437 animals raised under tropical conditions.

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 unique and double indicator system:**

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

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

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

$0.30\ mmol/BW^{0.75}$

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

$UA\ (mmol/d) = 0.1104 \times ALA$

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

$UCE\ (mg/d) = 37.88 \times SBW^{0.9316}$

- **Prediction of MCP:**

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

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

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

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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, 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*

	Animal Category	
Component	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,

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

this assumption compromises the accuracy of the digestible NDF estimates.

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.

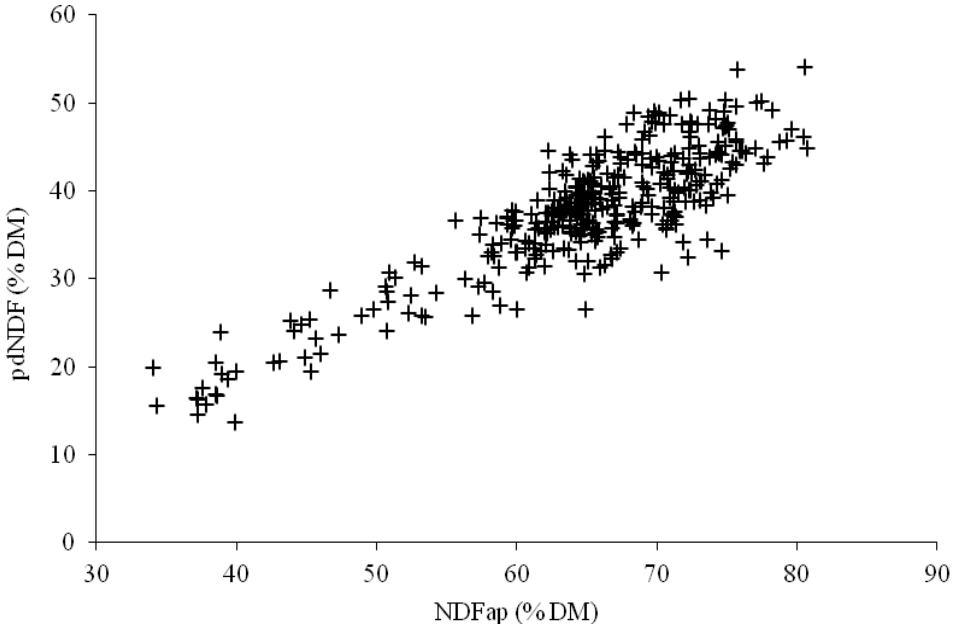

Figure 4.1 - Relationship between the contents of neutral detergent fiber corrected for ash and protein (NDFap) and potentially digestible neutral detergent fiber (pdNDF) in forage samples (n = 371).

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.

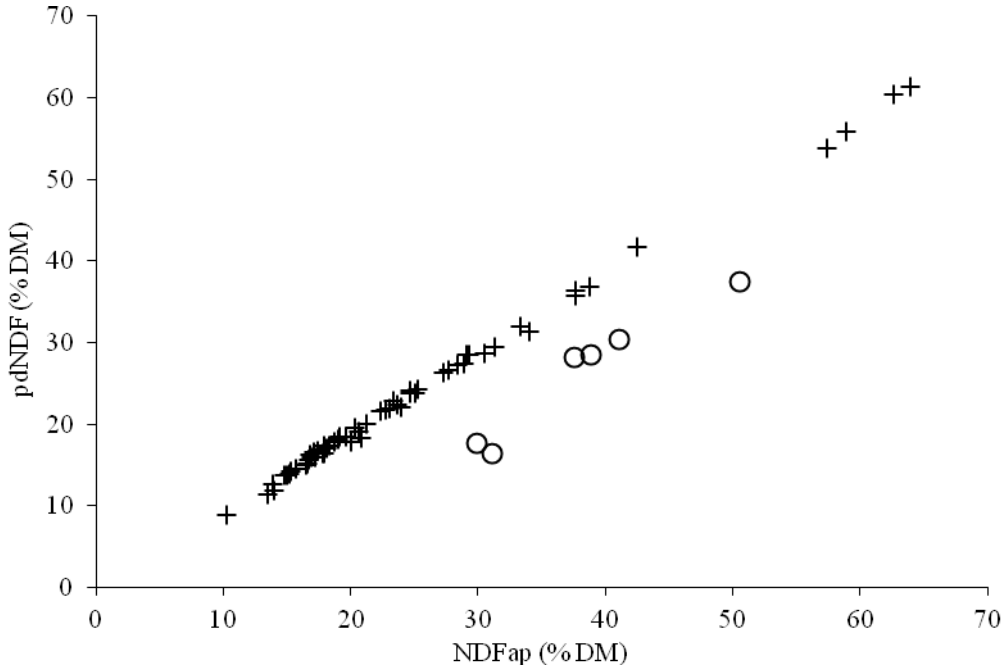

Figure 4.2 - Relationship between the contents of neutral detergent fiber corrected for ash and protein (NDFap) and potentially digestible neutral detergent fiber (pdNDF) in concentrate samples (n = 65; ○ = concentrates containing fiber with lesser potential degradation; + = other concentrate feeds).

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.

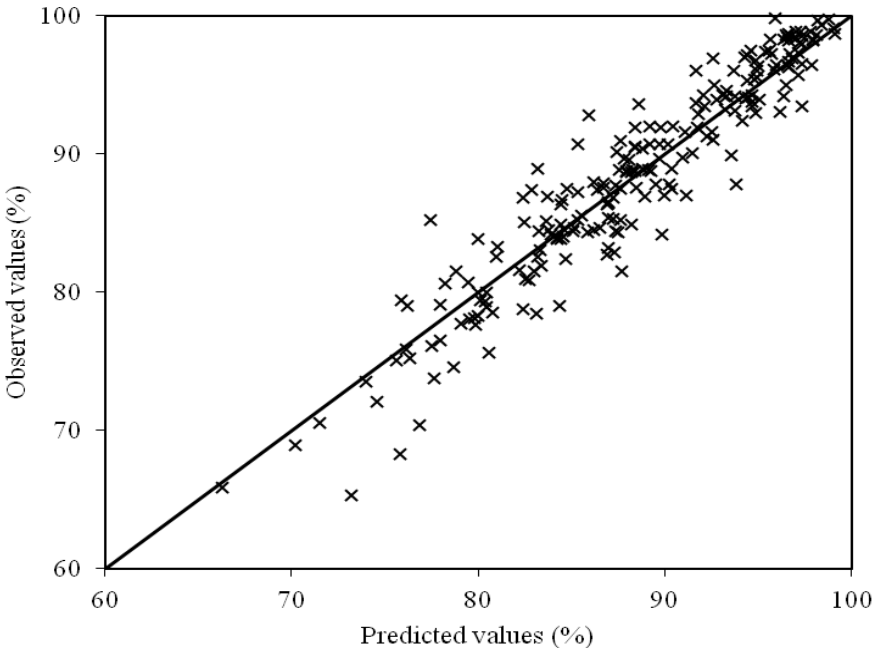

Figure 4.3 - Relationship between predicted and observed values for the digestibility coefficient of potentially digestible NDF in growing and finishing cattle (Equation 4.15; the continuous line represents the equality line; s_{XY} = 2.96; R^2 = 0.900; lack-of-fit: P>0.07).

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, FAI = 1.12 (FAI = 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:

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

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):

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

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:

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

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

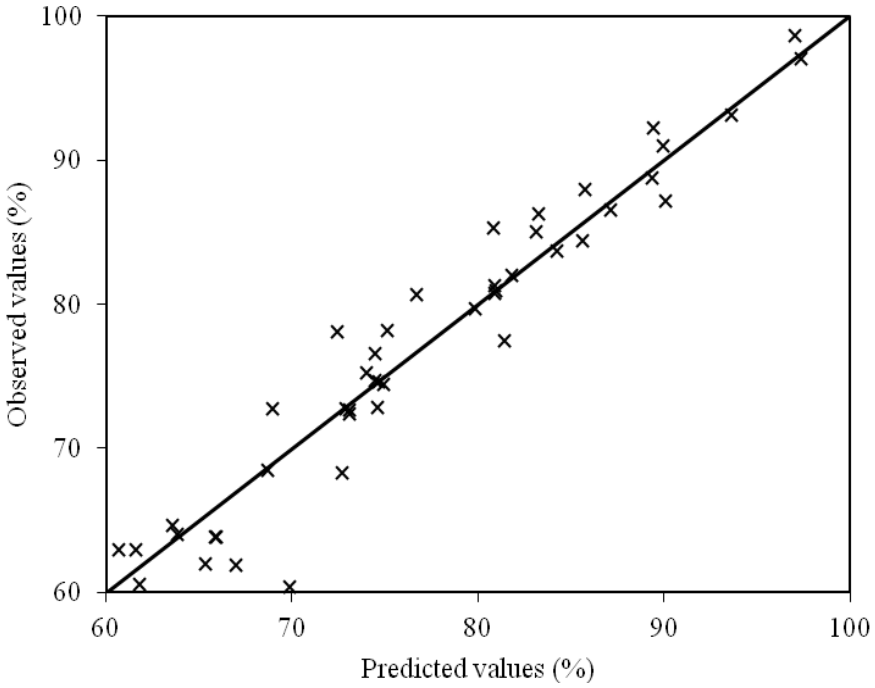

Figure 4.4 - Relationship between predicted and observed values for the digestibility coefficient of potentially digestible NDF in dairy cows (Equation 4.16; the continuous line represents the equality line; s_{XY} = 3.46; R^2 = 0.933; lack-of-fit: P>0.67).

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.

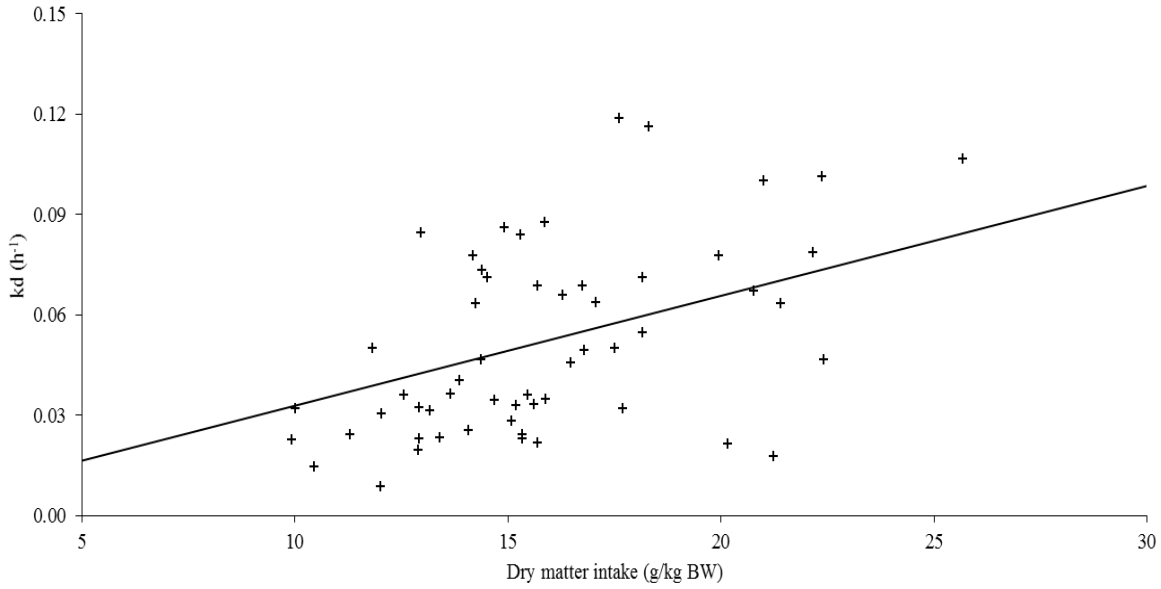

Figure 4.5 - Relationship between voluntary dry matter intake and degradation rate (kd) of potentially digestible neutral detergent fiber in forage-based diets (continuous line represents Equation 4.18).

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).

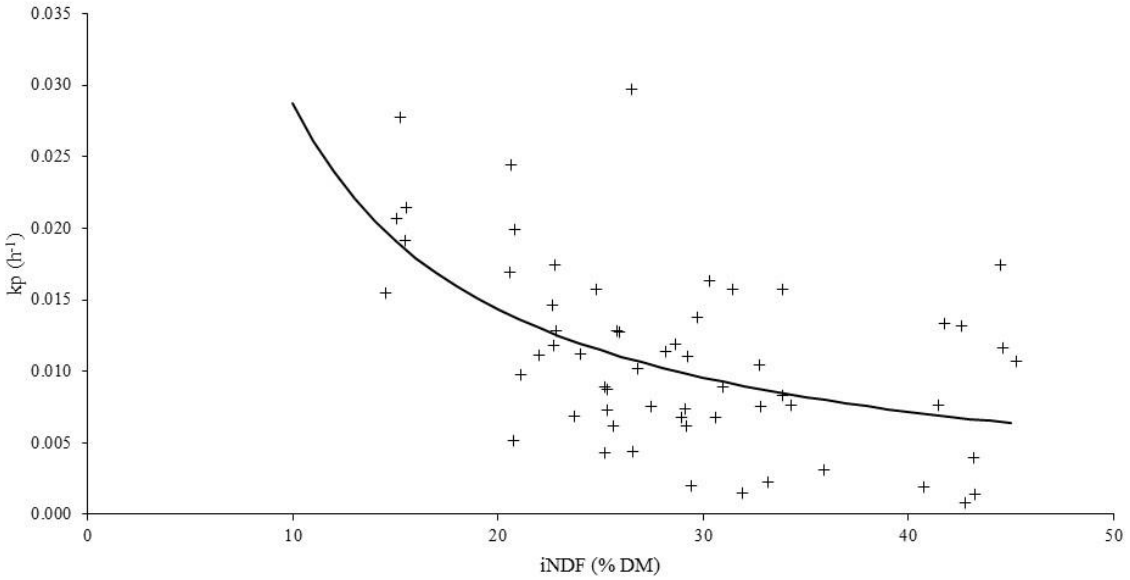

Figure 4.6 - Relationship between diet concentration of indigestible neutral detergent fiber (iNDF) and passage rate (kp) of potentially digestible neutral detergent fiber in forage-based diets (the continuous line represents Equation 4.19).

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:

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

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):

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

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); CM_{CP}, CM_{NFC}, CM_{EE}, fecal metabolic contributions from CP, NFC and EE, respectively (% DM); FM_{TDN}, 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 (MO), 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 Kejldhal 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):

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

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 4.2) 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)

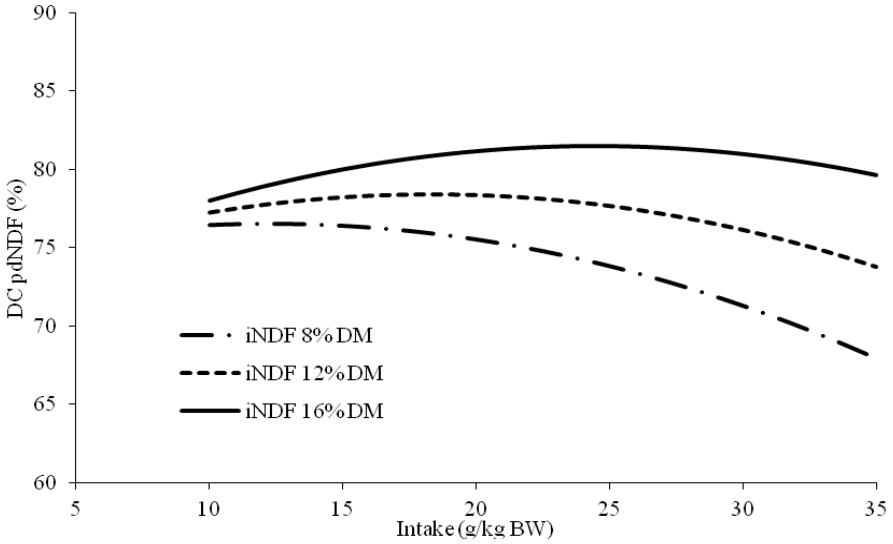

Figure 4.7 - Variations in the digestibility coefficient of potentially digestible neutral detergent fiber (DC pdNDF) according to voluntary dry matter intake and iNDF diet content for growing and finishing cattle fed forage with low starch content (Equation 4.15; presuming diet with 12% CP based on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

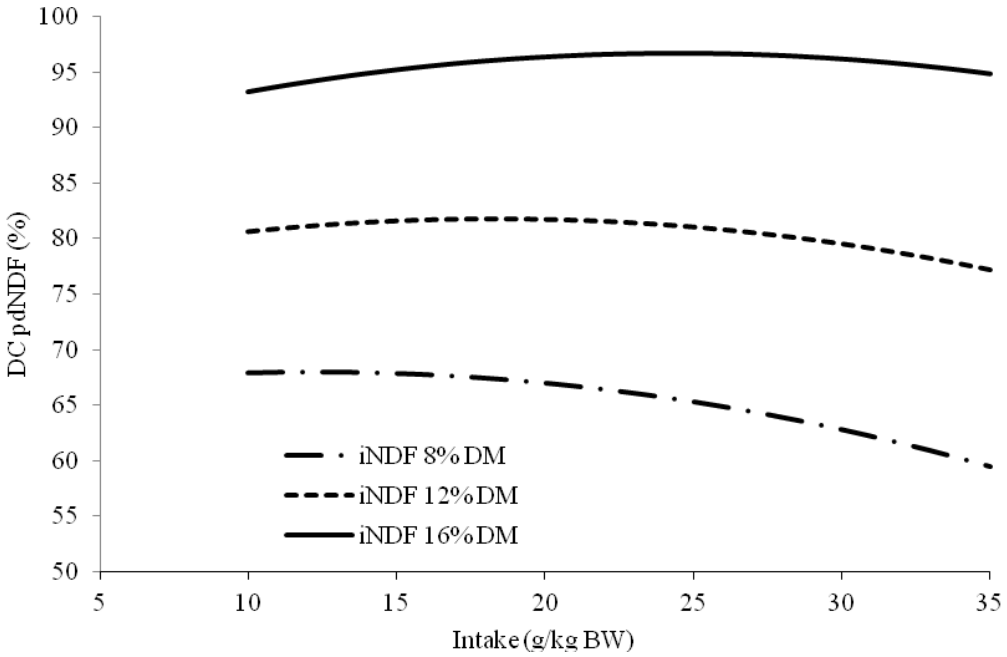

Figure 4.8 - Variations in the digestibility coefficient of the potentially digestible neutral detergent fiber (DC pdNDF) according to voluntary dry matter intake and iNDF diet content for growing cattle fed forage with high starch content (corn or sorghum silage; Equation 4.15; presuming diet with 12%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

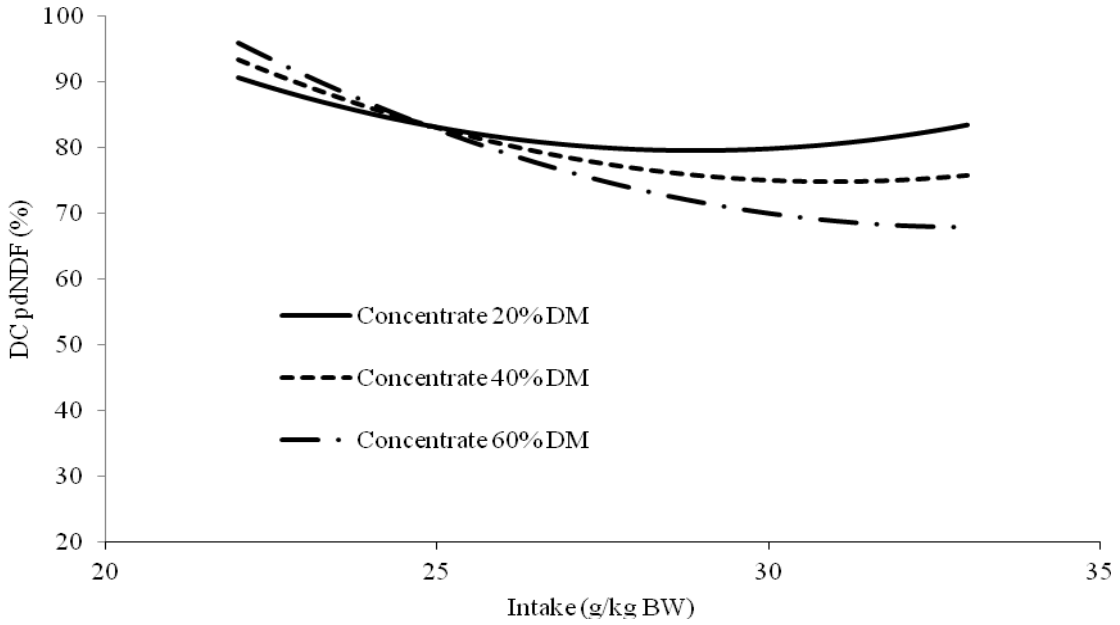

Figure 4.9 - Variations in the potentially digestible neutral detergent fiber digestibility coefficient (DC pdNDF) according to voluntary dry matter intake and concentrate level in diet for dairy cows (Equation 4.16).

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 (BCNRM, 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.

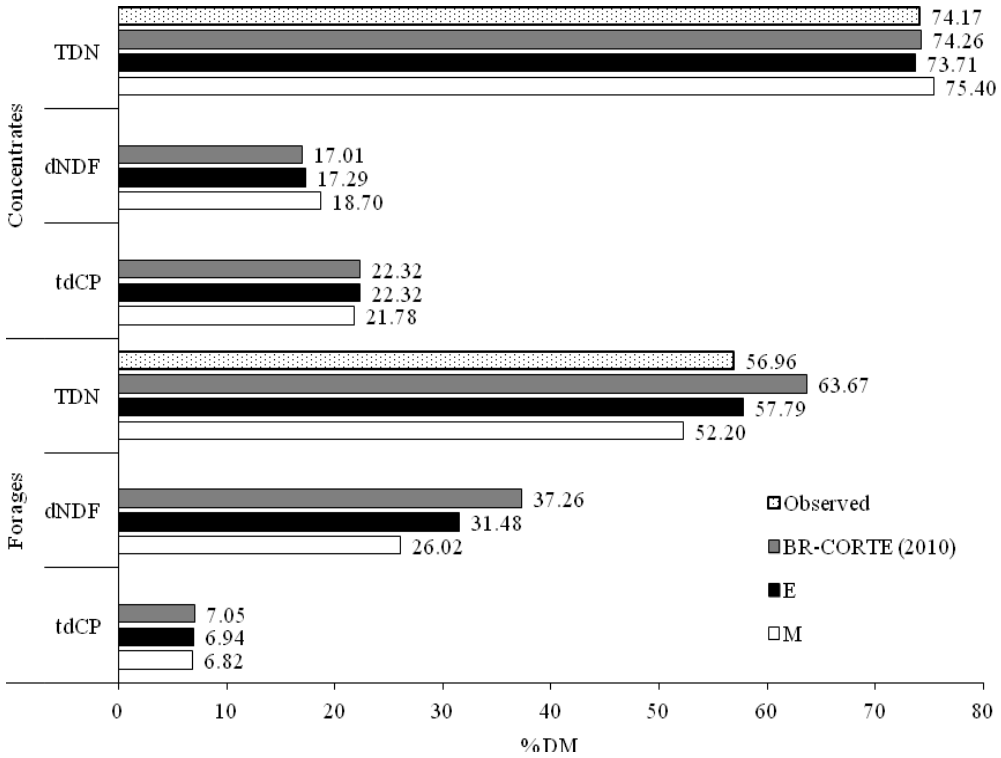

Figure 4.10 - Estimates of the truly digestible CP (tdCP), digestible NDF (dNDF) and the TDN content obtained by the sub-models adopted by the BR-CORTE (2010) and the meta-analytical (M) and empirical (E) approximations for growing and finishing cattle and TDN contents obtained from CQBAL 3.0 (forages, 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.

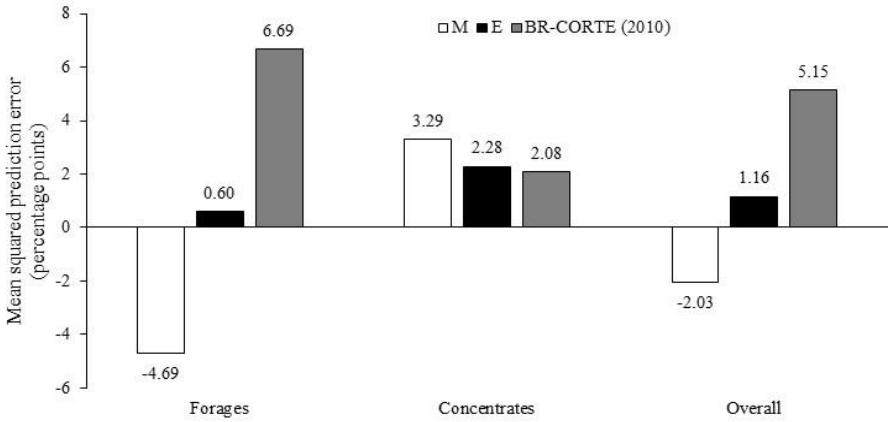

Figure 4.11 - Mean prediction error for TDN content (percentage points) in concentrate and forage feeds obtained by the sub-models adopted by the BR-CORTE (2010) and by the meta-analytical (M) and empirical (E) approximations for fiber and protein for growing and finishing cattle in relation to the mean 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.

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).

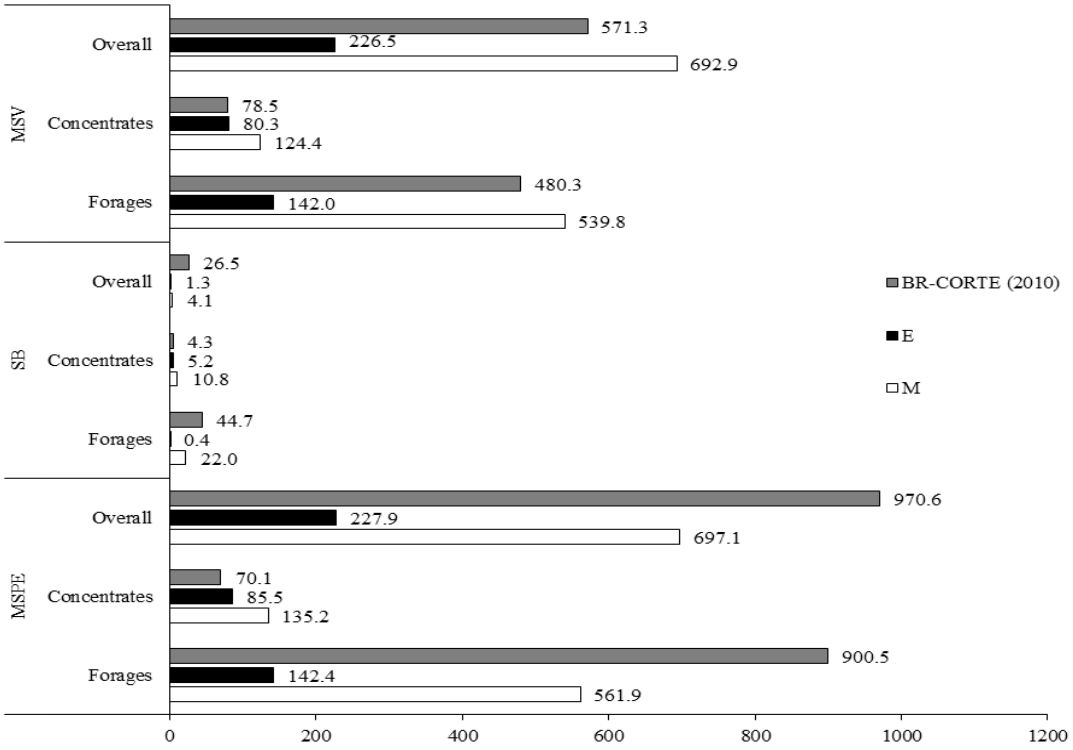

Figure 4.12 - Mean squared prediction error (MSPE), squared bias (SB) and mean squared variation (MSV) for the TDN contents in concentrate and forage feeds obtained by the sub-models adopted by the BR-CORTE (2010) and by the meta-analytical (M) and empirical (E) approximations for fiber and protein for 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)

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

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

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

$$iNDF(Diet) = NDFap - pdNDF = 30.38 - 20.28 = 10.55\%$$

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

$$D_{GF} = 80.21 \times 0 - 0.0166 \times 25^2 + 2.658 \times 10.55 + 3.691 \times 12$$
$$+ 0.0507 \times (25 \times 10.55) - 2.9673 \times (0 \times 12.05) - 3.9990 \times (0 \times 12) = 75.33\%$$

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

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)

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

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)

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

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

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

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

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

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

$$dNDF(C) = [(\frac{0.0823}{0.0823 + 0.0261}) \times 8.64] \times 1.12 = 7.34\%$$

$$dNDF(Diet) = 0.5 \times dNDF(F) + 0.5 \times dNDF(C) = 0.5 \times 30.42 + 0.5 \times 7.34 = 18.88\%$$

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)

$$TDN = tdCP + tdNFC + dNDF + 2.25 \times tdEE - FM_{TDN}$$
$$TDN = 11.02 + 47.45 + 18.88 + 2.25 \times 2.95 - 7.13$$
$$TDN = 83.99 - 7.13 = 76.86\%$$

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

$$DE = 0.056 \times tdCP + 0.042 \times tdNFC + 0.042 \times dNDF + 0.094 \times tdEE - FM_{DE}$$
$$DE = 0.056 \times 11.02 + 0.042 \times 47.45 + 0.042 \times 18.88 + 0.094 \times 2.95 - 0.322 = 3.358 \text{ Mcal/kg DM}$$

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					
	Alfalfa	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 body composition of the animals. The methods utilized to predict body composition can be classified as direct and indirect. Direct methods consist in separation and dissection of all body components and further quantification of physical and chemical components. Thereby, experiments conducted using direct methods become extremely labor-intensive, slow, and expensive due to the loss of at least half of the carcass of each animal as well as lot of people and laboratory analyses involved. However, indirect methods predict body composition from simple parameters without the need of complete carcass dissection.

Several indirect methods have been developed around the world. 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, 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 the complexity, high cost, lack of equipments, and/or lack of experience. In this context, the most utilized indirect method in Brazil is that proposed by Hankins and Howe (1946), which equations were developed to estimate cattle carcass composition based on composition of the section between the ninth and eleventh rib. This technique widely spread due to the ease of use and low cost involved. 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 NINTH AND ELEVENTH RIB CUT HH SECTION

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. The results led to the conclusion that the region of the ribs presented the best relationship with carcass composition. Then, based on these results, Hankins and Howe (1946) evaluated the use of cuts in the carcass of cattle to predict carcass physical and chemical composition developing a technique to obtain a sample of carcass between ninth and eleventh rib cut (HH section; Figure 5.1).

The section between ninth and eleventh ribs can be obtained considering a carcass hanging by transverse foramen located in the animal pelvis, where the cut between ninth and eleventh ribs is performed (Figure 5.1). The distance between the first and the last bone rib points is measured (distance between point A and B), and 61.5% of this distance is calculated (point C). The cut of this section might be performed in the point which a perpendicular line to rule crossed by point C (point D), as shown in the Figure 5.1.

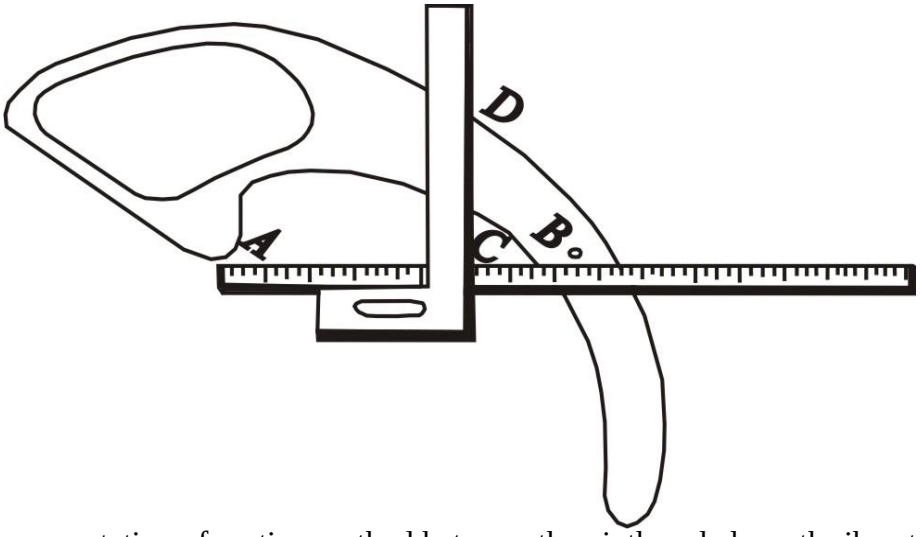

Figure 5.1 - Representation of section method between the ninth and eleventh rib cut developed by Hankins and Howe (1946).

CARCASS PHYSICAL AND CHEMICAL COMPOSITION AND EMPTY BODY CHEMICAL COMPOSITION

In the study developed by Hankins and Howe (1946), prediction equations for carcass physical and chemical composition were established. However, these equations were developed from data obtained from steers and heifers. Thus, equations for each sex and a general equation were defined (Table 5.1).

These equations have been widely used around the world and in Brazil due to the ease of obtaining HH section. Some studies (Cole et al., 1962; Powell and Huffman, 1973; Crouse and Dikeman, 1974; Nour and Thonney, 1994) aimed to evaluate these equations, however, presented distinct results. These differences may be related to fact that the prediction equations for chemical composition were estimated from soft tissue, while bone composition was not considered.

Some researchers have predicted the carcass chemical composition of beef cattle from the chemical composition of HH section (Peron et al., 1993; Jorge et al., 2000; Ferreira et al., 2001; Véras et al., 2001) by chemically analyzing samples of muscle, adipose, and bone tissues obtained from dissection of HH section and estimating carcass chemical composition. Nevertheless, carcass physical composition was estimated from the equations developed by Hankins and Howe (1946). Thereby, carcass chemical composition was estimated from data of chemical analyses obtained in samples of HH section, while body components was determined by the sum of carcass and non-carcass composition. As carcass is the main quantitative component of the empty body, the majority of these studies concluded that body chemical composition could be predicted from the chemical composition of HH section. However, other studies (Silva, 2001; Paulino et al., 2005a; Costa e Silva et al., 2013) reported that this premise could not be corrected, mainly in relation to EE content in the carcass.

Aiming to solve this problem, in the first edition of the Brazilian system – Nutrient Requirements for Zebu cattle (BR-CORTE; Valadares Filho et al., 2006), equations were developed to predict the carcass and empty body chemical composition of Zebu cattle from HH section. Only data from studies that evaluated chemical composition after the complete dissection of the half-carcass and chemical composition of the HH section were utilized. The database consisted of information from 66 animals from two studies (Paulino, 2002; Paulino, 2006; Table 5.2).

Table 5.1 - Prediction equations for physical and chemical carcass composition from composition of the section between ninth and eleventh rib 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.

Table 5.2 - Prediction equations for chemical carcass and empty body composition of Zebu cattle from chemical composition of the section between ninth and eleventh rib cut proposed by the BR-CORTE (Valadares Filho et al., 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.

In the first edition of the BR-CORTE (Valadares Filho et al., 2006), nutrient requirements were estimated based on complete dissection and sampling of the carcass from cattle used in the experiments. Moreover, this technique might be utilized until an adequate number of information was generated and, then, more comprehensive and representative equations could be developed. In this way, Marcondes et al. (2010; 2012) composed a new database with 247 animals from 6 experiments conducted in feedlot. Animals from this database were purebred Nellore cattle and their crossbred with Angus or Simmental. These authors evaluated the inclusion of new variables into models, as well as the effect of sex, study and breed, and, prediction equations for carcass physical and chemical composition and empty body chemical composition were developed (Table 5.3).

Table 5.3 - Description of data utilized by Marcondes et al. (2010; 2012) to develop equation for body composition of cattle from section between ninth and eleventh rib cut

Item	Mean	SD[1]	Maximum	Minimum
Empty body weight (EBW), kg	328	78.8	506	176
Carcass weight, kg	206	50.3	323	99.7
Organs + viscera, % EBW	15.3	1.60	21.8	12.2
Visceral fat[2], % EBW	4.60	1.60	8.80	1.40
Ether extract in the EBW, %	18.2	5.60	30.0	4.15
Crude protein in the EBW, %	17.6	1.62	23.4	12.9
Water in the EBW, %	58.5	4.27	71.4	49.1
Ether extract in the carcass, %	17.9	5.20	29.8	3.87
Crude protein in the carcass, %	17.3	1.93	28.5	12.4
Water in the carcass, %	58.0	3.91	73.5	43.9
Adipose tissue in the carcass, %	20.7	6.30	33.6	7.30
Muscle in the carcass, %	61.8	4.20	73.1	52.8
Bone in the carcass, %	17.5	3.00	28.1	12.6
Ether extract in the HH section, %	23.2	8.91	50.9	4.85
Crude protein in the HH section, %	16.7	2.07	24.0	11.4
Water in the HH section, %	52.8	6.53	67.6	29.3
Adipose tissue in the HH section, %	28.1	9.00	50.6	7.00
Muscle in the HH section, %	53.4	7.20	71.4	25.0
Bone in the HH section, %	18.7	3.90	32.7	11.4

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

The equations proposed by Marcondes et al. (2012) have already been utilized previously in the second edition of the BR-CORTE (Valadares Filho et al., 2010; Tables 5.4 and 5.5).

Table 5.4 - Prediction equations for the carcass physical and chemical composition and empty body chemical composition of Zebu and crossbred cattle from chemical composition of the section between ninth and eleventh rib cut proposed by 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 Nellore × Simmental	% Mcarc = 57.33 + 0.20 × % M_{HH} -1.39 × % VF	0.51	2.97
	Nellore × Angus	% Mcarc = 60.96 + 0.12 × % M_{HH} -1.39 × % VF		
Bone	Nellore Nellore × Simmental	% Bcarc = 29.26 + 0.30 × % B_{HH} - 0.21 × HCY - 0.95 × % VF	0.77	1.43
	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 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 the Table 5.5.

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

Sex	Genetic group	Intercept	Coefficient related to VF
Bulls	Nellore	0.689	1.177
	Nellore × Angus		1.198
Steers	Nellore	5.259	0.379
	Nellore × Angus		0.430
	Nellore × Simental		0.740
Heifers	Nellore	0.471	1.532
	Nellore × Angus		1.981
	Nellore × Simental		2.338

According to Marcondes et al. (2012), the inclusion of new variables in models and considering the effect of genetic group and sex provided better estimates. Among the variables utilized, the most important inclusion was the mesenteric fat plus renal, pelvic, and cardiac fat (VF) in the prediction equations due to fat present in the carcass is the most variable component. The VF, together with other variables, could present a better understanding of the animal's metabolism. The VF was consisted by the physical separation of fat from mesentery added to renal, pelvic, and cardiac fat (Valadares Filho et al., 2010). The effect of feeding level on body composition has been discussed extensively in the literature (Prior et al., 1977; Ferrell et al., 1978; Nour et al., 1981; Williams et al., 1983; Nour and Thonney, 1987); thus, VF in the equations might be very important for applicability of them.

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

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

In Brazil, few studies have tried to evaluate the applicability of the equations proposed by Hankins and Howe (1946) for Zebu cattle and crosses with *Bos taurus* breeds. In this way, some researches (Lana et al., 1995; Silva, 2001; Paulino et al., 2005b; Costa e Silva et al., 2013; Fonseca et al., 2014) evaluated if the section between ninth and eleventh rib cut could estimate carcass and empty body composition and concluded that the equations developed by Hankins and Howe (1946) are not applicable for Zebu cattle and their crosses.

In relation to physical composition, Costa e Silva et al. (2013) concluded that the equations proposed by Marcondes et al. (2012) adequately estimate the physical composition of Nellore bulls. The authors do not recommend using the equations proposed by Hankins and Howe (1946). Moreover, Fonseca et al. (2014) concluded that the equations proposed by Marcondes et al. (2012) estimate adequately muscle and adipose tissue of F1 Nellore × Angus bulls and steers, although they reported that none of the equations estimated correctly the amount of bone for F1 Nellore × Angus cattle.

In the same way, some studies (Prados, 2012; Costa e Silva et al., 2013; Neves, 2013; Fonseca et al., 2014) evaluated whether the equations proposed by Hankins and Howe (1946), Valadares Filho et al. (2006, BR-CORTE) and Valadares Filho et al. (2010, BR-CORTE) correctly estimate the carcass and empty body chemical composition of Zebu cattle and their crosses. Costa e Silva et al. (2013) recommended that the equations proposed by Valadares Filho et al. (2006) and Hankins and Howe (1946) should not be utilized to estimate carcass and empty body

composition of Nellore bulls, while the equations proposed by BR-CORTE (2010) presented accurate estimates.

Fonseca et al. (2014) utilized data from F1 Nellore × Angus bulls and steers and verified that the equations proposed by Marcondes et al. (2012) showed superior estimates, except for water 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). Furthermore, Fonseca et al. (2014) observed that the equation proposed by Marcondes et al. (2012) for EE in the empty body was accurate and precise, mainly when sex was considered. For bulls, the equation was satisfatory and does not require adjustment, while for steers, the equation was not adequate for fatter animals.

Because the equation proposed by Marcondes et al. (2012) was not adjusted sufficiently to estimate EE and water in the empty body for beef crossbred steers, a new database was developed utilizing data from Marcondes et al. (2012) and Fonseca et al. (2014) to estimate EE. The same data were used by Marcondes et al. (2012) to estimate water in the empty body.

Thus, the estimates of EE and water in the empty body of beef crossbred steers were readjusted using the cross-validation procedure (Duchesne and MacGregor, 2001). For EE in the empty body, 20% of data from each experiment were randomly separated for validation, while for water, an independent experiment was utilized for validation of the equations.

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

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

Therefore, the inclusion of new variables such as VF and organs and viscera (OV) improved the estimates of carcass and empty body chemical composition for Zebu cattle and their crosses, which will allow future use of the equations proposed here instead of promoting complete dissection of the half-carcass. The use of these equations is recommended to estimate empty body composition and, as result, there will be decreasing on costs and labor of experiments conducted to estimate nutrient requirements of beef cattle (Costa e Silva et al., 2013).

Body composition of Zebu cattle (steers and heifers)

No previous study has evaluated the accuracy and precision of the equations suggested by Marcondes et al. (2012) for Zebu steers and heifers. Thereby, data collected from thesis of Costa e Silva (2015) which 32 Nellore heifers and 18 Nellore steers were utilized to evaluate if the equations estimate correctly carcass and empty body chemical composition (Table 5.6).

Table 5.6 - 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.

Comparisons among equations were performed as proposed by Costa e Silva et al. (2013). We observed that the equations proposed by Hankins and Howe (1946), Valadares Filho et al. (2006) and Marcondes et al. (2012) correctly estimated the amount of crude protein (CP) in the carcass, while only the equations suggested by Marcondes et al. (2012) correctly estimate the amounts of EE and water in the carcass (Table 5.7).

For empty body, only equations proposed by Marcondes et al. (2012) and presented initially in the BR-CORTE (Valadares Filho et al., 2010), correctly estimated all components, while the equations proposed by Valadares Filho et al. (2006) presented inconsistencies on intercept and/or slope. So, they are not recommended to estimate body composition in Zebu steers and heifers (Table 5.8).

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

Item	Crude protein				Ether extract				Water			
	Obs[1]	HH	V06	V10	Obs	HH	V06	V10	Obs	HH	V06	V10
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); V06 – values predicted by equations from Valadares Filho et al. (2006); V10 – values predicted by equations from Valadares Filho et al. (2010). [2]CCC – concordance correlation coefficient; [3]H_0: $\beta_0=0$. [4]H_0: $\beta_1=1$. [5]MSE = mean square error.

Table 5.8 - 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]	V06	V10	Obs	V06	V10	Obs	V06	V10
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; V06 – values predicted by equations from Valadares Filho et al. (2006); V10 – values predicted by equations from Valadares Filho et al. (2010). [2]CCC – concordance correlation coefficient; [3]H_0: β_0=0. [4]H_0: β_1=1. [5]MSE = mean square error.

CARCASS AND EMPTY BODY CHEMICAL COMPOSITION FOR DAIRY CROSSBRED CATTLE

The equations to estimate carcass and empty body chemical composition in the last edition of the BR-CORTE (2010) were obtained from database of Zebu cattle (mainly Nellore) and beef crossbred cattle (crosses Nellore with beef breeds). Aiming to verify if these equations could be applicable to dairy crossbred cattle, Prados (2012), using ¼ Holstein × ¾ Zebu bulls, verified that CP in the empty body can be estimated adequately by the equation proposed by Valadares Filho et al. (2010) while EE and water in the empty body were correctly estimated by equations proposed by Valadares Filho et al. (2006). Neves (2013) evaluated Holstein × Zebu bulls and verified that equations proposed by Hankins and Howe (1946) estimated more accurately CP in the carcass and CP and water in the empty body. Also, this author concluded that equations proposed by Marcondes et al. (2012) were not able to estimate carcass and empty body chemical composition of Holstein × Zebu bulls.

Because the Holstein breed is included in the genotype, the prediction equations for carcass and empty body composition present problems of adjustment. Possibly, this might be due to database utilized by Marcondes et al. (2012) that is composed by Zebu (Nellore) and their crosses with beef breeds, such as Angus and Simmental, or so, breeds selected for beef production. Therefore, there is a need to develop new prediction equations for estimating the body composition of dairy crossbred cattle.

A database utilizing dairy crossbred cattle was developed from five experiments (Prados, 2012; Neves, 2013; Zanetti, 2014; Rodrigues, 2014; Silva, 2015). This database contained 180 observations, being 80 bulls, 56 steers, and 44 heifers (Table 5.9).

Table 5.9 - Description of data used to generate equation for body composition for dairy crossbred cattle from composition of the section between ninth and eleventh 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.

From this database, the prediction equations for body composition of Holstein × Zebu cattle were established (Table 5.10). Using the cross validation procedure (Duchesne and MacGregor, 2001), the effect of animal was considered in the statistical analyses which allow the generation of only one equation for each evaluated component (CP, EE, and water). The equations presented good precision; however, we highlight that these equations were not validated with an independent database. However, we recommend the use of these equations because the cross validation procedure is adequate to be used in a small dataset.

Table 5.10 - Prediction equations for carcass and empty body chemical composition for dairy crossbred cattle

Item	Equations[1]	r^2
	Carcass chemical composition	
Ether extract	$\%\ EEcarc = 4.54 + 0.48 \times \%\ EE_{HH} + 0.12 \times \%\ OV$	0.66
Crude protein	$\%\ CPcarc = 18.38 + 0.16 \times \%\ CP_{HH} - 0.20 \times \%\ OV$	0.53
Water	$\%\ Wcarc = 55.67 - 0.21 \times \%\ W_{HH} - 0.021 \times EBW$	0.40
	Empty body chemical composition	
Ether extract	$\%\ EE_{EBW} = 3.53 + 0.34 \times \%\ EE_{HH} + 0.80 \times \%\ VF + 0.10 \times \%\ OV$	0.73
Crude protein	$\%\ CP_{EBW} = 19.92 + 0.086 \times \%\ CP_{HH} - 0.19 \times \%\ OV$	0.58
Water	$\%\ W_{EBW} = 53.02 + 0.17 \times \%\ W_{HH} - 1.28 \times \%\ VF + 0.27 \times \%\ OV$	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; PBcarc = crude protein in the carcass; VF = percentage of mesenteric fat plus renal, pelvic, and cardiac fat in the empty body; PB_{HH} = crude protein in the HH section; Wcarc = water in the carcass; A_{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.

PREDICTION OF BODY MINERAL COMPOSITION

In the last edition of the BR-CORTE (2010), the prediction of body mineral composition was based on equations proposed by Marcondes et al. (2009) in which the composition of the section between the ninth and eleventh rib cut could be utilized as a possible estimator of empty body macromineral composition (calcium, phosphorus, sodium, potassium, and magnesium), using the data from two studies (Paulino, 2002; Marcondes, 2007; Table 5.11).

Table 5.11 - Prediction equations for macromineral composition (Ca, P, Mg, Na, and K) in the empty body for beef cattle from mineral composition of the section between ninth and eleventh rib cut (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.

Marcondes et al. (2009) verified a high correlation between mineral components found in the HH section and those found in the empty body (Table 5.11). However, after evaluation of these equations, from data of Costa e Silva (2011), we observed that the equations generated by Marcondes et al. (2009) do not estimate correctly body macromineral composition (Ca, P, Mg, Na, and K) of Zebu cattle (Table 5.12).

Because the equations were not adjusted, a new database was developed from the two studies utilized by Marcondes et al. (2009) and the thesis of Costa e Silva (2015; Table 5.13) for Zebu cattle. Moreover, data of two studies (Marcondes, 2010; Souza, 2010) were utilized for the development of equations to estimate mineral composition for beef crossbred cattle and data of two studies (Rodrigues, 2014; Zanetti, 2014) to estimate mineral composition for dairy crossbred cattle.

Table 5.12 - Means (kg) and descriptive statistics of the relationship between 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	-	0.0009	-	0.009	-	0.043
Mean bias	-	1.86	-	0.01	-	0.0004	-	0.001	-	0.037
Systematic error	-	0.01	-	0.15	-	0.0000	-	0.003	-	0.000
Random error	-	0.44	-	0.19	-	0.0005	-	0.005	-	0.007

[1]Obs – observed values; [2]CCC – concordance correlation coefficient; [3]H_0: β_0=0. [4]H_0: β_1=1. [5]MSE = mean standard error.

Table 5.13 - Description of data used to generate equations to predict mineral composition of Zebu, beef crossbred, and dairy crossbred 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
Beef crossbred 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
Dairy crossbred 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

A meta-analysis was performed to evaluate body macromineral composition (Ca, P, Mg, Na, and K) for Zebu, beef crossbred, and dairy crossbred cattle (Table 5.14).

Table 5.14 - Prediction equations for macromineral composition (Ca, P, Mg, Na, and K) in the empty body for Zebu, beef crossbred, and dairy crossbred cattle

Item	Equation[1]	r^2
Zebu cattle		
Calcium	% Ca_{EBW} = 1.4557 + 0.2362 × % ASH_{HH} – 0.00223 × EBW	0.80
Phosphorus	% P_{EBW} = 1.0068 - 0.00099 × EBW	0.10
Magnesium	% Mg_{EBW} = 0.02859 + 0.001721 × % ASH_{HH} – 0.00001 × EBW	0.54
Sodium	% Na_{EBW} = 0.1213 + 0.002116 × % ASH_{HH} – 0.00002 × EBW	0.51
Potassium	% K_{EBW} = 0.1942 + 0.000833 × % ASH_{HH} – 0.0001 × EBW	0.22
Beef crossbred cattle		
Calcium	% Ca_{EBW} = 1.7028 + 0.04638 × % ASH_{HH} – 0.00142 × EBW	0.52
Phosphorus	% P_{EBW} = 0.4619 - 0.0404 × % ASH_{HH}	0.49
Magnesium	% Mg_{EBW} = 0.02418 + 0.00196 × % ASH_{HH}	0.34
Sodium	% Na_{EBW} = 0.1205 + 0.002747 × % ASH_{HH} – 0.00002 × EBW	0.56
Potassium	% K_{EBW} = 0.1636 + 0.007102 × % ASH_{HH}	0.35
Dairy crossbred cattle		
Calcium	% Ca_{EBW} = 1.2445 + 0.0506 × % ASH_{HH} - 0.00035 × EBW	0.58
Phosphorus	% P_{EBW} = 0.7279 + 0.0333 × % ASH_{HH} - 0.00048 × EBW	0.58
Magnesium	% Mg_{EBW} = 0.0406 - 0.00106 × % ASH_{HH}	0.06
Sodium	% Na_{EBW} = 0.1454 + 0.00064 × % ASH_{HH}	0.05
Potassium	% K_{EBW} = 0.1411 + 0.01478 × % 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 the most of minerals as a function of genetic group were satisfactory. Nevertheless, the estimates of r^2 were close to zero for phosphorus and potassium in Zebu cattle, potassium in beef crossbred cattle, and magnesium and sodium in dairy crossbred cattle, showing that there is a tendency of constancy of this minerals in the body. However, we highlight that these equations will require validation to properly evaluate the effect of genetic group.

NON-CARCASS CHEMICAL COMPOSITION

Based on the equations proposed in the last edition of the BR-CORTE (2010; Table 5.4), the prediction equations for empty body chemical composition presented a better adjustment when compared with the equations for carcass chemical composition using the chemical composition of HH section as estimator. However, if the researcher makes the decision to utilize the equations for carcass chemical composition, or if there is a need to determine real carcass composition by dissection, the composition of other parts of the body (blood, hide, limbs, head, organs, and viscera) will need to be determined to ascertain empty body chemical composition.

The determination of non-carcass chemical composition implicates, necessarily, in greater cost, time, and labor, once there are at least 6 more samples (blood, hide, limbs, head, organs, and viscera) per animal that should be analyzed in laboratory. Carcass yield in relation to EBW may range from 60–65% (Costa et al., 2005; Missio et al., 2009), all non-carcass components, together, would represent from 35–40% EBW. Thus, the knowledge of non-carcass chemical composition is important due to its percentage of empty body composition.

Thus, Costa e Silva et al. (2012) evaluated the possibility of estimating chemical composition of blood, hide, limbs + head, and organs + viscera to decrease labor and experimental cost. These authors utilized a database with information from 335 animals to perform the evaluations, controlling for the effect of study and testing the effect of genetic group or sex on the composition of these non-

carcass components. Chemical composition of each non-carcass component (blood, hide, limbs, head, organs, and viscera) could be estimated, and adjustment for each component would be necessary. However, this procedure would produce a large number of equations, which renders their use impractical. Then, to simplify the estimates, the non-carcass components were grouped (head + limbs, hide + blood, and organs + viscera) to decrease the number of equations and to facilitate their estimation.

Nevertheless, Costa e Silva et al. (2013) evaluated the accuracy of the prediction equations for non-carcass components, as described in the BR-CORTE (2010), and verified that, for hide + blood, only CP was correctly estimated; the equations to estimate EE and water presented problems with reproducibility and precision. In relation to head + limbs, any equation estimated correctly chemical composition. For organs + viscera, only EE was correctly estimated. Therefore, these authors concluded that new equations should be developed, or so, instead of dividing non-carcass components in three groups (hide + blood, head + limbs, and organs + viscera), the composition of these components might be analyzed together generating only one equation for each constituent, considering, thus, all non-carcass components as a unique pool. In this context, a database was developed from the composition of non-carcass components as depicted in 19 dissertations and/or theses: Moraes (2006), Souza (2009), Marcondes (2007), Marcondes (2010), Chizzotti (2007), Porto (2009), Gionbelli (2010), Paixão (2009), Paulino (2006), Machado (2009), Costa e Silva (2011), Costa e Silva (2015), Valente (2013), Fonseca (2014), Silva (2015), Prados (2012), Rodrigues (2013), Zanetti (2014), and Neves (2014). The database was composed by 505 animals, being 231 Zebu, 94 beef crossbred, and 180 dairy crossbred cattle; and 248 bulls, 134 steers, and 123 heifers (Table 5.15).

Table 5.15 - Description of data used to generate equations to predict non-carcass chemical composition of Zebu, beef crossbred, and dairy crossbred cattle (n = 505)

Item	Mean	SD[1]	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]SD = standard deviation.

From the data obtained, prediction equations of non-carcass chemical composition were generated from the meta-analysis using the NLMIXED procedure, in which dependent variables were regressed as a function of EBW. Furthermore, effects of sex and genetic group were tested, where only sex was significant for all constituents, except phosphorus and magnesium (Tables 5.16 and 5.17).

Notably, these equations should be validated to verify that they correctly estimate non-carcass chemical composition for Zebu, beef crossbred and dairy crossbred cattle.

Table 5.16 - Prediction equations for non-carcass chemical composition for Zebu, beef crossbred, and dairy crossbred cattle in function of sex

Item	Sex	Equations
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 5.17 - Prediction equations for macromineral composition of non-carcass components for Zebu, beef crossbred, and dairy crossbred cattle in function of sex

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 could be estimated from body water content. The authors also indicated that the protein/ash ratio in the body would be constant in fat-free dry matter, influenced only by the age of the animal. In this context, Marcondes et al. (2010) studied the relationship between fat-free dry matter and EBW composition utilizing a database with 272 animals. Marcondes et al. (2010) proposed the equation presented below to estimate body EE based on water content, following the model suggested by Reid et al. (1955). There was no effect of genetic group or sex on regression parameters, presenting a r^2 and RSME of 0.96 and 1.26, respectively.

$$\% EE_{EBW} = 236.21 - 126.25 \times \log (W_{EBW}) + 1.114 \times \% VF,$$

where EE_{EBW} is the ether extract content in the empty body; W_{EBW} is the water percentage in the empty body; VF is the percentage of mesenteric fat, plus renal, pelvic, and cardiac fat in the empty body.

Knowing the proportion of the fat in the body, the protein concentration in the fat-free dry matter can be estimated as a function of the empty body mass. However, as opposed to Reid et al. (1955), that correlated protein/ash ratio with age, Marcondes et al. (2010) correlated this ratio with EBW, once age can be a relative measurement related to body composition, because different nutritional plans can cause different body weight at the same age, with consequent difference on body composition. Thus, the equation suggested by Marcondes et al. (2010), presented below, can be utilized alternatively. The ash percentage can be estimated as 100 – CP on the basis of fat-free dry matter.

$$\% CPFFDM_{EBW} = 74.09 + 0.0098 \times EBW,$$

where $CPFFDM_{EBW}$ is the percentage of crude protein on a fat-free dry matter basis in the empty body, and EBW is the empty body weight (kg).

NEW METHODS TO PREDICT BODY COMPOSITION OF CATTLE

Techniques that do not require animal slaughter to obtain body composition have been studied. They are useful for cattle sorting. In feedlot to reduce differences in relation to nutrient requirements of lots, in order to achieve carcass standardization.

Biometric measurements utilizing tape

Studies were developed (Fernandes et al., 2010; De Paula et al., 2013; Fonseca, 2013) aiming to predict body composition, main fat, from body measurements, known as biometric measurements. Fernandes et al. (2010) observed that the combination of different biometric measures (*in vivo* or *post-mortem*) can be important tools to estimate the amount of fat in the carcass and empty body of grazing animals. De Paula et al. (2013) suggested equations to estimate fat in different parts of the body, which divided as subcutaneous fat, intern fat, fat in the carcass, and fat in the empty body (Table 5.18).

Table 5.18 - Prediction equations for body fat from biometric measures using Nellore cattle

Item	Equations[1]	R^2	RSME
Subcutaneous Fat	$SF = 0.03 \times SBW - 0.099 \times BL + 0.052 \times WH$	0.97	0.94
Intern fat	$IF = 0.0405 \times SBW - 0.159 \times BPW$	0.98	1.26
Fat in the carcass	$F_{CARC} = 0.029 \times SBW + 25.941 \times F_{HH}$	0.99	2.41
Fat in the empty body	$F_{EBW} = 0.017 \times SBW + 1.184 \times F_{CARC}$	0.99	1.18

[1]SF = subcutaneous fat (kg); SBW = shrunk body weight (kg); BL = body length (cm); WH = wither height (cm); IF (Intern fat) = renal, pelvic, and cardiac fat (kg); BPW = bone pin width (cm); F_{CARC} = fat in the carcass (kg); F_{HH} = fat in the HH section (kg); F_{EBW} = fat in the empty body (kg). *Adapted from De Paula et al. (2013).*

However, even when biometric measurements are obtained (Fernandes et al., 2010; De Paula et al., 2013), there is a need for post-mortem measures, such as the amount of fat in the carcass and in the section between the ninth and eleventh rib cut in order to estimate the amount of fat in the empty body. Moreover, a problem found in biometric measurements is the need of measuring manually different points in the animal, and animal must being determined position. Due to the temperament of some animals, this technique becomes difficult to execute precisely.

Biometric measurements obtained from KINECT®

From the use of the Kinect® sensor (Microsoft, USA), an equipment composed by an infrared projector laser, an infrared camera, and a red, green, and blue (RGB) camera, new techniques have been used to estimate body composition without the need of animal slaughter. Thus, Monteiro (2015) evaluated several measures to predict body weight and body

composition in Nellore and Angus bulls. The author correlated physical variables, such as body weight, and chemical variables, such as fat in the empty body, with areas generated by the Kinect®. From dorsal height and dorsal area (Figure 5.2) and breast width, this author generated indexes to estimate body weight and fat in the empty body (Table 5.19).

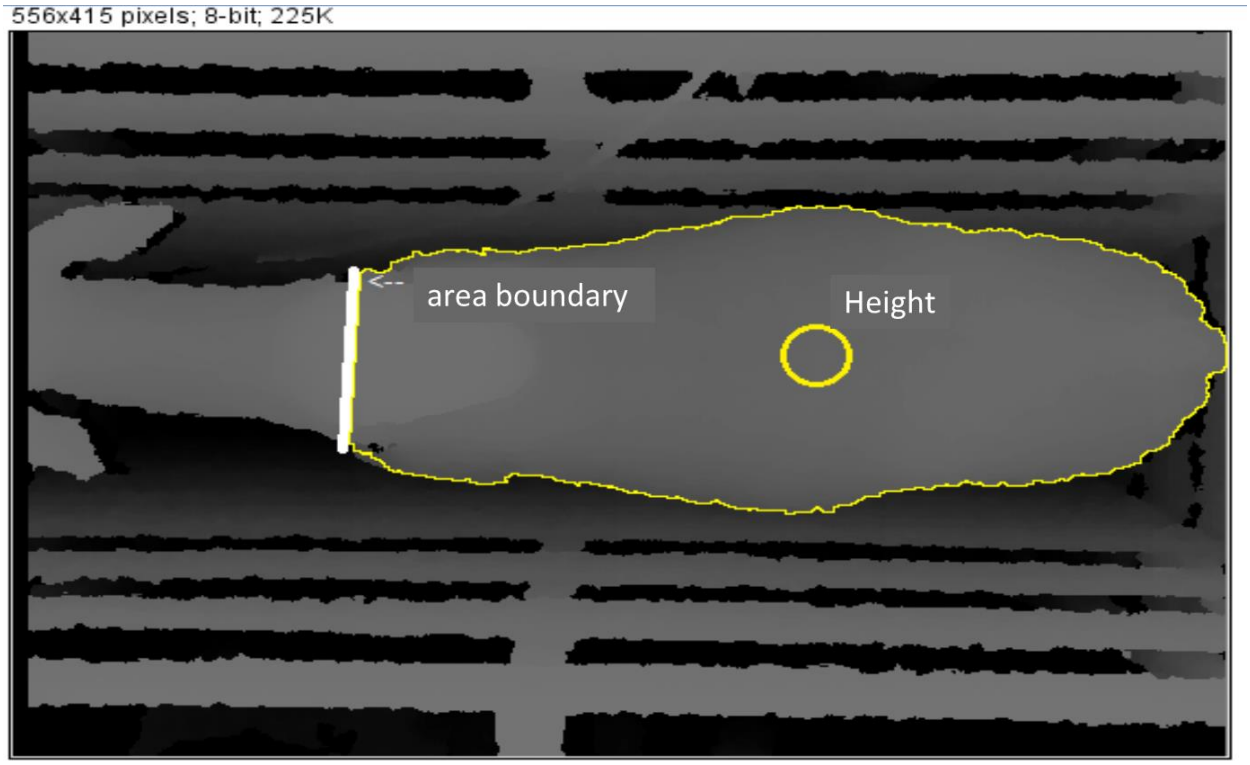

Figure 5.2 - Limit of the dorsal plan area obtained by three-dimensional image. Source: Monteiro (2015).

Table 5.19 - Description of indexes used in the equations

Index	Description[1]
I_1	Difference between dorsal height and the height whose breast width was measured
I_3	$(\text{dorsal area})^{0.75} / (\text{dorsal height})^2$
I_4	$(\text{breast width}) / (\text{dorsal area})^{1/2}$
I_5	$(\text{breast width})^2 \times \text{body length}$
I_6	$\text{dorsal area} / (\text{dorsal height}/1000)^2$

[1] height in mm, area in pixel^2, width and length in pixel.

From these indexes, animal body composition was determined by correlating the same with body fat and body weight (Table 5.20). However, more studies should be conducted to increase accuracy and to evaluate these equations using an independent database.

Table 5.20 - Regressions between body weight (BW), hot carcass weight (HCW), and body fat (BF) from body measurements obtained through digital image analyses in Nellore and Angus bulls

Model	Equations[1,2]	R^2	AIC	MSEP
	Body weight, kg			
1	$81.4 + 58.3 \times I_1 + 0.0000222 \times I_5 + 0.0310 \times I_3$	0.84	105.2	19.4
2	$164.6 + 0.0000278 \times I_5$	0.77	106.3	19.8
	Hot carcass weight, kg			
3	$74.8 + 0.0000141 \times I_5 + 0.0124 \times I_3$	0.83	87.8	15.4
4	$91.9 + 0.0000168 \times I_5$	0.80	88.3	16.5
	Body fat, % EBW			
5	$22.4 + 0.0319 \times BW - 6.46 \times I_1 - 28.2 \times I_4 - 118.2 \times I_6$	0.43	18.5	1.40

[1]The descriptions of the indexes are presented in the Table 5.19; [2]EBW = empty body weight, kg; BW = body weight.

Composition obtained from DXA

The technique of dual energy X-ray absorptiometry (DXA) becomes an alternative to carcass dissection to evaluate animal body composition. This method is the most utilized in human medicine aiming to evaluate the early reduction on bone mass and to evaluate body composition. It can thus be utilized without the need to dissect and chemically analyze the animal carcass. In this way, Prados et al. (2016) grouped a database with 116 observations, being 96 Nellore bulls and 20 Nellore × Angus bulls and developed equations to estimate the composition of the section between ninth and eleventh rib cut from the use of the equipment DXA (GE Lunar Prodigy Advance Dxa System, GE Healthcare, Madison, Wisconsin, USA). After scanning the section between the ninth and eleventh rib cut, these cuts were dissected and chemical composition was compared to parameters observed by DXA (Table 5.21).

Table 5.21 - Prediction equations for chemical composition of section between ninth and eleventh rib cut using dual-energy X-ray absorptiometry (DXA)

Variable[1]	Equations	R^2
Ether extract (EE)	$EE_{HH} = 122.40 + 1.12 \times F_{DXA}$	0.86
Fat free tissue (FF)	$FF_{HH} = 103.22 + 0.87 \times FF_{DXA}$	0.93
Lean tissue (LT)	$CP_{HH} = 37.08 + 0.91 \times LT_{DXA}$	0.95
Ash (A)	$A_{HH} = 18.72 + 1.02 \times BMC_{DXA}$	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_{SC} = 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) evaluated the accuracy of these equations and concluded that they are accurate, representing a feasible and easy tool to predict the chemical composition of the section between the ninth and eleventh rib cut. Therefore, these equations are recommended to be used in Nellore and Nellore × Angus cattle. However, Prados et al. (2016) highlighted that more studies should be conducted aiming to evaluate its use to estimate carcass composition.

CONSIDERATIONS

After evaluation of the prediction equations for body composition, we recommend the use of the equations proposed

by the BR-CORTE (2016) for Zebu and beef crossbred cattle as a replacement for carcass dissection, resulting in reduced costs and labor.

We expect that equations generated for dairy crossbred cattle can contribute for reduction of costs in experiments that aim to evaluate body composition of these animals.

Furthermore, the use of prediction equations for non-carcass components is an accurate approach. However, we highlight that more studies should be conducted to validate them.

New techniques, such as DXA and Kinect®, represent promising alternatives.

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6

Respirometry and nutritional requirements of Zebu and dairy crossbred 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, 1975).

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 6.1 describes the database used.

Table 6.1 - 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 6.2.

Table 6.2 - 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 6.3, 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 6.1, methane production is verified as a function of DMI.

Table 6.3 - 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.

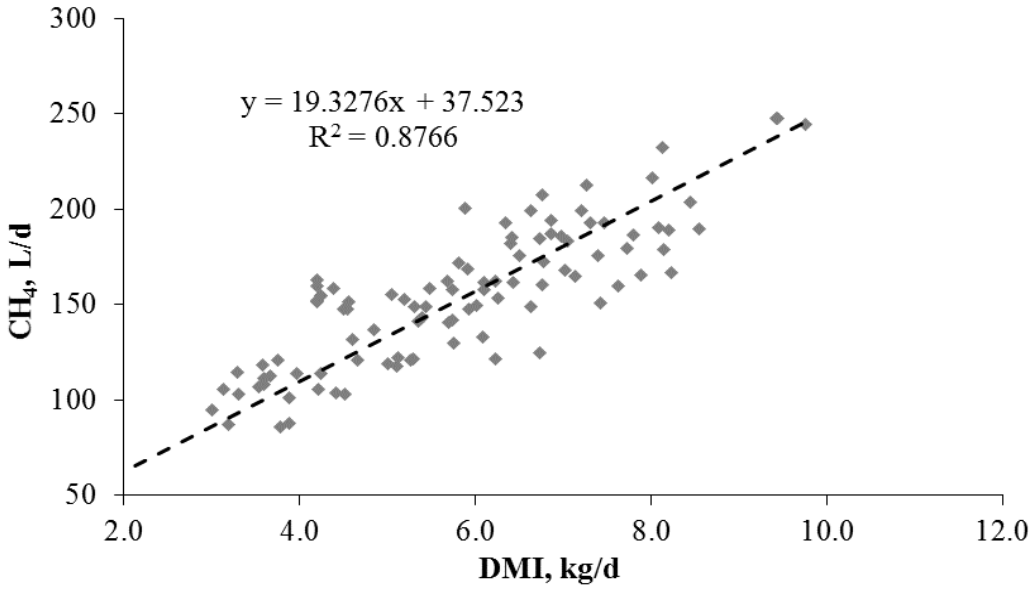

Figure 6.1 - Relationship between daily production methane (CH_4) and dry matter intake (DMI). The points represent the evaluations considered for the development model (n = 125).

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 6.1) 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 6.2) and DE (Figure 6.3), regression analyses were conducted on these values. They were significant and their prediction errors were 0.546 and 0.532 Mcal, respectively.

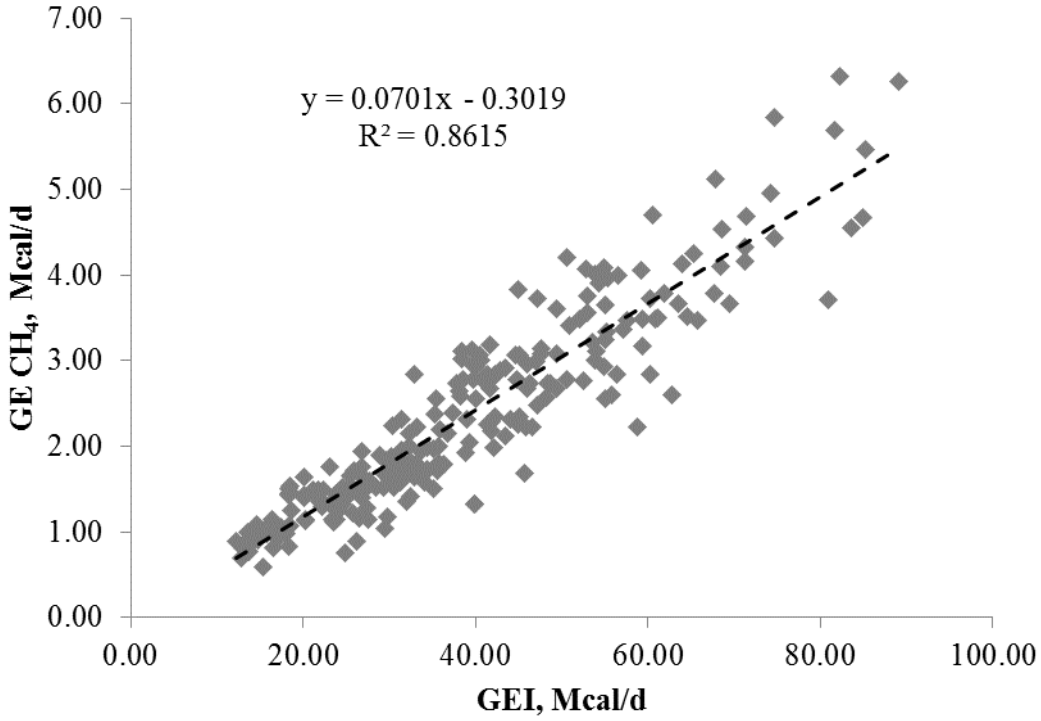

Figure 6.2 - Relationship between loss of gross energy as methane ($GECH_4$) and gross energy intake (GEI). The dots represent all evaluations contained in the database.

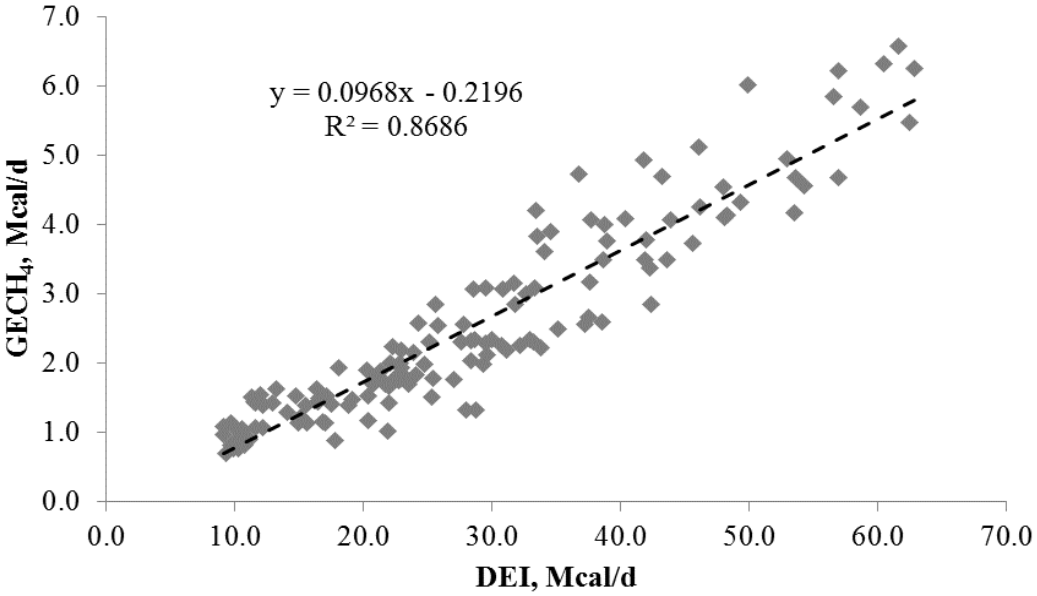

Figure 6.3 - Relationship between loss of gross energy as methane ($GECH_4$) and digestible energy intake (DEI). The dots represent all evaluations contained in the database.

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 6.2, 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 6.3 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 6.4.

Table 6.4 - 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 days	450	Gyr	2.86	-	0.15
		210 days			2.33	-	
		240 days			1.62	-	
	Dairy crossbred, pregnant females	180 days	550	F1 HxG	2.70	-	
		210 days			2.71	-	
		240 days			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 6.4. 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 6.4 and 6.5).

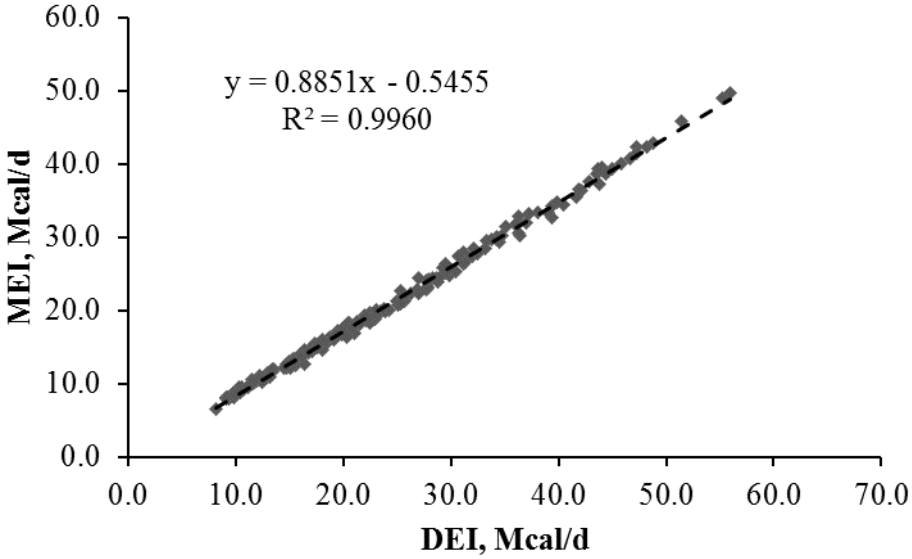

Figure 6.4 - Relationship between digestible energy intake (DEI) and metabolizable energy intake (MEI) expressed as Mcal/d.

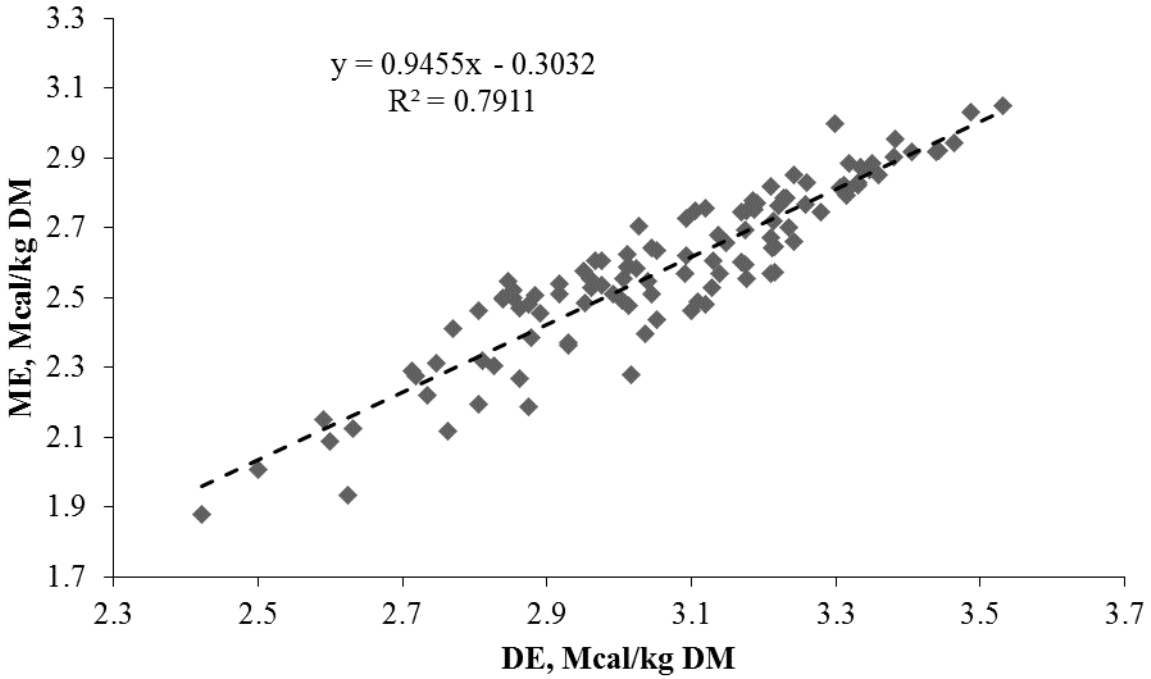

Figure 6.5 - Relationship between digestible energy and metabolizable energy expressed in Mcal per kg of dry matter.

The data presented high dependence of the MEI variable as a function of DEI (Figure 6.4, $R^2 = 0.99$). 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 6.5) and the one suggested by Galyean et al. (2016) is shown in Figure 6.6.

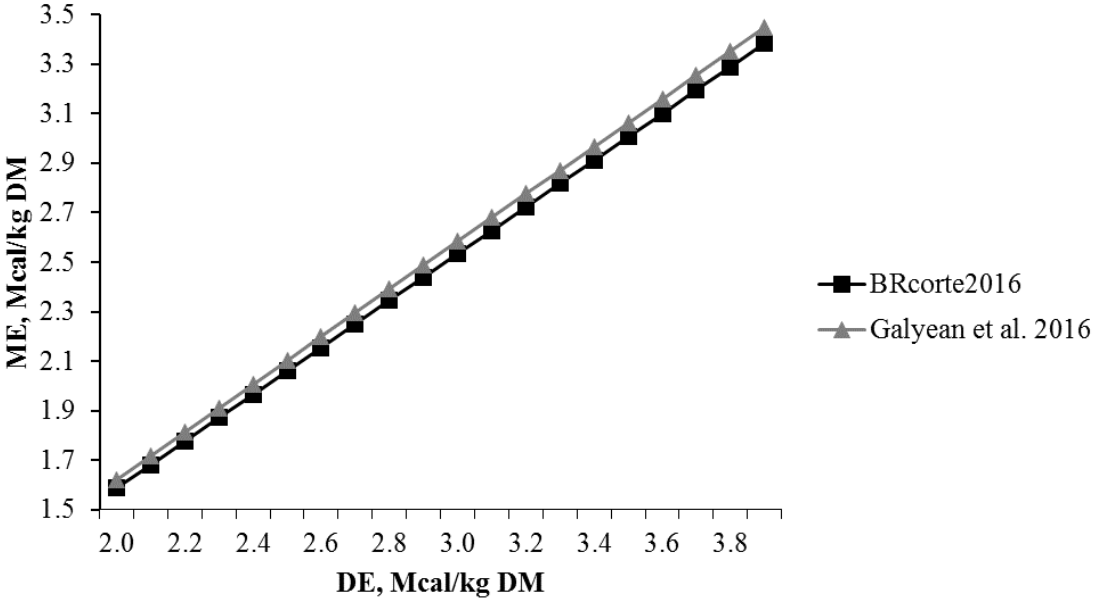

Figure 6.6 - Prediction of metabolizable energy (ME, Mcal/kg) from the digestible energy (DE, Mcal/kg) according to the model proposed by BR-CORTE 2016 and Galyean et al. (2016).

As may be seen in Figure 6.6, 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 6.5). 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 6.4, is recommended in order to determine the ME from DE.

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7

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. 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 (Valadares Filho et al., 2006) used individual data from 180 Zebu (nine studies) reared on feedlot. In the second edition (Valadares Filho et al., 2010), requirements for Zebu and crossbred cattle were estimated from individual data of 626 animals (25 studies) raised on feedlot or pasture. In the present edition, estimates are presented for nutritional requirements for Zebu, dairy and beef crossbred cattle, and cattle on pasture and feedlot from individual data from 1369 animals and 38 different studies.

The energy requirements for growing and finishing cattle were estimated in the BR-CORTE by the system presented to the scientific community by Lofgreen and Garrett (1968), entitled, "A system for expressing net energy requirement and feed values for growing and finishing beef cattle". 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 BCNRM, 2016). A summary of what was established by the CNES System can be understood from the equation below:

$$MEt = MEm + MEg = (NEm / km) + (NEg / kg) \quad \text{Eq. 7.1}$$

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 the metabolizable energy for gain.

It should be noted that the basis of the definitions proposed by CNES and presented in equation 7.1 were 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 are made based on what was established in equation 7.1, it is necessary to know the fractions presented in order to do the estimates. The BR-CORTE System uses a database of comparative slaughter experiments (Garrett et al., 1959). These experiments measure the 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 use of energy for maintenance $(1 - km)$ and gain $(1 - kg)$ represent the energy consumed that was transformed to heat (heat production) and are estimated by difference, based on the principles of energy conservation established in the first thermodynamic law (Clausius, 1850). An equation representative of these relationships is shown below:

$$MEI = RE + HP \quad \text{Eq. 7.2}$$

$$MEI = MEt \quad \text{Eq. 7.3}$$

$$RE = NEg \quad \text{Eq. 7.4}$$

$$HP = NEm + ((1 - km) \times MEm) + ((1 - kg) \times MEg) \quad \text{Eq. 7.5}$$

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 heat production (HP) value is obtained by the difference between metabolizable energy intake and retained energy, and three of the variables presented in equation 7.5 are derived from HP, mathematical models are used to estimate the NEm, *km* and *kg* values and they will be presented in the following text.

Based on the evolution of the database and knowledge of estimating nutritional requirements, the models used to estimate energy requirements for growing and finishing cattle were discussed, reassessed and validated. Thus, recommendations were generated for estimating the nutritional energy requirements for growing and finishing beef Zebu cattle and their crosses, reared on pasture or feedlot under tropical conditions.

DESCRIPTION OF THE DATABASE

The BR-CORTE system was updated based on a database consisting of 38 studies carried out under Brazilian conditions (appendix 7.1). The database of animals reared on feedlot showed great evolution, from 626 animals in the last edition (Valadares Filho et al., 2010) to 1369 animals in the current edition. The Zebu genetic group was the largest group represented in the database, with 744 animals (Table 7.1). The beef crossbred group of animals was formed by 142 Angus × Nellore, 62 Limousin × Nellore, 12 Marchigiana × Nellore, 73 Simental × Nellore, 11 Brown Swiss × Nellore, 23 Brangus and 16 twice crossbred animals, with a greater European blood fraction coming from the Angus breed (Table 7.2). The dairy crossbred group of animals was formed by 16 Holstein × Gyr, 15 Holstein × Guzerat, 155 Nellore × Holstein, 21 Holstein and 79 crossbred dairy animals (Table 7.3). The database of animals reared on pasture was formed by 127 animals, all of the Nellore breed (Table 7.4).

Table 7.1 - Descriptive statistics of the data used to obtain the nutritional energy requirements of Zebu animals on 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 7.2 - Descriptive statistics of the data used to obtain the nutritional energy requirements of beef crossbred animals on 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 7.3 - Descriptive statistics of the data used to obtain the nutritional energy requirements of dairy crossbred animals on 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 7.4 - 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

The 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). Posteriorly, 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.

The 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 oxygen consumption is necessary to produce CO_2, it is possible to estimate the NEm (ARC, 1965).

The 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, the 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). The 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, the NEm is known as the intercept (β_0) of the model (Ferrell and Jenkins, 1998; Figure 7.1).

$$HP = \beta_0 \times e^{\beta 1 \times MEI} \quad \text{Eq. 7.6}$$

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.

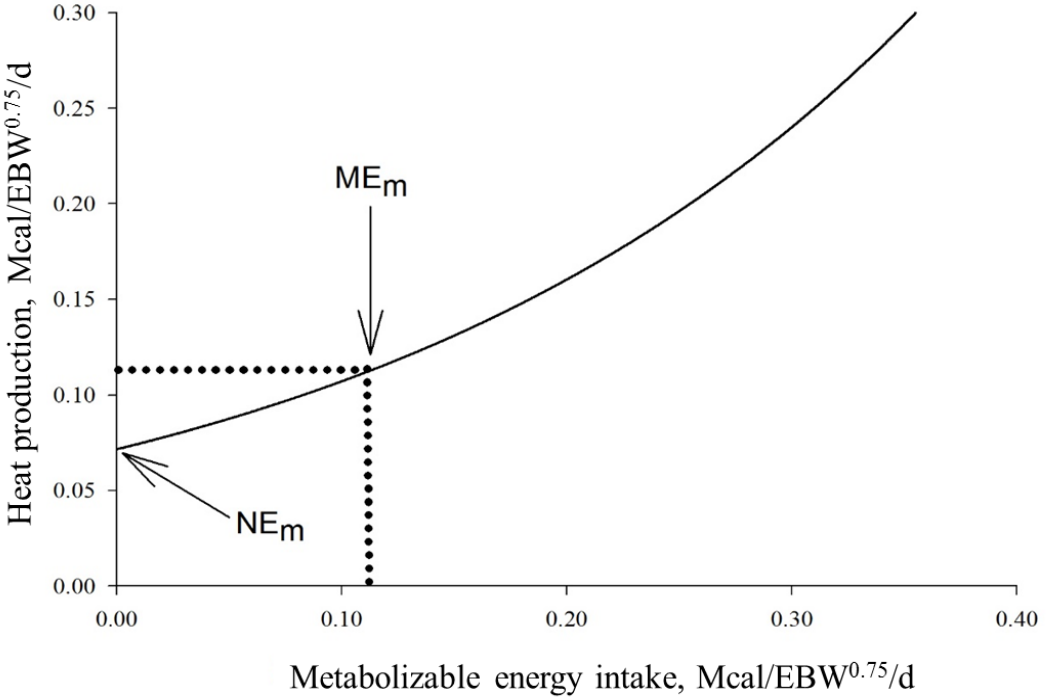

Figure 7.1 - Representation of the relationship between heat production and metabolizable energy intake.

The 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 had not been modified from the previous edition, the same recommendations were maintained as in the previous edition (Valadares Filho et al., 2010).

a) Animals on feedlot

When the model of equation 7.6 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 genetic group influences the efficiency of use of metabolizable energy for maintenance.

Zebu cattle:

$$HP = 0.0749 \times e^{3.8684 \times MEI} \quad \text{Eq. 7.7}$$

Beef crossbred cattle:

$$HP = 0.0749 \times e^{4.0612 \times MEI} \quad \text{Eq. 7.8}$$

Dairy crossbred cattle:

$$HP = 0.0749 \times e^{4.1487 \times MEI} \quad \text{Eq. 7.9}$$

where: HP = heat production (Mcal/EBW$^{0.75}$/d) and MEI = metabolizable energy intake (Mcal/EBW$^{0.75}$/d).

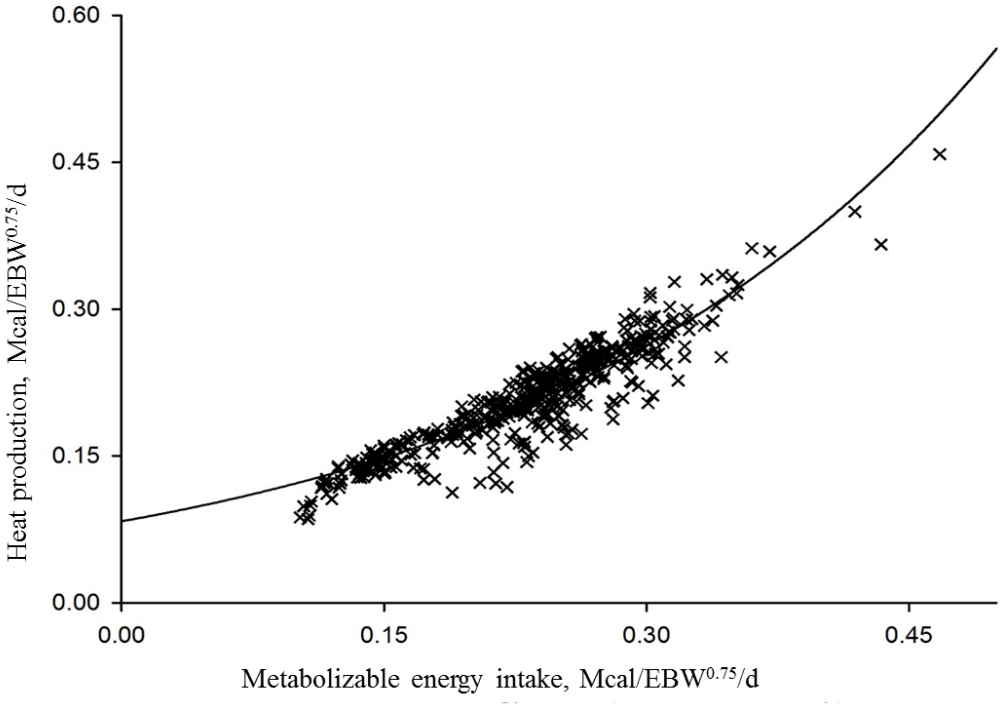

Figure 7.2 - Representation of the relationship between heat production and metabolizable energy intake for Zebu animals reared in feedlot, based on equation 7.7.

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, measured in a respirometric chamber, of 69 kcal/EBW$^{0.75}$/d (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 BCNRM (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, of around 69 kcal/SBW$^{0.75}$/d.

However, sex differences were not observed in our database. Similar results were observed by Chizzotti et al. (2008), who, in a study involving data from 389 Nellore or beef crossbred animals (Angus, Red Angus, Simental, Limousin and Brangus), did not observe genetic group effects and estimated a NEm of approximately 75 kcal/EBW$^{0.75}$/d. 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 previous edition of the BR-CORTE (Valadares Filho et al., 2010) presented differences in the NEm estimate according to the

rearing system, and values were obtained of 74.2 and 71.7 kcal/EBW$^{0.75}$/d for animals reared on feedlot and pasture, respectively. However, with the database of the current edition, there was no effect (P = 0.16) of the rearing system on the β_0 estimate of equation 7.6, and the same NEm value of 75 kcal/EBW$^{0.75}$/d was adopted for both feedlot and pasture reared animals. However, a significant difference (P = 0.039) was observed for the β_1 estimate suggesting differences regarding MEm.

$$HP = 0.0749 \times e^{4.1986 \times MEI} \quad \text{Eq. 7.10}$$

where: HP = heat production (Mcal/EBW$^{0.75}$/d) and MEI = metabolizable energy intake (Mcal/EBW$^{0.75}$/d).

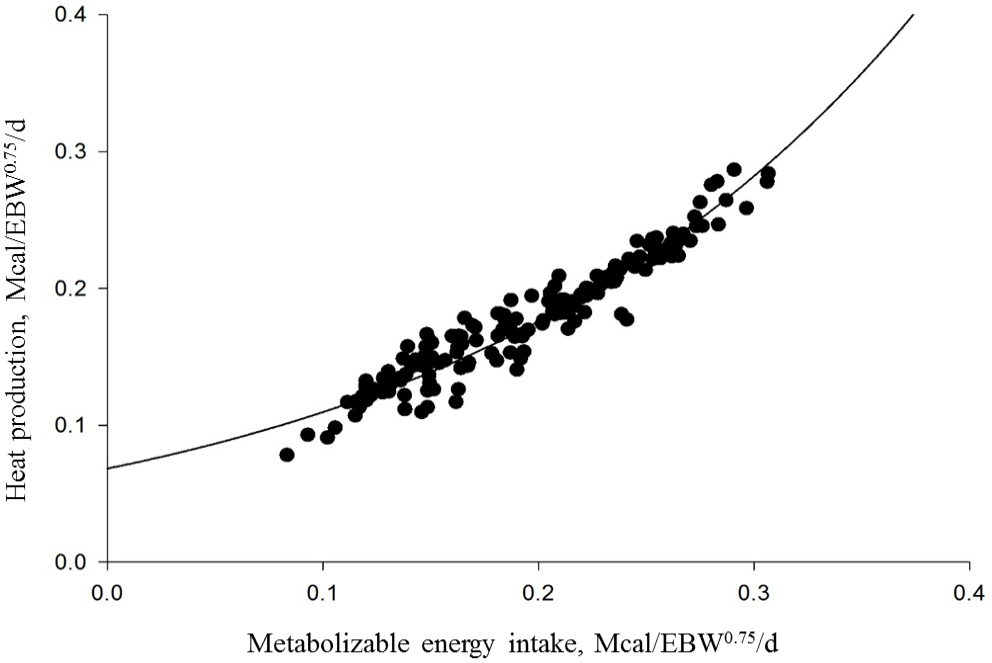

Figure 7.3 - Representation of the relationship between heat production and metabolizable energy intake for Zebu animals reared on pasture, based on equation 7.10.

Theoretically, NEm is influenced by characteristics that affect the basal metabolism and is independent of diet, which justifies having 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 7.1).

This technique of estimating the *km*, although classic and already used in the first edition of the BR-CORTE (Valadares Filho et al., 2006), was refuted in the last edition (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.7.11), which confirms that the maintenance requirements are affected by animal performance.

$$km = \left[\left(\beta_0 + \beta_1 \times kg + \beta_2 \times EBG\right) \times \theta\right]$$

Eq. 7.11

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 7.7, 7.8, and 7.9.

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 beef crossbred cattle. The data for Zebu and beef crossbred 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:

$$km = \left[\left(0.513 + 0.173 \times kg + \beta_2 \times EBG\right) \times \theta\right]$$

Eq. 7.12

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 beef crossbred and 0.010 for dairy crossbred 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 7.13 and 7.14, respectively). The *km* established by the NRC (2000, 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. 7.15), 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.

$$km = \left(0.35 \times q_m\right) + 0.503$$

Eq. 7.13

$$km = \left(0.02 \times q_m\right) + 0.500$$

Eq. 7.14

$$\left[NEm\right] = -1.12 + 1.37 \times \left[ME\right] - 0.138 \times \left[ME\right]^2 + 0.0105 \times \left[ME\right]^3$$

Eq. 7.15

where: *km* = efficiency of use of metabolizable energy for maintenance, qm = metabolizable energy and gross energy ratio in the diet (expressed in % in Eq. 7.13, and in MJ/kg DM in Eq. 7.14) and [ME] =

concentration of metabolizable energy in the diet (Mcal/kg dry matter).

As reported previously, the NRC (2000) and BCNRM (2016) suggested that *Bos 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 indicus* animals would be more efficient than beef crossbred cattle, which would be more efficient than dairy crossbred 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.7.7) and animals reared on pasture (Eq.7.10) 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.

$$km = \left[\left(0.513 + 0.173 \times kg + 0.100 \times EBG\right) \times \theta\right] \quad \text{Eq. 7.16}$$

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 present study, 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 ajust 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 7.4) since the animals in the database mostly have a low degree of marbling (NRC, 2000).

$$BF = \beta_0 \times e^{(\beta_1 \times EBW)} \qquad \text{Eq. 7.17}$$

where: BF = body fat content (kg); EBW = empty body weight (kg) and β_0 and β_1 are parameters of the equation.

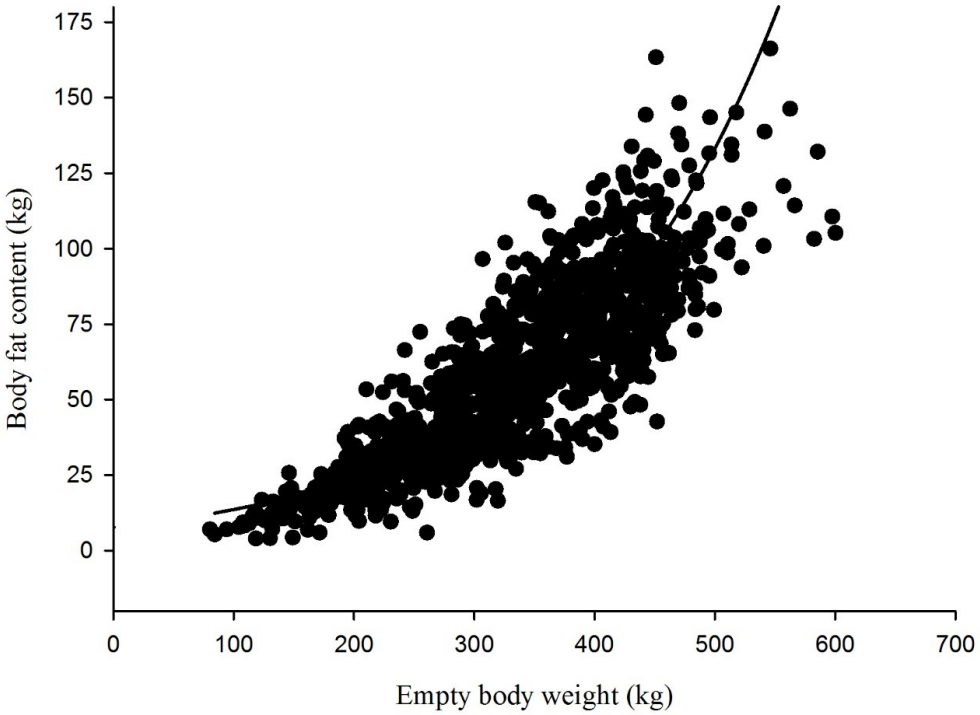

Figure 7.4 - Relationship between empty body weight and body fat, considering all the animals in the BR-CORTE database.

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 7.5).

Table 7.5 - Weight at maturity for different genetic groups/sexes of beef cattle estimated from the exponential ratio of the body fat content and empty body weight of the animals

Genetic group	Sex	Weight at maturity (kg)
Zebu cattle	Bulls	517
	Steers	433
	Heifers	402
Beef Crossbred	Bulls	560
	Steers	482
	Heifers	417
Dairy Crossbred	Bulls	616
	Steers	532
	Heifers	493

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) value suggested previously for each type of animal and a reference value for empty body weight (SREBW), adopting the following model:

$$EQEBW = (EBW / MEBW) \times SREBW$$

Eq. 7.18

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).

Using the EQEBW allows animals of 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 the animals would be at the same expected final body fat.

In the BR-CORTE (2010), a value was adopted of 440 kg for the SREBW, this value was calculated based on the database of that edition that contained all of the animals. For the current edition, 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 the most data, and therefore, possibly greater reliability in the estimates.

Net energy requirement for gain

The 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 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:

$$NEg = \beta_0 \times EQEBW^{0.75} \times EBG^{\beta_1}$$

Eq. 7.19

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 previous edition of the BR-CORTE used different models for each sex, and the differences between genetic groups would be absorbed by the EQEBW. However, analysis of the database in the current edition showed the possibility of the EQEBW absorbing not only the intrinsic differences in each genetic group (Figure 7.5A), but also the differences between the sexes (Figure 7.5B).

In this way, a joint equation was generated using the data from all animals finished on feedlot (Eq. 7.20) while the requirements for animals on pasture were not altered in relation to the last edition (Eq. 7.21).

$$NEg = 0.061 \times EQEBW^{0.75} \times EBG^{1.035}$$

Eq. 7.20

$$NEg = 0.052 \times EQEBW^{0.75} \times EBG^{1.062}$$

Eq. 7.21

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 7.5A). For beef crossbred animals, the NEg of steers was 12% higher than that of bulls and 13% lower than the heifers. For dairy crossbred animals, the NEg of steers was 12% higher than that for bulls and 6% lower than that for heifers.

The BR-CORTE used a similar model to that recommended in the NRC (2000) to

estimate the NEg, according to the equation: NEg = 0.0635 x EQEBW $^{0.75}$ x EBG$^{1.097}$ that is based on the 1984 edition (NRC, 1984) and was generated for medium-sized animals. Thus, to correct distortions in relation to animal body composition, the BCNRM (2016) recommends using 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.

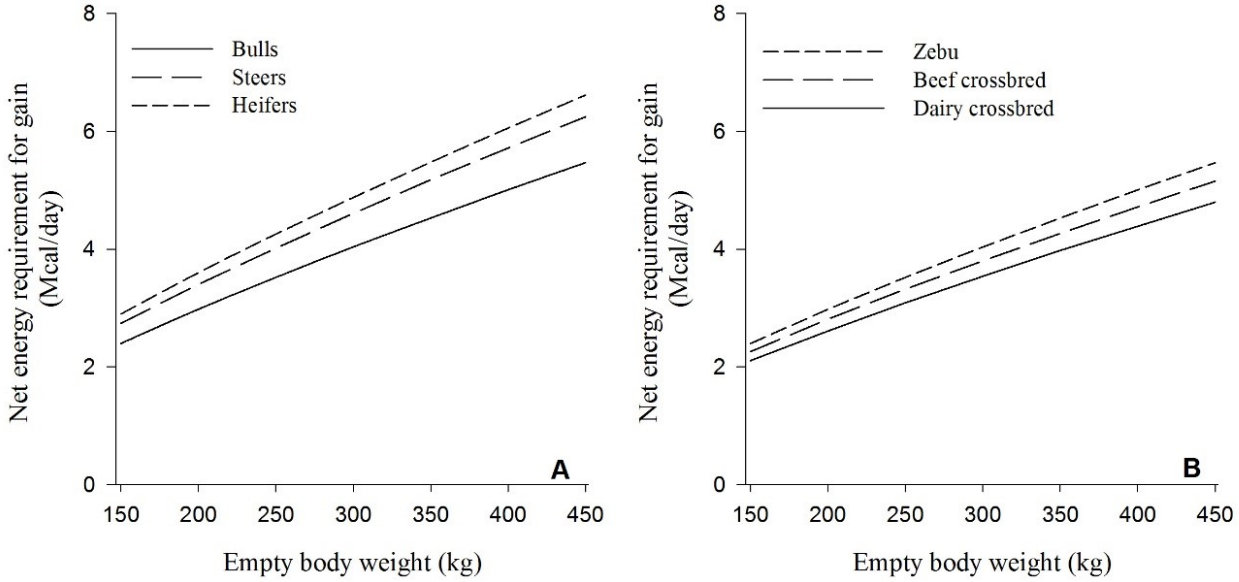

Figure 7.5 - Estimate of net energy requirement for gain for Zebu animals of different sexes (A) and for bulls from different genetic groups (B). For all estimates, the model used was proposed for animals on feedlot, considering the equivalent empty body weight inherent to each category and an empty 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:

$$EBG = 14.914 \times NEg^{0.9662} \times EQEBW^{-0.7246}.$$

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.

Metabolizable energy requirement for gain

Similarly to NEm, NEg cannot be applied directly to 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 7.6).

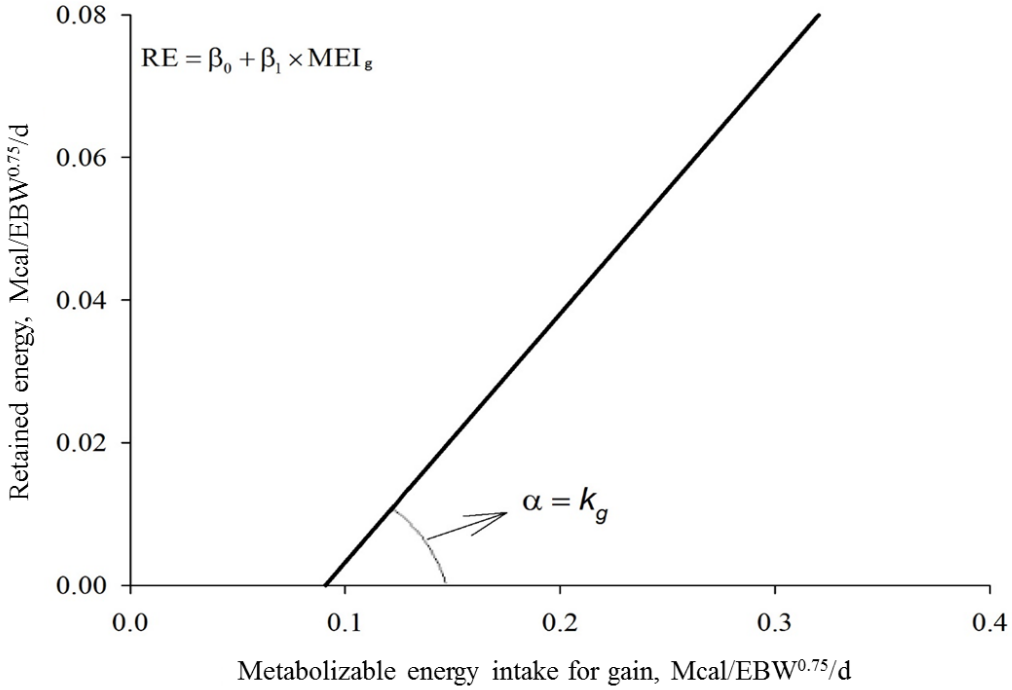

Figure 7.6 - Retained energy and metabolizable energy intake for gain ratio.

However, high variation was observed in the *kg* values between experiments when this value was considered as constant (Figure 7.6), 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:

$$kg = \frac{(kfat \times kp)}{\left[kp + \left(\frac{REp}{100}\right) \times (kfat - kp)\right]}$$

Eq. 7.22

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 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 the *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 7.7).

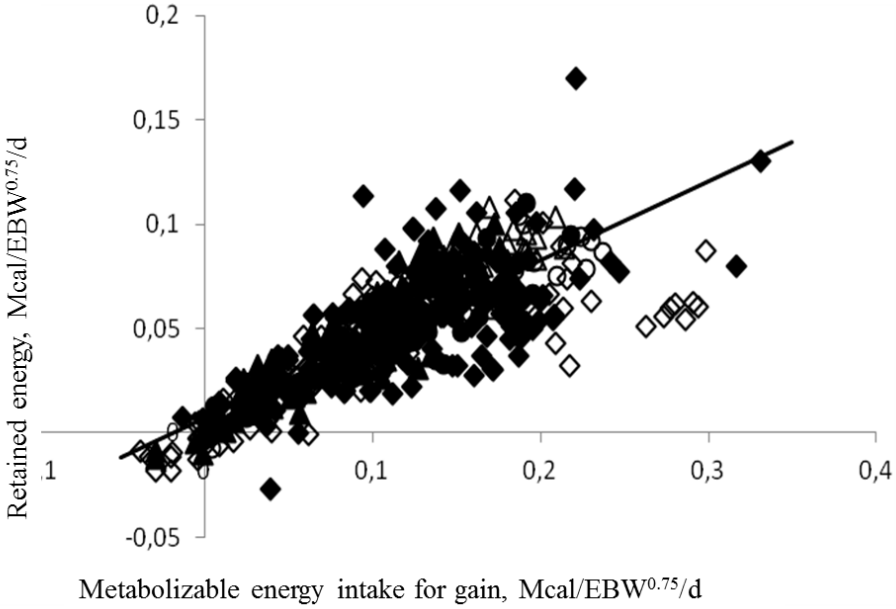

Figure 7.7 - Metabolizable energy intake for gain and retained energy ratio. Symbols represent data from bulls (▲, Δ), steers (◊,♦) and heifers (○, ●). Solid dots represent Zebu animals and empty dots represent beef crossbred cattle (adapted from Marcondes et al., 2010).

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:

$$kg = \frac{0.327}{(0.539 + REp)}$$

Eq. 7.23

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 as follows:

$$REp = 0.0554 + 1.6939 \times e^{\left[-0.5573 \times \left(\frac{RE}{EBG}\right)\right]}$$

$$REp = 10.1 + 166.7 \times e^{\left[-0.660 \times \left(\frac{RE}{EBG}\right)\right]}$$

However, Marcondes et al. (2013) did not use the same model, because for any one 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:

$$REp = 1.140 \times \left(\frac{RE}{EBG}\right)^{-1.137}$$

Eq. 7.24

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 (Eq. 7.25). Similarly, the AFRC (1993) considers the metabolizable energy and gross energy ratio to estimate the q_m and later the *kg* (Eq. 7.26).

$$[NEg] = -1.65 + 1.42 \times [ME] - 0.174 \times [ME]^2 + 0.0122 \times [ME]^3$$

Eq. 7.25

$$km = (0.78 \times q_m) + 0.006$$

Eq. 7.26

where: [ME] = metabolizable energy concentration in the diet (Mcal/kg dry matter), *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 the *kg* estimate.

FUTURE PERSPECTIVES

Due to some limitations of this study, some objectives were traced that should be reached by the release of the next version of the BR-CORTE, to improve the energy requirement estimates.

The database of animals on feedlot has a deficit of animals with extreme weights. Thus experiments need to be performed with animals that have average EBW lower than 150 kg and greater than 500 kg, in order to increase the power of the data that make up the prediction models for maintenance and gain requirements and also increase the accuracy of the models.

Another factor that will require great effort is increasing the database for animals reared on pasture, because there was no evolution from the previous edition to the current one. Thus, this is a fundamental point to be worked on for the next edition. Another point that should be studied is experimenting with animals on pasture that include the three genetic groups (Zebu, beef crossbred and dairy crossbred), to improve the interpretation in the database.

The use of the equation:

$$[ME] = 0.9455 \times [DE] - 0.3032$$

presented in Chapter 6, instead of a fixed ratio for converting digestible energy into metabolizable energy (0.82) can be considered an advance in the estimates, but more data are needed for validation.

SUMMARY OF THE MODELS AND CALCULATION EXAMPLES

A summary of the models described in this chapter is presented in Tables 7.6 and 7.7.

Table 7.6 - Summary of the models to estimate the energy requirements for animals on feedlot

Item		Models
SBW (kg)		Zebu cattle: $0.8800 \times BW^{1.0175}$
		Crossbred cattle: $0.9664 \times BW^{1.0017}$
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)		$\left(\frac{EBW}{MEBW}\right) \times 517$
NEm (Mcal/d)		$0.075 \times EBW^{0.75}$
NEg (Mcal/d)		$0.061 \times EQEBW^{0.75} \times EBG^{1.035}$
REp		$1.140 \times \left(\frac{RE}{EBG}\right)^{-1.137}$
kg		$kg = \frac{0.327}{(0.539 + REp)}$
km		Zebu: $\left[(0.513 + 0.173 \times kg + 0.100 \times EBG) \times 1\right]$
		Beef crossbred: $\left[(0.513 + 0.173 \times kg + 0.073 \times EBG) \times 1\right]$
		Dairy crossbred: $\left[(0.513 + 0.173 \times kg + 0.010 \times EBG) \times 1\right]$
MEm (Mcal/d)		NEm/*km*
MEg (Mcal/d)		NEg/*kg*
MEt (Mcal/d)		MEm + MEg
DE (Mcal/d)		$\left(\frac{\left(MEtotal / DMI\right) + 0.3032}{0.9455}\right) \times DMI$
TDN (kg/d)		DE/4.4

Table 7.7 - Summary of the models to estimate the energy requirements for animals on pasture

Item	Models
SBW (kg)	$0.8800 \times BW^{1.0175}$
EBW (kg)	$0.8507 \times SBW^{1.0002}$
EBG (kg/d)	$0.9630 \times ADG^{1.0151}$
EQEBW (kg)	$\left(\frac{EBW}{MEBW}\right) \times 517$
NEm (Mcal/d)	$0.075 \times EBW^{0.75}$
NEg (Mcal/d)	$0.052 \times EQEBW^{0.75} \times EBG^{1.062}$
REp	$1.140 \times \left(\frac{RE}{EBG}\right)^{-1.137}$
kg	$kg = \frac{0.327}{(0.539 + REp)}$
km	$\left[(0.513 + 0.173 \times kg + 0.100 \times EBG) \times 0.92\right]$
MEm (Mcal/d)	NEm/*km*
MEg (Mcal/d)	NEg/*kg*
MEt (Mcal/d)	MEm + MEg
DE (Mcal/d)	$\left(\frac{\left(MEtotal / DMI\right) + 0.3032}{0.9455}\right) \times DMI$
TDN (kg/d)	DE/4.4

To illustrate the application of the models presented in this Chapter, an estimate will be made of the energy requirements for a Nellore bull with 400 kg body weight with ADG of 1 kg/d on feedlot.

- SBW = 0.88 × $BW^{1.0175}$ → 0.88 × $400^{1.0175}$ → 391 kg
- EBW = 0.8126 × $SBW^{1.0134}$ → 0.8126 × $391^{1.0134}$ → 344 kg
- EBG = 0.963 × $ADG^{1.0151}$ → 0.963 × $1^{1.0151}$ → 0.963 kg/d
- EQEBW = (EBW / 517) × 517 → (344 / 517) × 517 → 344 kg
- NEg = 0.061 × $EQEBW^{0.75}$ × $EBG^{1.035}$ → 0.061 × $344^{0.75}$ × $0.963^{1.035}$ →4.69 Mcal/d
- REp = 1.140 × $(RE / EBG)^{-1.137}$ → 1.140 × $(4.69 / 0.963)^{-1.137}$ → 0.1885
- *kg* = 0.327 / (0.539 + REp) → 0.327 / [0.539 + 0.1885] → 0.45
- MEg = NEg / *kg* → 4.69 / 0.45 →10.4 Mcal/d
- NEm = 0.075 × $EBW^{0.75}$ → 0.075 × $344^{0.75}$ → 5.99 Mcal/d

- km = [(0.513 + 0.173 × kg + 0.100 × EBG) × 1] → [(0.513 + 0.173 × 0.45 + 0.100 × 0.963) × 1] → 0.69
- MEm = NEm / km → 5.99 / 0.69 → 8.72 Mcal/d
- MEtotal = MEg + MEm → 10.4 + 8.72 → 19.2 Mcal/d
- DE = [((MEtotal / DMI) + 0.3032) / 0.9455] × DMI → [((19.15 / 8.31) + 0.3032) / 0.9455] × 8.31 → 22.92 Mcal/d
- TDN = DE / 4.4 → 22.92 / 4.4 → 5.21 kg/d

TABLES OF ENERGY NUTRITIONAL REQUIREMENTS

In this section, tables present the estimates of net energy requirements for gain, total metabolizable energy requirements and total digestible nutrients requirements for Zebu, beef crossbred and dairy crossbred animals reared on feedlot and for Zebu animals reared on pasture.

Table 7.8 - Energy requirements for Zebu of different sexes, body weights and weight gain rates

Requirements	Body weight (kg)											
	300			350			400			450		
ADG (kg/d)	0.50	1.00	1.50	0.50	1.00	1.50	0.50	1.00	1.50	0.50	1.00	1.50
DMI (kg/d)	5.61	6.96	7.86	6.30	7.65	8.54	6.96	8.31	9.21	7.60	8.95	9.85
Bulls												
NEm (Mcal/d)		4.80			5.40			5.99			6.56	
MEm (Mcal/d)	7.59	7.04	6.56	8.51	7.89	7.36	9.39	8.72	8.14	10.3	9.52	8.89
NEg (Mcal/d)	1.81	3.75	5.74	2.04	4.23	6.47	2.26	4.69	7.18	2.48	5.13	7.86
MEg (Mcal/d)	4.37	8.97	13.7	4.72	9.71	14.8	5.07	10.4	15.9	5.41	11.1	17.0
MEt (Mcal/d)	12.0	16.0	20.2	13.2	17.6	22.2	14.5	19.2	24.0	15.7	20.7	25.9
TDN (kg/d)	3.28	4.36	5.44	3.64	4.79	5.95	3.98	5.21	6.45	4.32	5.62	6.94
Steers												
NEm (Mcal/d)		4.81			5.45			6.08			6.69	
MEm (Mcal/d)	7.57	7.03	6.56	8.54	7.93	7.40	9.5	8.8	8.22	10.4	9.7	9.0
NEg (Mcal/d)	2.08	4.30	6.59	2.35	4.87	7.46	2.62	5.43	8.31	2.88	5.97	9.15
MEg (Mcal/d)	4.78	9.83	15.0	5.21	10.7	16.3	5.64	11.6	17.7	6.05	12.5	19.0
MEt (Mcal/d)	12.4	16.9	21.5	13.8	18.7	23.7	15.1	20.4	25.9	16.4	22.1	28.0
TDN (kg/d)	3.38	4.56	5.75	3.76	5.04	6.33	4.14	5.51	6.90	4.51	5.97	7.45
Heifers												
NEm (Mcal/d)		4.86			5.51			6.14			6.76	
MEm (Mcal/d)	7.62	7.08	6.60	8.6	7.99	7.46	9.6	8.9	8.3	10.5	9.7	9.1
NEg (Mcal/d)	2.22	4.59	7.03	2.51	5.20	7.97	2.80	5.80	8.88	3.08	6.39	9.78
MEg (Mcal/d)	5.00	10.3	15.7	5.46	11.2	17.1	5.92	12.2	18.6	6.37	13.1	20.0
MEt (Mcal/d)	12.6	17.4	22.3	14.1	19.2	24.6	15.5	21.1	26.9	16.9	22.9	29.1
TDN (kg/d)	3.44	4.68	5.93	3.84	5.18	6.54	4.23	5.67	7.13	4.61	6.15	7.72

ADG = average daily gain; DMI = dry matter intake; NEm = net energy requirement for maintenance; MEm = metabolizable energy requirement for maintenance; NEg = net energy requirement for gain; MEg = metabolizable energy requirement for gain; MEt = total metabolizable energy requirement; TDN = total digestible nutrients requirement.

Table 7.9 - Energy requirements for beef crossbred of different sexes, body weights and weight gain rates

Requirements	Body Weight (kg)											
	300			350			400			450		
ADG (kg/d)	0.50	1.00	1.50	0.50	1.00	1.50	0.50	1.00	1.50	0.50	1.00	1.50
DMI (kg/d)	5.81	7.28	8.45	6.38	7.85	9.02	6.93	8.40	9.57	7.46	8.93	10.1
Bulls												
NEm (Mcal/d)		4.77			5.37			5.96			6.53	
MEm (Mcal/d)	7.56	7.01	6.53	8.48	7.86	7.33	9.36	8.69	8.11	10.22	9.49	8.85
NEg (Mcal/d)	1.70	3.51	5.38	1.91	3.96	6.06	2.12	4.39	6.72	2.32	4.81	7.36
MEg (Mcal/d)	4.19	8.60	13.1	4.52	9.29	14.2	4.85	9.96	15.2	5.16	10.6	16.2
MEt (Mcal/d)	11.7	15.6	19.6	13.0	17.2	21.5	14.2	18.6	23.3	15.4	20.1	25.0
TDN (kg/d)	3.25	4.28	5.33	3.59	4.70	5.82	3.92	5.10	6.30	4.24	5.48	6.76
Steers												
NEm (Mcal/d)		4.80			5.42			6.02			6.61	
MEm (Mcal/d)	7.57	7.03	6.55	8.51	7.90	7.37	9.42	8.75	8.16	10.3	9.57	8.93
NEg (Mcal/d)	1.91	3.96	6.06	2.16	4.47	6.84	2.40	4.96	7.60	2.63	5.45	8.34
MEg (Mcal/d)	4.52	9.29	14.2	4.91	10.1	15.4	5.28	10.9	16.6	5.65	11.6	17.7
MEt (Mcal/d)	12.1	16.3	20.7	13.4	18.0	22.7	14.7	19.6	24.7	16.0	21.2	26.7
TDN (kg/d)	3.33	4.45	5.59	3.69	4.90	6.12	4.04	5.33	6.64	4.38	5.75	7.15
Heifers												
NEm (Mcal/d)		4.86			5.49			6.11			6.71	
MEm (Mcal/d)	7.63	7.08	6.61	8.6	7.98	7.44	9.5	8.8	8.25	10.4	9.7	9.0
NEg (Mcal/d)	2.16	4.47	6.84	2.44	5.05	7.73	2.71	5.62	8.60	2.98	6.17	9.44
MEg (Mcal/d)	4.90	10.1	15.4	5.35	11.0	16.8	5.78	11.9	18.1	6.20	12.8	19.5
MEt (Mcal/d)	12.5	17.2	22.0	13.9	19.0	24.2	15.3	20.7	26.4	16.6	22.5	28.5
TDN (kg/d)	3.44	4.66	5.90	3.81	5.13	6.48	4.18	5.60	7.04	4.54	6.05	7.59

ADG = average daily gain; DMI = dry matter intake; NEm = net energy requirement for maintenance; MEm = metabolizable energy requirement for maintenance; NEg = net energy requirement for gain; MEg = metabolizable energy requirement for gain; MEt = total metabolizable energy requirement; TDN = total digestible nutrients requirement.

Table 7.10 - Energy requirements for dairy crossbred of different sexes, body weights and weight gain rates

Requirements	Body weight (kg)											
	300			350			400			450		
ADG (kg/d)	0.50	1.00	1.50	0.50	1.00	1.50	0.50	1.00	1.50	0.50	1.00	1.50
DMI (kg/d)	5.21	6.75	7.80	5.96	7.49	8.55	6.68	8.21	9.27	7.37	8.91	9.96
Bulls												
NEm (Mcal/d)		4.77			5.37			5.96			6.53	
MEm (Mcal/d)	7.58	7.03	6.55	8.50	7.88	7.35	9.39	8.71	8.12	10.25	9.51	8.87
NEg (Mcal/d)	1.58	3.27	5.01	1.78	3.68	5.64	1.97	4.09	6.26	2.16	4.48	6.85
MEg (Mcal/d)	4.01	8.23	12.5	4.32	8.87	13.5	4.62	9.49	14.5	4.91	10.10	15.4
MEt (Mcal/d)	11.6	15.3	19.1	12.8	16.8	20.9	14.0	18.2	22.6	15.2	19.6	24.3
TDN (kg/d)	3.17	4.16	5.15	3.52	4.57	5.64	3.85	4.97	6.10	4.18	5.36	6.56
Steers												
NEm (Mcal/d)		4.80			5.42			6.02			6.61	
MEm (Mcal/d)	7.60	7.05	6.57	8.54	7.92	7.39	9.45	8.77	8.18	10.3	9.59	8.95
NEg (Mcal/d)	1.77	3.67	5.63	2.00	4.15	6.35	2.23	4.61	7.06	2.44	5.06	7.75
MEg (Mcal/d)	4.31	8.85	13.5	4.67	9.59	14.6	5.01	10.3	15.7	5.35	11.0	16.8
MEt (Mcal/d)	11.9	15.9	20.1	13.2	17.5	22.0	14.5	19.1	23.9	15.7	20.6	25.8
TDN (kg/d)	3.24	4.31	5.39	3.61	4.76	5.91	3.96	5.18	6.42	4.31	5.60	6.92
Heifers												
NEm (Mcal/d)		4.86			5.49			6.11			6.71	
MEm (Mcal/d)	7.67	7.11	6.64	8.63	8.01	7.47	9.56	8.88	8.28	10.5	9.7	9.07
NEg (Mcal/d)	1.90	3.94	6.03	2.15	4.45	6.82	2.39	4.95	7.58	2.63	5.44	8.33
MEg (Mcal/d)	4.51	9.26	14.1	4.89	10.06	15.3	5.27	10.8	16.5	5.64	11.6	17.7
MEt (Mcal/d)	12.2	16.4	20.7	13.5	18.1	22.8	14.8	19.7	24.8	16.1	21.3	26.8
TDN (kg/d)	3.31	4.43	5.55	3.68	4.89	6.11	4.05	5.34	6.64	4.41	5.78	7.17

ADG = average daily gain; DMI = dry matter intake; NEm = net energy requirement for maintenance; MEm = metabolizable energy requirement for maintenance; NEg = net energy requirement for gain; MEg = metabolizable energy requirement for gain; MEt = total metabolizable energy requirement; TDN = total digestible nutrients requirement.

Table 7.11 - Energy requirements for Zebu bulls of different weights and weight gain rates reared on pasture

Requirements	Body Weight (kg)											
	300			350			400			450		
ADG (kg/d)	0.50	1.00	1.50	0.50	1.00	1.50	0.50	1.00	1.50	0.50	1.00	1.50
DMI (kg/d)	5.24	6.11	7.76	6.11	7.13	9.05	6.98	8.15	10.3	7.85	9.17	11.6
NEm (Mcal/d)		4.69			5.28			5.85			6.40	
MEm (Mcal/d)	7.36	6.67	6.18	8.23	7.48	6.94	9.08	8.26	7.67	9.9	9.02	8.38
NEg (Mcal/d)	1.77	3.67	5.62	1.99	4.13	6.32	2.21	4.57	7.00	2.42	5.00	7.66
MEg (Mcal/d)	3.97	6.73	9.6	4.28	7.41	10.7	4.59	8.06	11.7	4.89	8.70	12.7
MEt (Mcal/d)	11.3	13.4	15.8	12.5	14.9	17.6	13.7	16.3	19.4	14.8	17.7	21.1
TDN (kg/d)	3.10	3.67	4.36	3.45	4.10	4.89	3.79	4.52	5.41	4.13	4.93	5.91

ADG = average daily gain; DMI = dry matter intake; NEm = net energy requirement for maintenance; MEm = metabolizable energy requirement for maintenance; NEg = net energy requirement for gain; MEg = metabolizable energy requirement for gain; MEt = total metabolizable energy requirement; TDN = total digestible nutrients requirement.

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8

Protein requirements for beef cattle

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INTRODUCTION

Proteins are molecules that play several function 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 in two main portions: rumen degradable protein (RDP) and rumen undegradable protein (RUP) (NRC, 1985). In addition, metabolizable protein requirements are met by intestinal amino acids absorption. These amino acids came 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 Oliveira and Millen (2014), commercial feedlots in Brazil use high crude protein contents (CP) in diets of finishing animals (in some cases up to 16.6% CP) as strategy to stimulate dry matter intake and to reduce feedlot period. However, there is a 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 diets of finishing cattle is possible without affecting animal performance besides to reduce 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 also lead to fertility impairment (Rhoads et al., 2006). Thus, more studies should be done as a way to adopt management strategies to reduce the amount of N in diets, leading to reduce economic losses, and also, environmental impact. Therefore, the knowledge of the protein required for maintenance and growth of growing and/or finishing animal is necessary to optimize beef production.

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 amino acids available for absorption. The sources of protein that reach intestine of ruminants are microbial crude protein, 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 metabolizable protein (ARC 1980).

Formulation based on crude protein intake can cause several estimation errors, once this intake does not consider biological value of crude protein as well as the efficiency of microbial crude protein synthesis (MCP) per kg of digestible organic matter. The current systems of nutrient requirements for cattle evolved and recommended metabolizable protein intake, accounting for available protein absorbed as amino acids in the intestine.

According to Santos (2006), the use of metabolizable protein (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 RUP content and of the amount and quality of MP supplied by the animal, reduction in losses of nitrogenous compounds to reduce the negative impact of the release of these compounds into the environment.

Protein requirements can be divided to 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 into 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 (2010)

This edition of the BR-CORTE (2016) was developed to improve and to ratify the protein requirements for beef cattle. According to Galyean (2014), changes on nutrient requirements associated with sex, genetic groups, physiological status, and environment turn the establishment of the requirements more complex and this is a challenge for the committees that try to stablish nutrient requirements. This highlights the importance of constantly updating the database and the use of environmental conditions and handling consistent with the environment of 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 observed values of CP intake for finishing Nellore bulls submitted to diets containing 10, 12, and 14% CP, respectively. Prados et al. (2015) worked with growing crossbred (Holstein × Zebu) bulls and observed overestimation of 27.5% in crude protein intake (CPI), with a predicted value of 1,200 g/d for CP requirements in relation to observed CP intake of 870 g/d. Additionally, Amaral et al. (2014) observed predicted CP intake (1,580 g/d) 17% greater than that observed (1,348 g/d) for finishing crossbred (Holstein × Zebu) bulls while Costa e Silva et al. (2013) found overestimated values of CP intake in 16.75% in relation to the average of observed values for finishing Nellore bulls. Thus, before generating new equations, the prediction of crude protein intake (CPI) by the BR-CORTE (2010) was tested. 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 (PhD thesis, work in progress) and Zanetti (PhD thesis, work in progress). The database included dissertations and theses that were concluded after 2010 and were not part of the BR-CORTE's database (2010).

The descriptive statistics of data of crude protein intake referring to observed values in the studies and the values predicted by the BR-CORTE (2010) are shown in the Table 8.1, and these data were evaluated using 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 errors associated with the estimates and as the lower its value, the better the estimates. Furthermore, from 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 8.1 – Regression analysis and descriptive statistics from observed values and those predicted by the BR-CORTE (2010) for dietary crude protein requirement

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 equation to estimate CP requirement was significant ($P < 0.01$), showing that the intercept and slope differ from zero and 1, respectively, and indicating that the estimates of the BR-CORTE (2010) were inappropriate (Figure 8.1). Moreover, CP requirements were overestimated 12.24% in relation to the observed CP intake. In the error decomposition, the majority of the errors is not associated with random errors, showing that there is a tendency of overestimation. Diets with an excess of protein will result in expensive diet cost with increased N excretion. This shows that new adjustments on the estimates of protein requirements need to be performed.

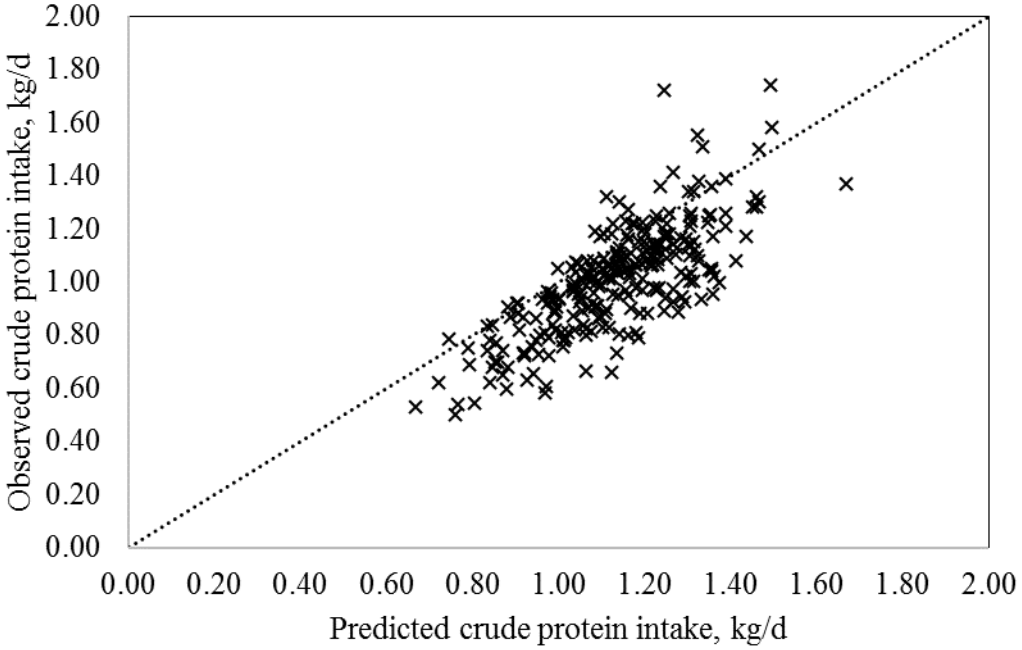

Figure 8.1 - Relationship between observed values and those predicted by the equation proposed by the BR-CORTE (2010) for crude protein intake.

Diets with protein content below the requirements of the animals can affect productivity. However, diets with excess of protein result in higher cost with feeding beyond the increase of nitrogen excretion. Knowledge of nutrient requirements of beef cattle are necessary to formulation of diets, contributing to the environment and optimization of animal performance.

The results of the predicted crude protein intake highlight the need to adequate then to genetic, physiological, and environment factors in Brazil. Then, the estimates of CP requirements of the BR-CORTE (2010) require adjustment for use in beef cattle production systems, a fact evidenced by the overestimate of crude protein intake (Table 8.1). Therefore, this edition of the BR-CORTE proposes some changes on protein requirements with the inclusion of new variables for MCP and data of animals with different body weights, sexes, and genetic groups.

DATABASE

In this edition of the BR-CORTE, 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). The complete references are presented in Appendix 8.1 of the online

publication. Among data presented, 767 animals were utilized in feedlot system and 148 in grazing system. In relation to genetic group, 406 animals were Zebu cattle, 212 animals were beef crossbred cattle, and 149 animals were dairy crossbred cattle (Tables 8.2, 8.3, and 8.4, respectively). For pasture, the descriptive statistics can be seen in the Table 8.5.

Table 8.2 - Descriptive statistics for Zebu cattle raised in feedlot and utilized to determine protein requirements

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 8.3 - Descriptive statistics for beef crossbred cattle raised in feedlot and utilized to determine protein requirements

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 8.4 - Descriptive statistics for dairy crossbred cattle raised in feedlot and utilized to determine protein requirements

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 8.5 - Descriptive statistics for Zebu cattle raised on pasture and utilized to determine protein requirements

Itens	N[1]	Mean	SD[3]	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.

PROTEIN REQUIREMENTS FOR MAINTENANCE

The demand of protein for maintenance of cattle is equal to endogenous nitrogen losses through feces, urine, and scurf (NRC, 2000). In the first edition of the BR-CORTE, in 2006, the value of 2.69 g/$BW^{0.75}$, obtained by Véras et al. (2007), was adopted as the net protein required for maintenance. The authors evaluated bulls, steers, and heifers fed four dietary crude protein levels (7, 10, 13 and 15%) and did not found effect of sex on the relationship between retained nitrogen and nitrogen intake (Figure 8.2). The net requirement of protein for maintenance (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.

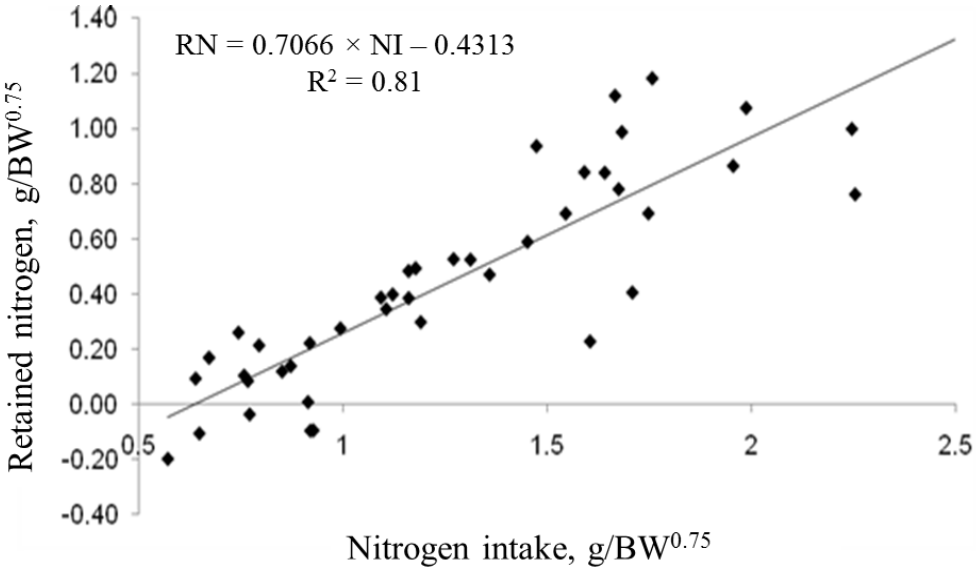

Figure 8.2 - Relationship between retained nitrogen (RN) and nitrogen intake (NI), expressed as g/BW$^{0.75}$. Adapted of Véras et al. (2007).

The AFRC (1993) adopted the value of 2.30 g/BW$^{0.75}$/d, 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, 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 metabolizable protein required for maintenance of 4.13 g/BW$^{0.75}$/d.

To convert the net protein for the metabolizable protein required for maintenance, the BR-CORTE (2006) utilized the factor of 0.667, obtained from the relationship between retained nitrogen and absorbed nitrogen (Figure 8.3), which is close to the recommendation of the NRC (1985) of 0.67. Utilizing this efficiency and considering the net protein required for maintenance of 2.69 g/BW$^{0.75}$, the metabolizable protein required for maintenance was estimated as 4.03 g/BW^{0,75}. Thus, the BR-CORTE (2006) recommended the use of 4 g/BW$^{0.75}$/d as the metabolizable protein required for maintenance (MPm).

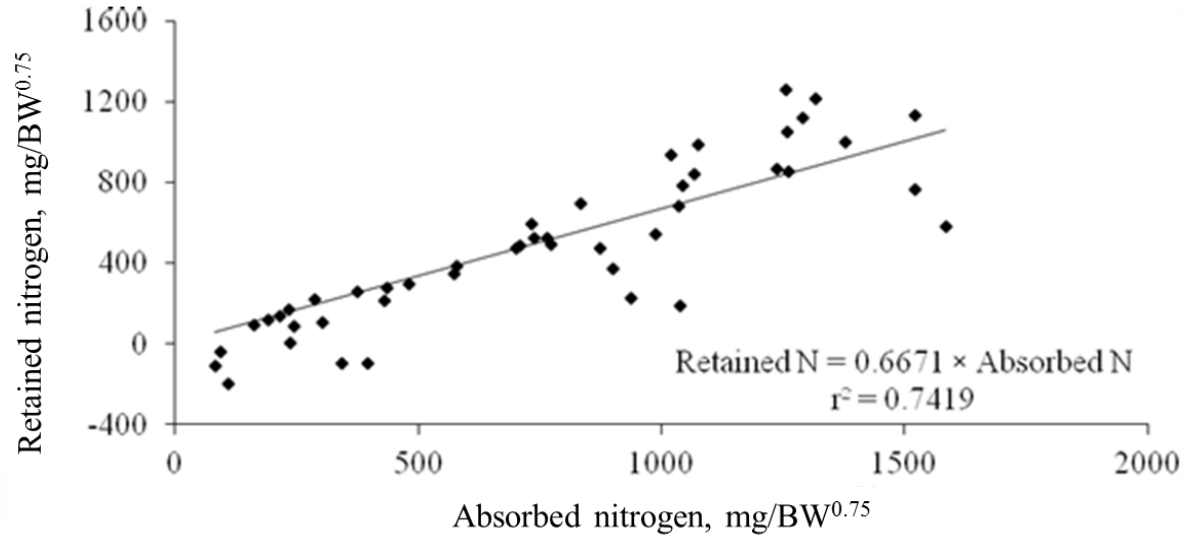

Figure 8.3 - Relationship between retained nitrogen and absorbed nitrogen. Adapted of Véras et al. (2007).

The NRC (2000) adopted the value of 3.8 g/$BW^{0.75}$, obtained by Wilkerson et al. (1993), as the metabolizable protein required for maintenance. This value was calculated by the division of the intercept (242) of the regression between metabolizable protein intake (g/d) and average daily gain (kg/d) of the animals, by the average of metabolic body weight of the animals (63.44) utilized in the database, 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. However, the BCNRM (2016) recommends for MPm the value of 3.8 g/$SBW^{0.75}$.

However, the second edition of the BR-CORTE, in 2010, correlated metabolizable protein intake (MPI) with avarage daily gain and empty body gain to estimate the metabolizable protein required for maintenance. The two equation estimated MPm values close to that proposed in the first edition of the BR-CORTE as 4.0 g/$BW^{0.75}$, and this value was maintained by the BR-CORTE (2010).

Initially, to convert crude protein intake for metabolizable protein intake of the database, the microbial crude protein synthesis (MCP) 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 to be known, the requirements of rumen degradable protein (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 was considered in the rumen. Then, the requirements of RDP (g/d) were calculated as 1.11 × MCP. In this edition, the inefficiency of this process, represented by the factor 1.11, was removed (for more details, see section "Considerations regarding to nitrogen compound recycling"); thereby, the requirements of RDP are equal to MCP. Additionally, the RUP intake was estimated by the difference of crude protein and RDP intakes. Therefore, the metabolizable protein intake (MPI) is obtained from the following equation:

$$MPI = (MCP \times 0.64) + (RUP/0.80).$$

In this edition, the same methodology of the BR-CORTE (2010) to estimate MPm correlating MPI and empty body gain was used. After evaluations, the effect of production system was observed, suggesting that MPm must be estimated separately for pasture and feedlot. Moreover, effects of genetic group and sex were tested for animals raised in feedlot and none effect was observed, allowing the development of only one equation for animals raised in feedlot (Figures 8.4 and 8.5; Table 8.5).

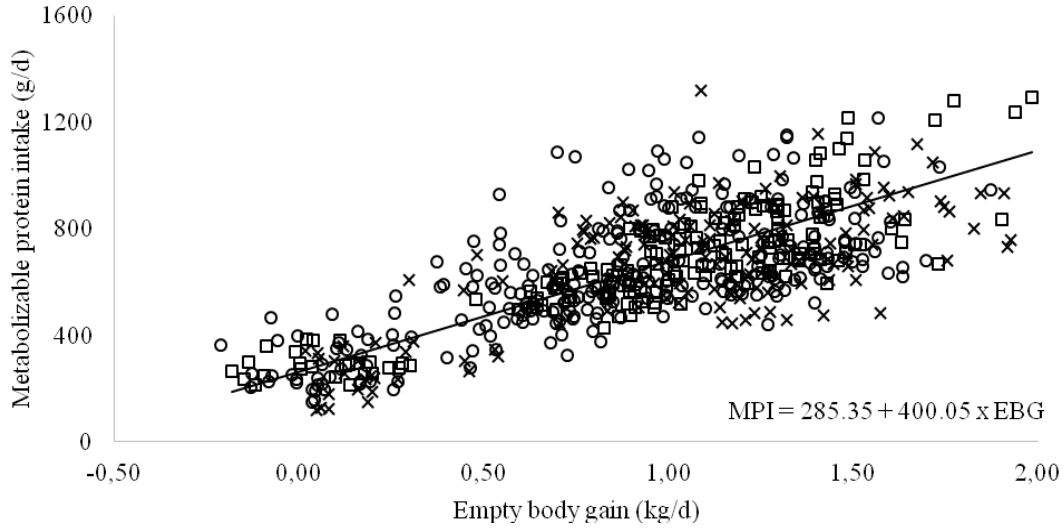

Figure 8.4 - Relationship between metabolizable protein intake and empty body gain of animals raised in feedlot. Symbols represent data from Zebu cattle (○), beef crossbred cattle (□), and dairy crossbred cattle (×).

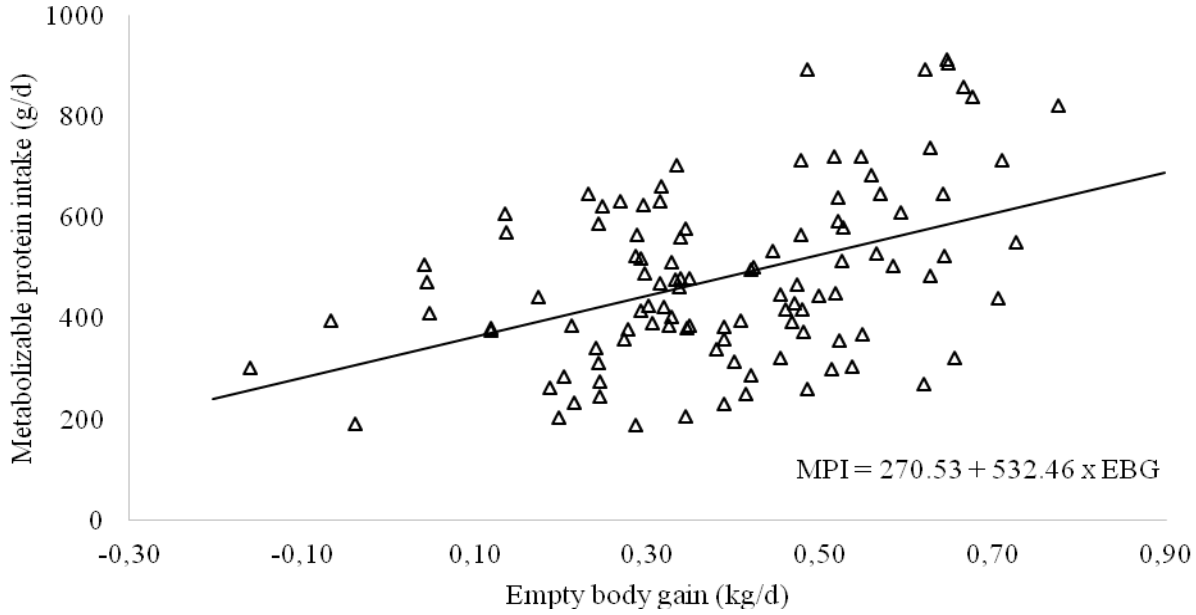

Figure 8.5 - Relationship between metabolizable protein intake and empty body gain of animals raised on pasture

Table 8.5 - Metabolizable protein required for maintenance of beef cattle raised on pasture and feedlot

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 last edition of 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 this edition (3.96 g/EBW$^{0.75}$) for cattle raised in feedlot. For pasture, the value estimated in this edition for MPm was 4.31 g/EBW$^{0.75}$, which was lower than that in the last edition of the BR-CORTE (2010; 4.87 g/EBW$^{0.75}$). In both cases, converting these values for shrunk body weight, the estimates are 3.6 and 3.9 g/SBW$^{0.75}$ for animals raised in feedlot and pasture, respectively. The value obtained for animals raised in feedlot was lower than those of the BCNRM (2016) and the BR-CORTE (2010) values of 3.8 g/SBW$^{0.75}$ and 4.0 g/BW$^{0.75}$, respectively.

Comparing the metabolizable protein required for maintenance of animals raised in feedlot and those raised on pasture, we noticed that these last ones were more demanding (8.0%) than animals raised in feedlot.

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 a 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 phase. The NRC (2000) reported that body fat and protein contents present quadratic behavior in relation to body weight with inverse relationships: as body weight increases, fat content increases and protein content decreases.

The proportion and rate of tissues deposition in the body influences growth, body composition, and feed efficiency (Shahin et al., 1993), and, consequently, the nutrient requirements. The proportions of tissues and their chemical compositions are influenced by several factors, such as body weight, age, breed, energy intake and sex (Ferreira et al., 1999). According to Garret (1980), breed would have greater influence on body composition at the same body weight than the nutritional level.

Differences in the protein required for growth are attributed to variations in composition of body gain (Garret et al., 1959; Geay, 1984). Protein required for growth are greater for late-maturity bulls than early-maturity steers (Geay, 1984). Boin (1995) observed greater protein content per kilogram of empty body gain for Nellore bulls in relation to Nellore steers. According to Geay (1984), the net protein requirements tend to be less important compared to those 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 amino acids from microbial fermentation (Geay, 1984). The majority of studies indicate reduced net protein required for growth as body weight 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 the BR-CORTE, in 2006, the net protein required for growth (NPg) was estimated from regression equations of retained protein (RP) and average daily gain (ADG), and three equations were obtained as a function of sex for Zebu cattle raised in feedlot. In the second edition of the BR-CORTE, in 2010, a model similar to that proposed by the NRC (2000) was utilized which RP was correlated with retained energy and the empty body gain.

In this edition, the same model utilized in the previous edition was used, where equations of net protein required for growth (Table 8.6) were obtained as a function of production system (feedlot and pasture), genetic group (Zebu, beef crossbred, and dairy crossbred cattle) and sex (bulls, steers, and heifers).

As obtained in the previous edition of the BR-CORTE, the equations indicate greater coefficients of EBG for bulls in relation to steers and heifers, evidencing the anabolic effect of testosterone on protein deposition. Thus, bulls present greater growth potential but also greater requirements of NPg. For Zebu cattle, lower values of NPg

were observed for steers than heifers, probably due to the lower empty body weight and fat content in heifers.

Grazing animals presented lower estimates of NPg for the same EBG and RE in comparison with animals raised in feedlot of the same sex and genetic group (Zebu bulls). Furthermore, in the database of this edition, animals raised on pasture were slaughtered with lower body weight, and the average of metabolic body weight was 53.9 kg, while for animals raised in feedlot, this value was 71.9 kg, showing that there is the need of more studies with heavier animals raised on pasture.

Table 8.6 – Equations used to estimate net protein required for growth of animals raised on pasture and in feedlot of different genetic groups and sex

System	Genetic group	Sex	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
	Beef crossbred 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
	Dairy crossbred 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).

Efficiency of the use of metabolizable protein

To convert the net protein requirements to metabolizable protein requirements, the partial efficiency of the use of metabolizable protein for growth (*k*) must be estimated. The metabolizable protein contain the digestible rumen undegradable protein (dRUP) and the digestible true microbial crude protein (dtMCP) which represents the amount of amino acids that reach small intestine to be absorbed.

Among the international systems for nutrient requirements of beef cattle, the NRC (1984) reported the mean biological value of amino acids absorbed by cattle as 66%, a value obtained by Zinn and Owens (1983). Then, based in this study and others, the NRC (1985) adopted values of 50 and 65% for the efficiency of the use of metabolizable protein for growth (*k*), being these values based on the biological value of protein and on the value of an ideal mixture of amino acids (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 amino acids. 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 amino acids 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 of the mixed quality of amino acids in the dRUP and the proportion between dRUP and dtMCP that reaches 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 amino acids from microbial crude protein, the biological value of the microbial crude protein is high, and therefore, the proportion of microbial crude protein that reaches small intestine could alter the efficiency of the use of metabolizable protein (NRC, 2000). However, the French system (INRA, 1988) considers that as body weight increases, efficiency 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, and NRC (2000) adopted the equation 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 300 kg 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 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 report values of efficiency of the use of MP for growth 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 (2014) and Silva (2015) obtained values of *k* equal to 29.7 and 25.2% for Holstein × Zebu steers and heifers, respectively. Several factors such as age, body composition, and feeding condition can affect the efficiency of the use of protein for growth (Blaxter et al., 1966; Garrett, 1980; Gionbelli et al., 2012, Marcondes et al., 2013).

The first edition of the BR-CORTE, in 2006, utilized the recommendations of the NRC (2000) for *k*, which the value of *k* was considered the slope obtained from the regression between retained protein and MPI. Notably, the BR-CORTE (2010) evaluated protein retained (RP) as a function of MPI (Figure 8.6) and found no effect of genetic group or sex on *k*, and the equation adopted was:

$RP = -2.223 + 0.4691 \times MPI$,

where RP is the retained protein (g/EBW$^{0.75}$) and MPI is the metabolizable protein intake (g/EBW$^{0.75}$).

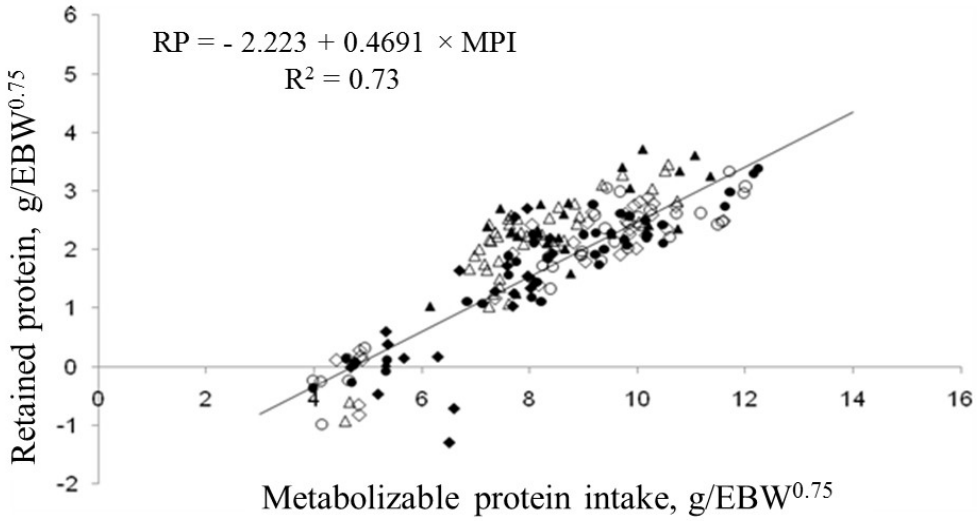

Figure 8.6 - Relationship between retained protein and metabolizable protein intake. Symbols represent data from bulls (▲, Δ), steers (◊, ♦), and heifers (○, ●). Solid points represent Nellore and empty point represent crossbred Bos indicus × Bos taurus cattle.

From this equation, the efficiency of the use of MP for growth was 46.9% for Zebu and crossbred cattle. This value is close to that recommended by the NRC (2000) of 49.2%. In the previous edition of the BR-CORTE, the same efficiency used for animals raised in feedlot were adopted for grazing animals due to few amount of data available.

In this edition of the BR-CORTE, a similar equation was adjusted; the value obtained was 47.4% (Figure 8.7) for animals raised on pasture and in feedlot. Also, the amount of data from animals raised on pasture was little which avoid us the evaluation of the effect of production system on *k*.

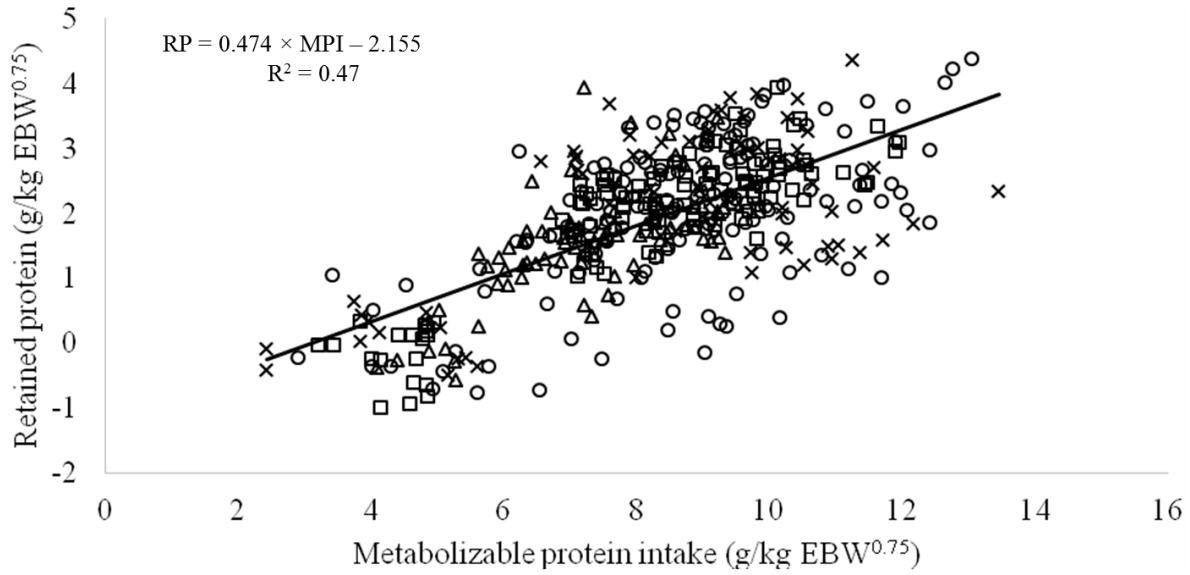

Figure 8.7 - Relationship between retained protein (RP) and metabolizable protein intake (MPI) of animals raised in feedlot. Symbols represent data from Zebu cattle (○), beef crossbred cattle (□), dairy crossbred cattle (×), and animals raised on pasture (Δ).

The majority of the nutrient requirement systems (CSIRO, 2007; NRC, 2000; AFRC, 1993; INRA, 1988) report that the use of a constant efficiency does not represent the real efficiency of the animals. The efficiency of the use of MP for growth seems to be more related to metabolizable protein composition that reaches the small intestine than EQEBW (Oldham,1987), as suggested by the INRA (1988).

In the last edition of the BR-CORTE (2010), an average efficiency of each experiment was estimated and these values were correlated with the mean EQEBW of each experiment to generate the equation to estimate *k*:

$$k\,(\%) = 84.665 - 0.1179 \times \text{EQEBW},$$

where EQEBW is the equivalent empty body weight.

The equation recommended in the previous edition was kept in this edition. However, in the last edition of the BR-CORTE (2010), the recommendation was this equation would be utilized for animals that present SBW < 350 kg. As the efficiency of the use of MP for growth increased for adult animals (46.9 vs. 47.4%), the new recommendation would be the use of this equation for animals with SBW < 340 kg. Therefore, considering an animal with 150 kg SBW, using the equation, the efficiency might be 67%. This value is close to that suggested by the equation of the NRC (2000) of 66%. Additionally, as the animal grows, the *k* decreases up to SBW equals to 340 kg. After this body weight, the efficiency might be constant and equal to 47.4%. The NRC (2000) considered the value of 49.2% as this efficiency for animals with body weight greater than 300 kg.

The microbial crude protein synthesis (MCP) was calculated by considering the recommendation presented in Chapter 3, where microbial synthesis was calculated as a function of crude protein intake (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 rumen degradable protein (RDP) were calculated from recommendations of this edition where microbial crude protein synthesis equals to RDP requirements:

$$\text{RDP} = \text{MCP},$$

while the requirements of rumen undegradable protein (RUP) were obtained by the following equation:

RUP = (Total metabolizable protein – (MCP × 0.64))/0.80.

To obtain crude protein requirements, RDP and RUP requirements should be added.

We highlight that the values used for microbial CP true digestibility and RUP digestibility in the small intestine were recently confirmed by Mariz (2016), that evaluating Nellore and Angus × Nellore cannulated bulls in the rumen and ileum, estimated MCP and RUP true digestibilities as approximately 80%.

CONSIDERATIONS REGARDING TO NITROGEN COMPOUND RECYCLING

The 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 (BCNRM, 2016) considers urea recycling for the rumen as:

$$N\ urea = (-0.1113 + 0.996 \times \exp^{(-0.0616 \times CP)}) \times (0.745 \times NI - 11.98),$$

where N urea = N recycled for rumen as urea (g/d); CP = dietary crude protein content (% DM); NI = nitrogen intake (g/d). Thereby, the BCNRM (2016) aims that the values of CP requirements would be closer than 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 previous edition of the BR-CORTE, nitrogen recycling was not considered in the calculations of protein requirements, which may have contributed to overestimation of the recommendation of crude protein in the diets of cattle.

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 total microbial N in the control diet was from urea recycling while in supplemented diets this incorporation was of 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 synthesis (MN) 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, the N recycling for rumen might contribute with 10 to 20% of microbial N, considering diets varying from 5 to 13% CP. These values are lower than those calculated by the equation suggested by the BCNRM (2016).

Therefore, the BR-CORTE (2016), while recognizing the importance of N recycling, also considers that only Batista et al. (2016) effectively measured urea recycling using animals fed low-quality forage and N infusions under tropical conditions. The committee therefore does not recommend any value for N recycling but, rather, suggests that if the user desires to compute N recycling, values from 5% to 10% for conventional diets would be reasonable. Thus, RDP requirements could be reduced by those values.

PRACTICAL EVALUATION OF CRUDE PROTEIN LEVELS IN DIETS OF BEEF CATTLE

Two studies were developed to evaluate the effect of reducing crude protein levels in the diets of beef cattle, with contemporary animals. In Study 1 (Amaral, work in progress), the animals were weaned and growing/finishing phase were conducted in feedlot. In Study 2

(Menezes et al., 2016), the animals were weaned, stocked on pasture for one year following a finishing phase in feedlot. In both experiments, levels of 10, 12, and 14% CP on DM basis were used.

Study 1

This study was consisted by three experimental periods. Two periods lasted 84 days each (representing growing phase) and the third period lasted 56 days (representing finishing phase). Bulls were divided in three groups, receiving diets with 10, 12, and 14% CP. Bulls fed 10 and 12% CP presented greater dry matter intake during the evaluated periods (Figure 8.8); however, bulls fed 14% CP had average daily gain (ADG) equal to bulls fed 12% CP in the two first evaluation periods (Figure 8.9) and greater than those fed 10% CP, while in the last period, all bulls had the same ADG.

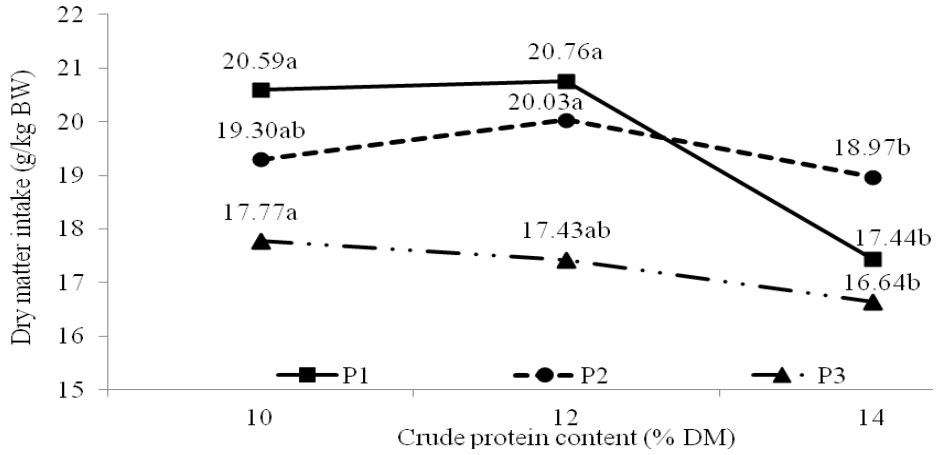

Figure 8.8 - Dry matter intake (g/BW) as a function of crude protein contents in diet and evaluation periods.

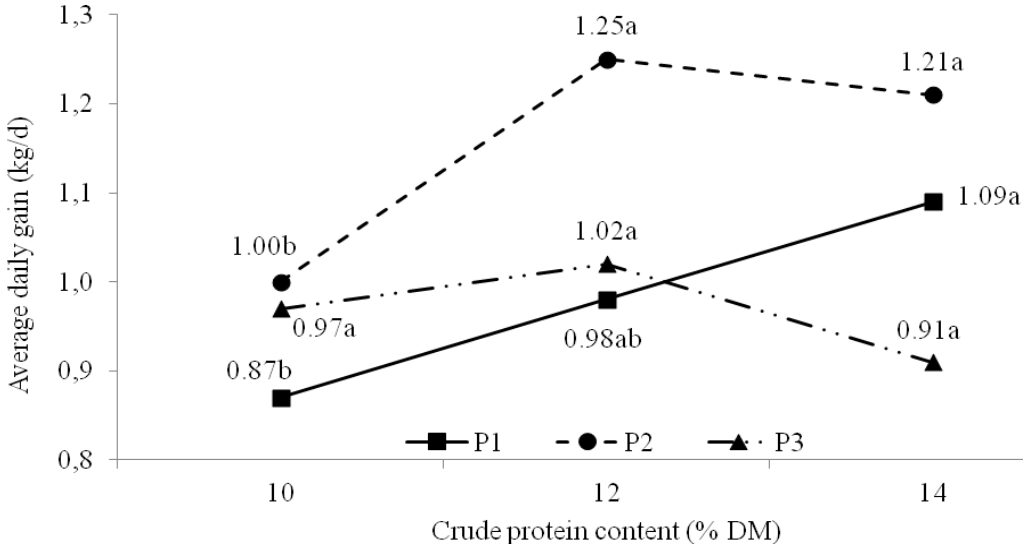

Figure 8.9 - Average daily gain (kg/d) as a function of crude protein content in diet and evaluation periods.

Considering the entire experimental period, dietary CP content did not affect ($P > 0.05$) final body weight or subcutaneous fat thickness. However, it did influence daily carcass gain, which was lower ($P < 0.05$) for diets with 10% CP. There was a difference among genetic groups for shrunk body weight (SBW), empty body weight (EBW), daily carcass gain (DCG) and subcutaneous fat thickness that were greater ($P < 0.05$) for crossbred cattle (Angus × Nellore)

than Nellore cattle. The greater final body weight of crossbred cattle can be explained by greater initial body weight and DCG.

Table 8.8 - Carcass characteristics of Nellore (N) and crossbred Angus x Nellore (AxN) cattle obtained with diets containing different crude protein content

Item	Crude protein content			Genetic group		*P*-value		
	10%	12%	14%	N	AxN	CP	GG	CP*GG
Initial SBW (kg)	218	214	226	213	226	0.08	<0.01	0.89
Final SBW (kg)	441	461	472	418	498	0.15	<0.01	0.20
EBW (kg)	408	429	433	388	459	0.17	<0.01	0.22
DCG[1] (kg/d)	0.61b	0.70a	0.70a	0.58	0.76	0.02	<0.01	0.16
Subcutaneous fat thickness (mm)	5.84	6.71	5.89	4.86	7.43	0.60	<0.01	0.51

[1]DCG = daily carcass gain.

This shows that calves that are weaned and thereafter finished in feedlot should receive diets with CP levels of approximately 12% during the initial growing phase. At the end of this period, or during the finishing phase, dietary CP content can be reduced to 10% of DM without affecting animal performance during this phase.

Study 2

In this experiment, contemporary Nellore animals from previous study were utilized, however, only in the finishing phase, being confined during 112 days, divided in the same diets of the previous study. However, Menezes et al. (2016) did not observe effect of CP levels on animal performance and carcass characteristics during evaluation period (Table 8.9).

Table 8.9 - Performance and carcass characteristics of finishing Nellore bulls fed three different crude protein content

Item	Crude protein content			SEM	Contrast	
	10%	12%	14%		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), crude protein levels influence the average daily gains of growing animals, although the same behavior is not observed for finishing animals. This occurs because protein requirements reduces as the animals reach maturity (NRC, 2000), when start depositing more fat, increasing fat:muscle ratio on animal carcass.

Nevertheless, Brazilian feedlot normally adopt CP levels ranging from 9.3 to 16.6%, with average values of 13.4% CP (Oliveira and Millen, 2014), because higher CP levels stimulate intake and are related to high weight gain (Véras et al., 2007). However, Menezes et al. (2016) showed that dry matter intake is not affected by dietary protein levels and the reduction of CP contents during finishing phase contributes to reduction of feeding costs. According to these authors, the excessive CP intake 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 finishing phase, which generates reduction on feeding costs.

Based on these experiments, the BR-CORTE (2016) suggests that if the aim is to produce very early animals, the adoption of different CP contents during the growing and finishing phases can reduce production costs and thus increase system profitability. During the finishing phase, which animals started with 330 kg BW in the experiments by Menezes et al. (2016), no difference in animal performance among Nellore bulls fed diets containing 10, 12 or 14% CP were detected.

TABLES OF PROTEIN REQUIREMENTS

In Tables 8.10 and 8.11, the equations used to estimate protein requirements for Zebu, beef crossbred, and dairy crossbred cattle are presented for different sexes, raised in feedlot or pasture.

In Tables 8.12, 8.13, and 8.14, protein requirements are shown for Zebu, beef crossbred, and dairy crossbred cattle, respectively, as a function of sex, and for different body weight and body weight gain rates. Moreover, in Table 8.15, protein requirements are presented for animals raised on pasture for different body weights and body weight gain rates.

Table 8.10 - Summary of equations utilized to convert body weight and average daily gain for empty body weight and empty body gain of Zebu, beef crossbred, and dairy crossbred cattle from three sexes, raised in feedlot or pasture

Item	System	Genetic group	Sex	Equations	Unit
SBW		Zebu cattle		$0.8800 \times BW^{1.0175}$	kg
		Crossbred cattle		$0.9664 \times BW^{1.0017}$	
EBW	Feedlot	Zebu cattle	Bulls	$0.8126 \times SBW^{1.0134}$	kg
			Steers	$0.6240 \times SBW^{1.0608}$	
			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	
		Beef crossbred cattle	Bulls	(EBW/560) × 517	
			Steers	(EBW/482) × 517	
			Heifers	(EBW/417) × 517	
		Dairy crossbred cattle	Bulls	(EBW/616) × 517	
			Steers	(EBW/532) × 517	
			Heifers	(EBW/493) × 517	

Table 8.11 - Summary of equations utilized to estimate protein requirements for Zebu, beef crossbred and dairy crossbred cattle of three different sexes raised in feedlot or pasture

Item	System	Genetic group	Sex	Equations	Unit
MPm	Feedlot Pasture			$3.6 \times SBW^{0.75}$ $3.9 \times SBW^{0.75}$	g/d
RE				$0.061 \times EQEBW^{0.75} \times EBG^{1.035}$	Mcal/d
NPg	Feedlot	Zebu cattle	Bulls	$210.09 \times EBG - 10.01 \times RE$	g/d
			Steers	$153.13 \times EBG - 2.53 \times RE$	
			Heifers	$193.90 \times EBG - 12.16 \times RE$	
		Beef crossbred	Bulls	$281.77 \times EBG - 27.66 \times RE$	
			Steers	$219.94 \times EBG - 12.04 \times RE$	
			Heifers	$174.65 \times EBG - 3.14 \times RE$	
		Dairy crossbred	Bulls	$171.43 \times EBG - 3.08 \times RE$	
			Steers	$236.36 \times EBG - 19.84 \times RE$	
			Heifers	$206.58 \times EBG - 15.39 \times RE$	
	Pasture			$181.43 \times EBG - 2.88 \times RE$	
k				SBW < 340 kg: $84.665 - 0.1179 \times EQEBW$ SBW > 340 kg: 47.4	%
MPg				NPg/k	g/d
MPtotal				MPm + MPg	g/d
MCP				$- 53.07 + 304.9 \times CPI + 90.8 \times NDTI - 3.13 \times NDTI^2$	g/d
RDP				MCP	g/d
RUP				$(MPt - (MCP \times 0.64))/0.80$	g/d
CP				RDP + RUP	g/d

Thus, considering a 400 kg Nellore bull gaining 1 kg/d raised in feedlot:

- $SBW = 0.88 \times BW^{1.0175} = 0.88 \times 400^{1.0175} = 390.9$ kg
- $EBW = 0.8126 \times SBW^{1.0134} = 0.8126 \times 390.9^{1.0134} = 344.1$ kg
- $EBG = 0.963 \times ADG^{1.0151} = 0.963 \times 1.0^{1.0151} = 0.96$ kg/d
- $EQEBW = (EBW/517) \times 517 = (344.1/517) \times 517 = 344.1$ kg
- $MPm = 3.6 \times SBW^{0.75} = 3.6 \times 390.9^{0.75} = 316$ g/d
- $RE = 0.061 \times EQEBW^{0.75} \times EBG^{1.035} = 0.061 \times 344.1^{0.75} \times 0.96^{1.035} = 4.69$ Mcal/d
- $NPg = 210.09 \times EBG - 10.01 \times RE = 210.09 \times 0.96 - 10.01 \times 4.69 = 155.4$ g/d
- $k = 47.4\%$
- $MPg = NPg/k = 155.4/0.474 = 328$ g/d
- MP total = MPm + MPg = 316 + 328 = 644 g/d
- $MCP = - 53.07 + 304.9 \times CPI + 90.8 \times TDNI - 3.13 \times TDNI^2 = - 53.07 + 304.9 \times 0.929 + 90.8 \times 5.21 - 3.13 \times 5.21^2 = 618$ g/d
- RDP = MCP = 618 g/d
- $RUP = [MPt - (MCP \times 0.64)]/0.80 = [644 - (618 \times 0.64)]/0.80 = 311$ g/d
- CP = RDP + RUP = 618 + 311 = 929 g/d

For beef crossbred cattle, considering a 400-kg bull gaining 1.0 kg/d raised in feedlot:

- $SBW = 0.9664 \times BW^{1.0017} = 0.9664 \times 400^{1.0017} = 390.5$ kg
- $EBW = 0.7248 \times SBW^{1.0314} = 0.7248 \times 390.5^{1.0314} = 341.4$ kg
- $EBG = 0.963 \times ADG^{1.0151} = 0.963 \times 1.0^{1.0151} = 0.96$ kg/d
- $EQEBW = (EBW/560) \times 517 = (341.4/560) \times 517 = 315.2$ kg

• MPm = $3.6 \times SBW^{0.75} = 3.6 \times 390.5^{0.75} = 316.3$ g/d
• RE = $0.061 \times EQEBW^{0.75} \times EBG^{1.035} = 0.061 \times 315.2^{0.75} \times 0.96^{1.035} = 4.39$ Mcal/d
• NPg = 281.77 × EBG – 27.66 × RE = 281.77 × 0.96 – 27.66 × 4.39 = 150 g/d
• k = 47.4%
• MPg = NPg/k = 150/0.474 = 316.4 g/d
• MP total = MPm + MPg = 316.3 + 316.4 = 633 g/d
• MCP = $- 53.07 + 304.9 \times CPI + 90.8 \times TDNI – 3.13 \times TDNI^2 = - 53.07 + 304.9 \times 0.912 + 90.8 \times 5.10 – 3.13 \times 5.10^2 = 606$ g/d
• RDP = MCP = 606 g/d
• RUP = [MPt – (MCP × 0.64)]/0.80 = [632 – (606 × 0.64)]/0.80 = 306 g/d
• CP = RDP + RUP = 606 + 306 = 912 g/d

Table 8.12 - Protein requirements for Zebu cattle of different sexes, body weights, and body weight gain rates

Requirements	Body weight (kg)											
	300			350			400			450		
ADG (kg/d)	0.50	1.00	1.50	0.50	1.00	1.50	0.50	1.00	1.50	0.50	1.00	1.50
DMI (kg/d)	5.61	6.96	7.86	6.30	7.65	8.54	6.96	8.31	9.21	7.60	8.95	9.85
Bulls												
MPm (g/d)		254			286			316			346	
NPg (g/d)	82.0	165	248	79.7	160	241	77.5	155	234	75.3	151	227
MPg (g/d)	150	302	455	168	338	507	163	328	493	159	318	478
MPt (g/d)	404	556	709	454	623	793	480	644	809	505	665	824
RDP (g/d)	389	527	658	435	583	723	471	618	757	504	651	788
RUP (g/d)	194	274	359	219	313	413	223	311	406	228	310	400
CP (g/d)	583	801	1018	654	896	1,136	694	929	1,163	732	961	1,188
Steers												
MPm (g/d)		254			286			316			346	
NPg (g/d)	67.7	137	206	67.0	135	204	66.3	134	202	65.7	132	199
MPg (g/d)	140	282	425	141	285	430	140	282	425	139	279	421
MPt (g/d)	394	536	679	427	571	716	456	599	742	485	625	767
RDP (g/d)	392	532	665	434	578	712	472	618	753	508	656	790
RUP (g/d)	179	244	317	187	251	324	193	254	325	199	257	326
CP (g/d)	571	776	981	621	829	1,037	665	872	1,078	708	913	1,117
Heifers												
MPm (g/d)		254			286			316			346	
NPg (g/d)	65.4	131	196	61.8	123	185	58.3	116	174	54.9	109	163
MPg (g/d)	145	290	434	130	260	390	123	245	367	116	230	344
MPt (g/d)	399	544	688	416	546	676	440	562	683	462	576	690
RDP (g/d)	399	544	679	435	577	707	471	612	741	506	646	771
RUP (g/d)	180	245	318	173	222	279	173	212	261	173	204	246
CP (g/d)	578	788	996	607	798	986	644	824	1,002	679	850	1,017

Table 8.13 - Protein requirements for beef crossbred cattle of different sexes, body weights and body weight gain rates

Requirements	Body weight (kg)											
	300			350			400			450		
ADG (kg/d)	0.50	1.00	1.50	0.50	1.00	1.50	0.50	1.00	1.50	0.50	1.00	1.50
DMI (kg/d)	5.81	7.28	8.45	6.38	7.85	9.02	6.93	8.40	9.57	7.46	8.93	10.1
Bulls												
MPm (g/d)		255			286			316			346	
NPg (g/d)	87.4	174	261	81.4	162	242	75.7	150	224	70.1	138	206
MPg (g/d)	153	305	457	172	342	510	160	316	472	148	292	434
MPt (g/d)	408	560	712	458	628	796	476	633	788	493	637	780
RDP (g/d)	388	524	653	433	579	717	464	606	740	494	632	761
RUP (g/d)	200	281	367	226	322	422	223	306	393	222	291	366
CP (g/d)	587	805	1,020	659	900	1,139	688	912	1,133	715	923	1,127
Steers												
MPm (g/d)		255			286			316			346	
NPg (g/d)	81.8	164	247	78.8	158	237	75.9	152	228	73.1	146	219
MPg (g/d)	156	314	472	166	333	501	160	321	481	154	308	462
MPt (g/d)	411	569	727	452	619	787	476	637	798	500	654	808
RDP (g/d)	395	539	675	438	588	730	473	622	762	506	654	792
RUP (g/d)	198	280	368	215	304	399	217	298	387	220	294	376
CP (g/d)	593	819	1,043	653	892	1,129	690	921	1,149	726	948	1,168
Heifers												
MPm (g/d)		255			286			316			346	
NPg (g/d)	76.4	154	232	75.6	152	230	74.7	151	227	73.9	149	224
MPg (g/d)	164	331	498	159	321	484	158	318	479	156	314	473
MPt (g/d)	419	585	753	445	607	770	474	634	795	501	659	818
RDP (g/d)	406	559	703	445	598	743	482	637	782	517	674	818
RUP (g/d)	198	285	379	201	281	369	207	282	368	213	285	369
CP (g/d)	605	844	1,082	646	879	1,111	689	920	1,150	730	959	1,187

Table 8.14 - Protein requirements for dairy crossbred cattle of different sexes, body weights, and body weight gain rates

Requirements	Body weight (kg)											
	300			350			400			450		
ADG (kg/d)	0.50	1.00	1.50	0.50	1.00	1.50	0.50	1.00	1.50	0.50	1.00	1.50
DMI (kg/d)	5.21	6.75	7.80	5.96	7.49	8.55	6.68	8.21	9.27	7.37	8.91	9.96
Bulls												
MPm (g/d)		260			291			322			352	
NPg (g/d)	76.8	155	234	76.2	154	232	75.6	153	230	75.0	151	228
MPg (g/d)	153	309	466	161	324	489	160	322	485	158	319	481
MPt (g/d)	413	569	726	452	616	780	482	644	807	510	671	833
RDP (g/d)	384	519	648	426	566	699	462	603	737	496	638	772
RUP (g/d)	209	296	389	225	317	416	232	322	419	240	328	423
CP (g/d)	593	815	1037	650	883	1,115	694	925	1,156	737	966	1,196
Steers												
MPm (g/d)		260			286			316			346	
NPg (g/d)	77.4	155	232	72.9	145	217	68.5	136	203	64.2	127	190
MPg (g/d)	140	280	419	154	307	459	144	287	429	135	268	400
MPt (g/d)	399	539	679	440	593	745	461	603	745	481	614	746
RDP (g/d)	384	517	643	427	568	701	461	600	729	493	630	755
RUP (g/d)	192	260	334	208	286	370	207	274	348	206	264	328
CP (g/d)	576	777	977	635	854	1,071	668	874	1,078	700	893	1,084
Heifers												
MPm (g/d)		255			286			316			346	
NPg (g/d)	77.2	156	235	76.5	154	232	75.7	153	230	75.0	151	228
MPg (g/d)	147	297	447	161	325	490	160	322	485	158	319	480
MPt (g/d)	402	552	702	447	611	776	476	638	802	504	664	826
RDP (g/d)	390	530	663	436	585	725	474	624	764	509	660	800
RUP (g/d)	190	265	348	210	296	391	216	299	391	222	302	392
CP (g/d)	580	796	1010	646	881	1,115	690	923	1,155	731	962	1,192

Table 8.15 - Protein requirements for Zebu cattle raised on pasture of different sexes, body weights, body weight gain rates

Requirements	Body weight (kg)											
	300			350			400			450		
ADG (kg/d)	0.50	1.00	1.50	0.50	1.00	1.50	0.50	1.00	1.50	0.50	1.00	1.50
DMI (kg/d)	5.24	6.11	7.76	6.11	7.13	9.05	6.98	8.15	10.3	7.85	9.17	11.6
MPm (g/d)		254			286			316			346	
NPg (g/d)	81.3	164	247	80.7	163	245	80.1	162	244	79.5	160	242
MPg (g/d)	147	296	447	170	344	518	169	341	514	168	338	510
MPt (g/d)	401	551	701	456	629	804	485	657	830	514	684	856
RDP (g/d)	374	477	587	423	539	663	459	579	706	494	617	746
RUP (g/d)	202	307	407	232	355	474	239	358	473	247	362	473
CP (g/d)	576	783	994	655	895	1,137	699	937	1,179	741	979	1,219

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9

Mineral requirements for beef cattle

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INTRODUCTION

Minerals are present in variable amounts and proportions in all feeds and animal tissues (Underwood, 1981). The prominence of each mineral is closely related to its functional role. There are 22 essential minerals that are known to provide specific functions in the body and are necessary for animal (McDonald et al., 2002): calcium (Ca), phosphorus (P), potassium (K), sodium (Na), chlorine (Cl), magnesium (Mg), and sulfur (S), which are considered macrominerals; and 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), which are considered microminerals (Spears and Kegley, 2002). Due to their concentration, macrominerals are expressed as g/kg of animal tissue and microminerals as 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. Erickson (1999) studied two levels of calcium in the diet (0.35 and 0.70%) and showed animals fed at 0.70% had lower performance. Thus, ensuring adequate mineral nutrition is fundamental to optimize animal performance and avoid contamination of soil and water, resulting from mineral excretion into the environment via feces and urine. Fundamentally, minerals have five 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 microminerals. The regulation of lipid metabolism and synthesis by Cu and spermatogenesis by Zn are 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 when 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 replace minerals lost to milk yield, for example (Suttle, 2010). The feedstuffs, commonly fed to beef cattle, can provide these 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 microminerals, and protein-energy supplements fortified with microminerals.

Factorial models are the most common methods used to predict the mineral dietary requirements of cattle (ARC, 1980). The dietary requirement for each mineral is predicted as the sum of the net mineral required for maintenance and production divided by the absorption coefficient of each mineral, in the gastrointestinal tract of the animal, to allow for the inefficient use of dietary mineral supply. However, not all

mineral absorbed by the animal has function in the body, being excreted via urine. Thus, using the absorption coefficient does not seem to be the most suitable, but the true retention coefficient, which considers mineral losses in the 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, the knowledge about the bioavailability, or proportion of the mineral released during digestion of the feed, enabling its absorption and use, is required. Additionally, differences exist between feeds produced in tropical and temperate regions, regarding mineral release in animals. Hence, dietary requirements are needed to validate factorial-derived requirements.

This chapter discusses the dietary requirements of macrominerals (Ca, P, Mg, Na, K, and S) and microminerals (Co, Cr, Cu, Fe, Mn, Mo, Se, and Zn) for maintenance as well as the true retention coefficient of each mineral, using a database developed by researches conducted in Brazil. Also, equations to estimate the net requirements for weight gain (NRG) will be presented from a database of animals raised under tropical conditions. Finally, tables of dietary macromineral and micromineral requirements will be presented for beef cattle.

DIETARY MINERAL REQUIREMENTS

Mineral requirements for maintenance include those needed to support normal 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 for external losses and normal animal movements. These requirements are related to the needs of the animal whilst 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 few available studies present variable results, hence, it has not been possible to establish their precise recommendations for cattle raised under Brazilian conditions. The BR-CORTE is an online software (www.brcorte.com.br/en) that optimizes the diets for beef cattle under tropical conditions. In the BR-CORTE (2010), mineral requirements suggested for maintenance and their respective absorption coefficients, for both macrominerals and microminerals, were mainly based on ARC (1980) and NRC (2000) recommendations.

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 mineral recycling in the kidneys. However, Costa e Silva et al. (2015a) verified that some mineral losses via urine can reach 35% of the mineral intake and therefore should not be disregarded. These values enable the true retention coefficients for all minerals to be considered rather than their true 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 true 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:

$$RM = MI - MIf - MIu,$$

where RM is retained mineral, MI is mineral intake, MIf is mineral excreted via feces, and MIu 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 (work in progress). The minerals intake, and the mineral excretion in the feces and urine are presented in Tables 9.1 (macrominerals) and 9.2 (microminerals). This database included 325 observations; 181 bulls, 73 steers, and 71 heifers. The animals were from the following genetic groups: Nellore (n = 243), Holstein × Zebu (n = 46), Angus × Nellore (n = 18), and Simmental × Nellore (n = 18). A meta-analysis was used whereby sex (fixed effect), genetic group (fixed group), and study (random effect) were considered classificatory effects to evaluate differences for each mineral.

Table 9.1 - Descriptive statistics of data used to estimate the net macromineral (Ca, P, Mg, Na, K, and S; g/d) requirements for maintenance of beef cattle and their retention coefficients

Item	*n*	Mean	SD	Maximum	Minimum
Body weight (kg)	325	302	82.3	557	125
Calcium (g/d)					
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 (g/d)					
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 (g/d)					
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 (g/d)					
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 (g/d)					
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 (g/d)					
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.

However, only two studies (Costa e Silva et al., 2015a; Zanetti, work in progress) evaluated the net mineral requirement for maintenance and retention coefficient for S and microminerals, therefore, only the recommendations suggested by these authors will be used in this BR-CORTE edition (Table 9.2).

Table 9.2 - Descriptive statistics of data used to estimate the net micromineral (Cu, Fe, Mn, Se, Zn, Co, Cr, and Mo; mg/d) requirements for maintenance of beef cattle and their retention coefficients

Item	*n*	Mean	SD	Maximum	Minimum
Body weight (kg)	149	307	92.6	557	125
Copper (mg/d)					
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 (mg/d)					
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 (mg/d)					
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 (mg/d)					
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 (mg/d)					
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 (mg/d)					
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 (mg/d)					
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 (mg/d)					
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 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 β1 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 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 more mineral deposition in the body, hence, the 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 (2005), 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 (work in progress). The data used to estimate macromineral requirements for gain are shown in Table 9.3.

In the BR-CORTE (2010), two methods were suggested to estimate the NRGCa and NRGP: plateau quadratic and plateau power methods. In this BR-CORTE edition, these methods were tested and the plateau power method presented the best estimates (lower values of mean square of error of prediction, MSEP), and consequently it was chosen as the standard method to estimate NRGCa and NRGP. For NRGMg, NRGNa, and NRGK, the power method was used, but the plateau of deposition of these minerals was not estimated due to these minerals are more related to body fluid than deposition in bones and body tissues.

Due to the lack of literature data on the NRGS and NRG for microminerals (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 (work in progress; Table 9.4).

Table 9.3 - Descriptive statistics of data used to estimate the net macromineral (Ca, P, Mg, Na, and K) requirements for growth of beef cattle

Genetic group/system	Sex	*n*	Item	EBW	EBG	Ca (kg)	P (kg)	Mg (g)	Na (g)	K (g)
Zebu (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
Crossbreed (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
Zebu (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 included 823 animals; 411 bulls, 255 steers, and 157 heifers, from Zebu (n = 473) and crossbred cattle (n = 350). Meta-analysis was adopted and production system (feedlot and pasture), sex (bulls, steers, and heifers), genetic group (Zebu, beef crossbred, and dairy crossbred cattle) and study were considered random effects. For the macromineral (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 beef and dairy crossbred cattle for any of the minerals, so the data of beef and dairy crossbred cattle were combined. Thereby, the equations could be generated separately for Zebu and crossbred cattle when differences were observed in the macromineral (Ca, P, Mg, Na, and K) data, enabling the direct effect of genetic group to be observed.

Table 9.4 - Descriptive statistics of total contents of each mineral used to estimate the net S and micromineral (Co, Cr, Cu, Fe, Mn, Mo, Se, and Zn) requirements for 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
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
Fe (g)	87	31.2	22.2	78.5	7.02
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
S (g)	87	610	506	2,197	86
Zn (g)	87	20.4	20.2	65.0	2.17

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 macromineral (Ca, P, Mg, Na, and K) absorption coefficient data was based on literature studies (Table 9.5). 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 ARC (1980) for Mg, Na, and K.

Table 9.5 - True 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
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 BR-CORTE (2010) are in bold; [2]Experiments conducted in Brazil; [3] True 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 low relative to their intake, such as Ca (4.29%), P (4.33%), Cu (3.82%), Fe (3.59%), Mn (1.72%), Se (6.47%), and Zn (4.03%; Table 9.2). Nevertheless, the urinary

excretion of other minerals was considered high, such as Na (39.3%), S (34.8%), Mg (24.9%), K (30.3%), Co (14.6%), and Cr (14.6%). Hence, it is impractical to use the absorption coefficient to convert from the net to dietary requirements, for all minerals. Therefore, in this BR-CORTE edition, all 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; in the animal body, 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, heart beats regulation, hormonal secretion, and enzyme activation and stabilization (Lalman, 2005). Ruminants have low capacity to excrete Ca absorbed in excess to their needs, represented by low urinary Ca excretions, while fecal endogenous losses are constant, which indicates that absorption is regulated at an intestinal level (Field, 1983a). Indeed, Costa e Silva et al. (2015a) verified that only 3.85% 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 and 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; BCNRM, 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) suggests 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 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 26.5 mg/kg BW was the estimated net Ca requirement for maintenance. 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 9.1).

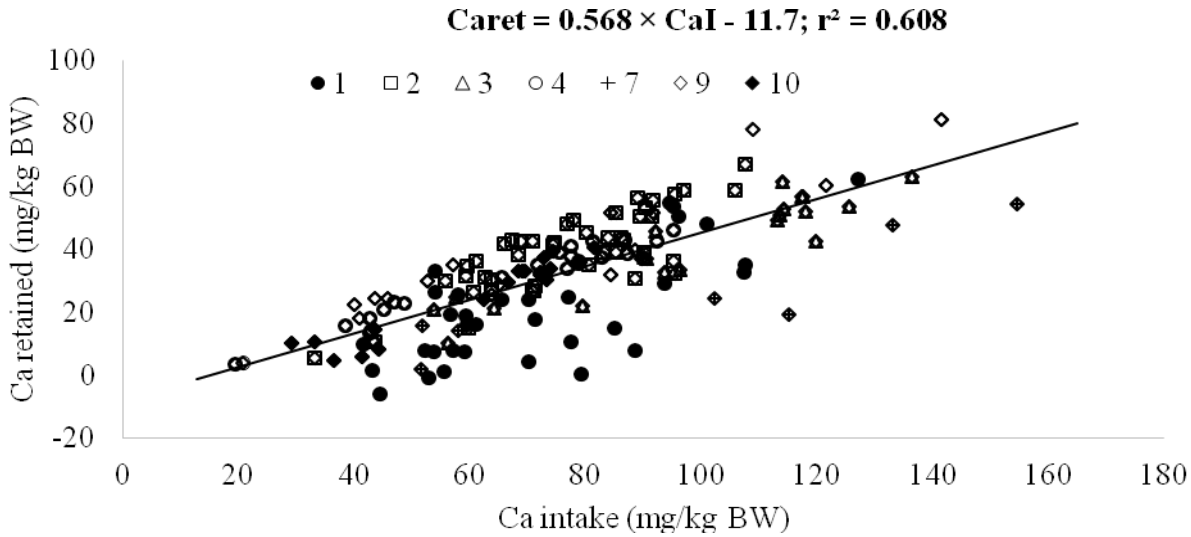

Figure 9.1 - Relationship between Ca retained (Caret) and Ca intake (CaI) in beef cattle. Costa e Silva et al. (2015a - 1 and 2), Zanetti (2014 - 3), Prados (2016 - 4), Gionbelli (2010 - 7), Prados (2012 - 9), Zanetti (work in progress - 10).

Based on the estimates in this BR-CORTE (2016) edition and the NRC (2000) recommendation, a 300 kg animal would require a respective 3.51 and 4.62 g/d for net Ca requirement for maintenance, respectively. Thus, the Ca required to compensate the endogenous losses was lower in BR-CORTE (2016). Hence, a decreased supply of this mineral to the animals should decrease fecal Ca excretions into 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 is 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 supplemental 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 the greatest Ca absorption occurring in the rumen while in the absence of an inorganic source, absorption of Ca occurs mostly in the small and large intestines.

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 cattle but verified differences between bulls and steers, with steers presenting lower NRGCa values. In contrast, Marcondes et al. (2009) did not find a sex effect on the NRGCa. Similarly, several nutrient requirements councils (AFRC, 1991; NRC, 2000; CSIRO, 2007) did not find effects of sex or genetic group on dietary Ca 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 9.6). Moreover, for all equations, a plateau at which the mineral deposited in the body becomes constant and the NRGCa value is equal to zero was calculated (Table 9.6).

Table 9.6 - Net Ca requirements 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] (g/d)
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 the 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 the plateau for protein, Ca and P deposition occurred at 450, 416 and 416 kg EBW for Nellore × Angus cattle. When the mineral requirements have been calculated as a function of protein deposition, they would have been overestimated for EBW between 416 and 450 kg. In 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 beef crossbred cattle). In this BR-CORTE edition, the inclusion of data for heavier animals resulted in better fit, differences among genetic groups were verified and a plateau for Ca deposition could be estimated for each genetic group (Table 9.6). Therefore, we suggest that the EBW at which there is no more Ca deposition would 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 requirement 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 bone concentrations. These authors concluded that lowering the Ca supply could decrease costs in feedlot operations and Ca excretion into the environment. Therefore, more studies that evaluate decrease Ca in cattle diets, to lessen 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 it is important for 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 saliva (ARC, 1965). Thereby, the net P requirements for maintenance have been calculated by the sum of fecal and urinary metabolic P excretions. The ARC (1980) suggest this value is 12 mg/kg BW. The AFRC (1991) calculated the net P requirement for maintenance from an equation based on studies in sheep, whereby metabolic P losses were calculated as a function of DMI. Furthermore, the NRC (2000) considers the net P requirement 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 9.2).

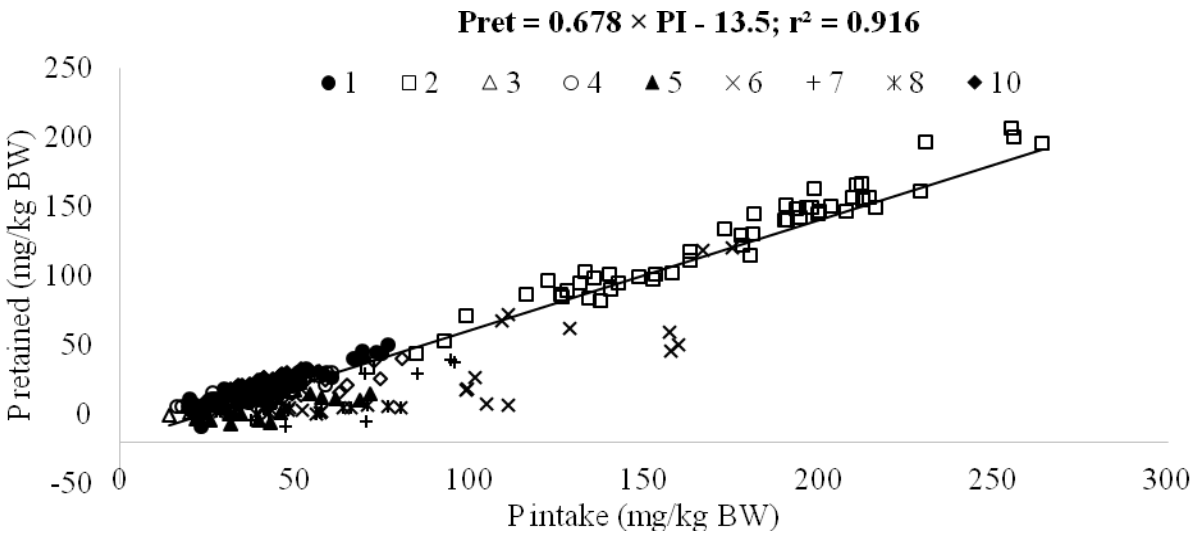

Figure 9.2 - Relationship between P retained (Pret) and P intake (PI) in beef cattle. Costa e Silva et al. (2015a - 1 and 2), Zanetti (2014 - 3), Prados (2016 - 4), Souza (2010 - 5), Marcondes (2010 - 6), Gionbelli (2010 - 7), Sathler (2015 - 8), Zanetti (work in progress - 10).

Sathler (2015) evaluated P absorption in diets with and without a supplemental inorganic P source (dicalcium phosphate) and observed that independent of the P supply, ruminal P absorption is negative due to P recycling via saliva that arrives in the rumen and is not considered as entrance into the system. Thus, there is a need to evaluate the amount of P that is recycled by saliva as a function of dietary P content. Furthermore, this author verified that 67.3 and 25.5% P intake is absorbed in the small and large intestines, respectively, being the main sites of P absorption. According to the NRC (2000), supplemental P sources can be ranked according to 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 which provided data for the estimates used in this BR-CORTE edition were based on dicalcium phosphate as the supplemental P source, 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 absorption coefficient.

The NRGP are presented in Table 9.7. The EBW at which there is no significant P increase was also estimated. As observed with Ca, studies of nutrient requirements did not consider the effects of sex or genetic group on dietary P requirements and this has been documented in 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 9.7). 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 an EBW of 445 and 479 kg, respectively.

Table 9.7 - Net P requirements for growth and plateau of P deposition as a function of genetic group (Zebu and crossbred cattle)

GG	Plateau	Body content (kg)	NRGP[2] (g/d)
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 P requirement for growth; EBW = empty body weight (kg); EBG = empty body gain (kg).

Current publications have addressed the need to decrease environment impacts caused by cattle P excretions (Vasconcelos et al., 2007; Costa e Silva et al., 2015b; Prados et al., 2015). Costa e Silva et al. (2015b) verified a 20% P decrease in the diet of Nellore steers and heifers did not impact on intake, nutrient digestibility or animal performance. Similarly, Prados et al. (2015) found that decreasing the BR-CORTE (2010) recommended dietary P requirements 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 the P requirements recommended by the NRC (2000). Call et al. (1978) fed beef heifers during a two-year period 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 excess dietary P is excreted in the feces. Furthermore, mineral nutrition of cattle is not fully understood and we recommend further studies in this area to obtain 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 recommend 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 increased metabolic excretion of P when Ca intake was low and suggested 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 from three sexes raised in a feedlot. Zanetti (work in progress) found the feeding behavior, nutrient intake and performance of Nellore bulls during growing and finishing phases was 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 respective fecal excretion, resulting in less environment impact.

In this BR-CORTE (2016), the average 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 bones while the remaining 30% is found in muscle and other soft tissues. Only 1% Mg is found in extracellular fluids. In the soft tissues, Mg is involved in energy metabolism, mainly through the Mg-ATP complex, maintenance of electric potential that affects intra and extracellular ionic gradients, and enzyme activation. The maintenance of ideal Mg concentrations is essential for its functions. According to the ARC (1980), endogenous Mg losses via urine are disregarded. However, from dataset used in this BR-CORTE edition, on average, 49.5% of the Mg intake (Table 9.1) was excreted in feces, while 24% was excreted via urine. Therefore, urinary excretion of Mg

should be considered to accurately estimate its true retention coefficient, which is 35.5 % (Figure 9.3). In comparison, the ARC (1980) and NRC (2000, 2001) considered absorption coefficients with lower mean values of 29.4% and 17%, respectively. The ARC (1980) and NRC (2001) suggested 3 mg/kg BW as the net Mg requirement for maintenance. However, this BR-CORTE edition shows the estimated net Mg requirement for maintenance is 5.9 mg/kg BW (Figure 9.3).

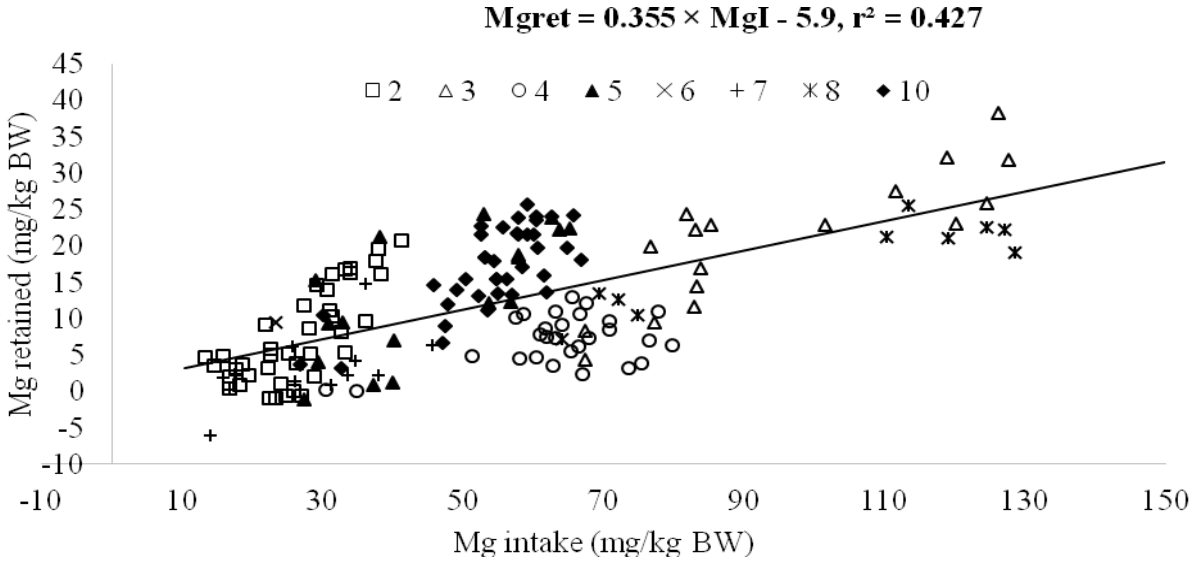

Figure 9.3 - Relationship between Mg retained (Mgret) and Mg intake (MgI) in beef cattle. Costa e Silva et al. (2015a - 2), Zanetti (2014 - 3), Prados (2016 - 4), Souza (2010 - 5), Marcondes (2010 - 6), Gionbelli (2010 - 7), Sathler (2015 - 8), Zanetti (work in progress - 10).

In the BR-CORTE (2010), the NRGMg values were estimated from the EBG. This BR-CORTE edition adopted the power model with the aim to standardize mineral requirements. Thus, the NRGMg were estimated and the effect of genetic group was observed (Table 9.8).

Table 9.8 - Net Mg requirements for growth as a function of genetic group (Zebu and crossbred cattle)

GG	Body content (g)	NRGMg[2] (g/d)
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 Mg requirement for growth; EBW = empty body weight (kg); EBG = empty body gain (kg).

Sodium

Among the ions that contribute to the osmotic balance, Na presents the greatest concentration. Moreover, Na contributes to muscle contraction, nerve impulse transmission, and nutrient (e.g. glucose) transport. The ARC (1980) suggests that dietary Na is uncomplexed 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, on average, 37.5 and 38.6% of the Na intake, respectively (Table 9.1). Based on this data, the net Na requirement for maintenance and the true retention coefficient of Na were estimated as 6.3 mg/kg BW and 37.1%, respectively (Figure 9.4). This net Na requirement 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), the Na losses

through 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 saliva.

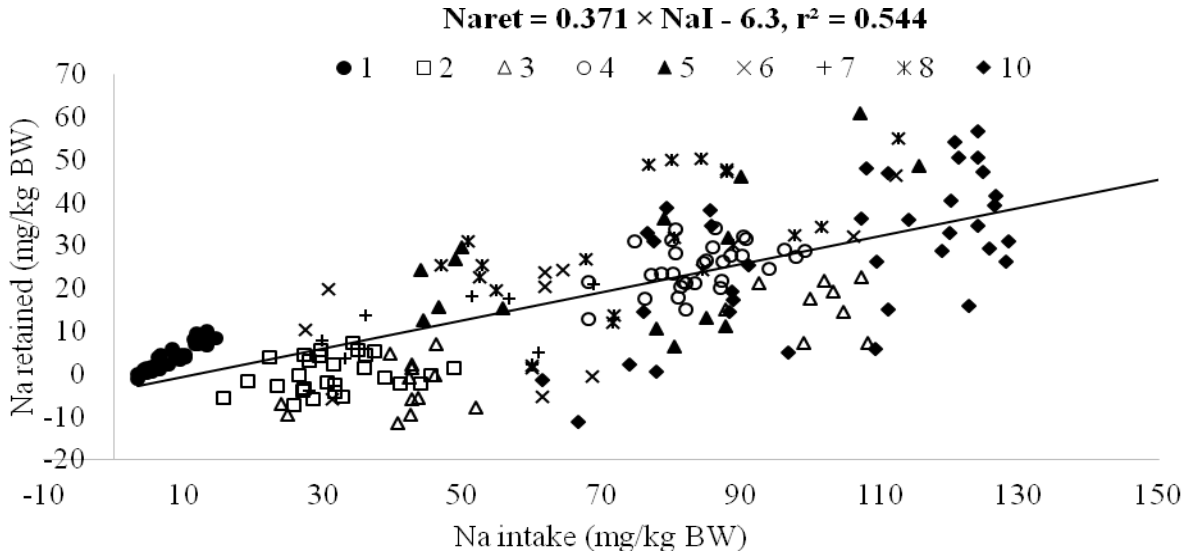

Figure 9.4 - Relationship between Na retained (Naret) and Na intake (NaI) in beef cattle. Costa e Silva et al. (2015a - 1 and 2), Zanetti (2014 - 3), Prados (2016 - 4), Souza (2010 - 5), Marcondes (2010 - 6), Gionbelli (2010 - 7), Sathler (2015 - 8), Zanetti (work in progress - 10).

The NRC (2000) and NRC (2001), recommended 91 and 90% as the absorption coefficient of Na, respectively. However, from the BR-CORTE database, the true retention coefficient was estimated as 37.1% (Figure 9.4). This difference may be due to the excretion of Na in the urine, which is not accounted for global councils (NRC, 2000; NRC, 2001), despite urinary Na reaching approximately 38.6% (Table 9.1). 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 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 that used for Mg. Thus, in this BR-CORTE edition, the effect of genetic group was observed on NRGNa using the power model (Table 9.9).

Table 9.9 - Net Na requirements for growth as a function of genetic group (Zebu and crossbred cattle)

GG[1]	Body content (g)	NRGNa[2] (g/d)
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 the Na source. One of the main reasons for the innate desire of ruminants to consume salt was justified as reflex responses to dietary requirements and physiological status (Cheeke, 2005). However, ruminants have a considerable appetite for salt, consuming amounts much greater than required (Morris, 1980). Thereby, the best indicator of Na nutrient status is its association 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 ratio (can

reach a minimum limit of 10:1), contributing to an enhanced Na appetite in herbivores.

Ruminants show a high capacity to retain Na in the rumen because Na can be absorbed into the blood in instances of Na deficiency, and under these conditions, K replaces Na in the saliva (Cheeke, 2005). A Na deficiency can decrease osmotic pressure, causing body dehydration. Among the symptoms of Na deficiency are decreased growth and protein efficiency and energy use (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 K losses 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 K requirement for maintenance calculated as the sum of these losses. These estimates were adopted by the BR-CORTE (2010). Nevertheless, 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. With the aim to standardize the net mineral requirements for maintenance, the BR-CORTE dataset estimates the net K requirement for maintenance as 23.5 mg/kg BW (Figure 9.5). This value is lower than the 38 mg/kg BW, recommended by the NRC (2001).

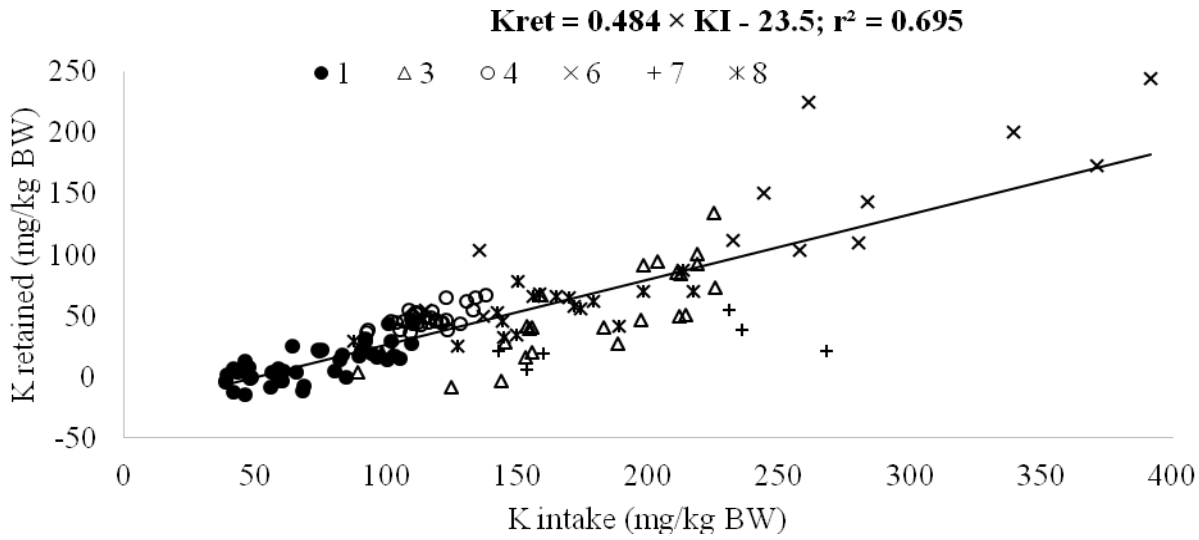

Figure 9.5 - Relationship between K retained (Kret) and K intake (KI) in beef cattle. Costa e Silva et al. (2015a - 1), Zanetti (2014 - 3), Prados (2016 - 4), Marcondes (2010 - 6), Gionbelli (2010 - 7), Sathler (2015 - 8).

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 large intestine, suggesting the secretion of K in these sites is greater than its absorption. The substantial amount of ruminal K was due to salivary K secretions that were not quantified as part of the K intake. The substantial large intestine 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 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 K excretion cannot be neglected and the urinary K excretion does not represent total daily K excretion. Indeed, fecal and urinary excretions of K were, on average, 35.3 and 30.3% of the K intake (Table 9.1), respectively, which provided a true retention coefficient of 48.4% (Figure 9.5), considerably lower than those recommended by several nutrient requirement councils. This shows that there is no main route for K excretion. Therefore, the true retention coefficient was 48.4% (Figure 9.5) and it is the value recommended for this edition of the BR-CORTE.

The NRGK, with respect to the effect of genetic group, resulted in distinct equations for Zebu and crossbred cattle (Table 9.10). This NRGK is approximately 17% lower than that previously reported in the BR-CORTE (2010).

Table 9.10 - Net K requirements for growth as a function of genetic group (Zebu and crossbred cattle)

GG[1]	Body content (g)	NRGK[2] (g/d)
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 K requirement 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 in safety animals against Cu, Cd, and Zn excesses (Suttle, 2010).

Despite affirming 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 S requirement for maintenance or retention coefficient were provided. From the database of this BR-CORTE edition, the net S requirement for maintenance and the retention coefficient for Nellore cattle were 10.4 mg/kg BW and 77.3%, respectively (Figure 9.6).

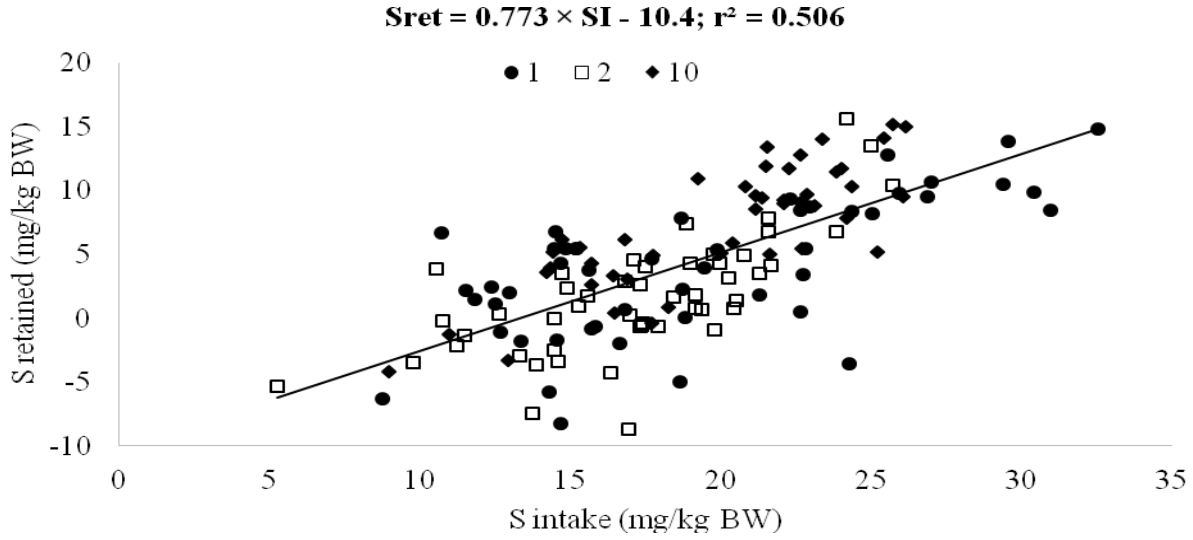

Figure 9.6 - Relationship between S retained (Sret) and S intake (SI) in beef cattle. Data from Costa e Silva et al. (2015a - 1 and 2) and Zanetti (work in progress – 10).

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 recommended equation:

$$NRGS\ (g/d) = EBG \times (0.03 \times EBW^{0.89}),$$

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 S requirement is 1.36 g/kg DM, which approximates that recommended by the NRC (2000) but is lower than that recommended by the NRC (2001) for dairy cows. 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 S requirements to improve the accuracy of these estimates.

Chlorine

In nature and the body, Cl exists primarily as the chloride anion, Cl^-, which is the main anion present in the extracellular fluid. This mineral is needed for HCl production 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 with 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 Cl^- requirement 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 is 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 in tropical conditions have a high Cl^- maintenance requirement 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 Cl^- recommendation is 0.9 g/d for each 100 kg BW. Smith et al. (2012) reported an average Cl^- (as $NaClO_3$) absorption in cattle of 12.6% based on a compilation of studies that evaluated several chlorides using $^{36}Cl^-$ as an 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.

MICROMINERALS

Due to the lack of studies on dietary requirements of microminerals in the literature, the recommendations in this BR-CORTE edition are only based on two studies (Costa e Silva et al, 2015a; Zanetti, work in progress) and their descriptive statistics are shown in Table 9.4.

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 Cu intake 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 38.2 to 61.2% of Cu intake, depending on whether macrominerals and/or microminerals were included in the diet. However, the urinary Cu excretion was not measured.

In this BR-CORTE edition, the net Cu requirement for maintenance was 95.6 µg/kg BW (Figure 9.7). This is higher than the 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 4.0 µg/kg BW as the Cu requirements for maintenance, based on the results of a single study (Suttle, 1974) that evaluated Cu bioavailability in sheep.

The 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 the absorption coefficient of Cu changing from 38.2 to 61.2%, depending on whether macrominerals and/or microminerals were included in the diet; the lowest absorption occurred when macrominerals but no microminerals were supplied.

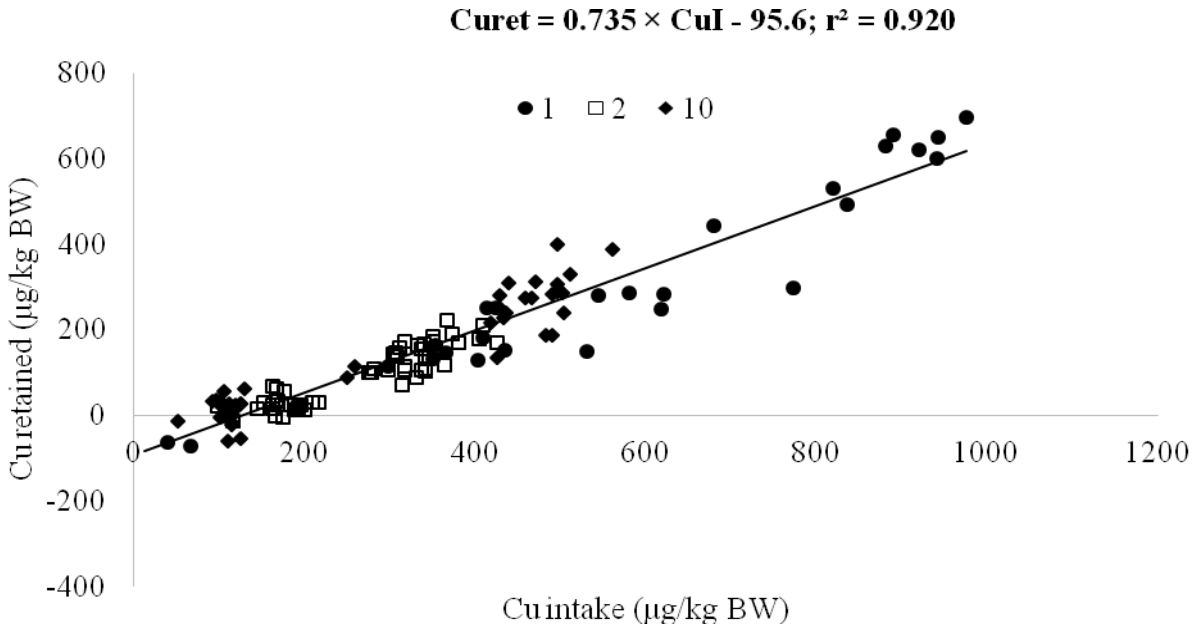

Figure 9.7 - Relationship between Cu retained (Curet) and Cu intake (CuI) in beef cattle. Data from Costa e Silva et al. (2015a - 1 and 2) and Zanetti (work in progress – 10).

Several factors 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 Cu requirements varied from 4 to 15 mg/kg DM depending on dietary Mo and S concentration. Thus, further studies that evaluate the interference of Mo and S in Cu absorption should be conducted to investigate the Cu amount required to prevent Cu deficiency in animals. Furthermore, some studies have shown a decrease in ruminal Cu absorption 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 macromineral and/or micromineral supplementation.

Costa e Silva et al. (2015a) suggested that the retention coefficient provides the most accurate estimate of dietary requirements and urinary mineral excretion cannot be discarded. A total 3.8% of Cu intake is excreted via urine (Costa e Silva et al., 2015a). Thus, the retention

coefficient is 73.5% (Figure 9.7). This value is higher than the 6% reported by the ARC (1980), which was recommended based on studies with sheep.

The NRGCu was estimated as follows:

$$NRGCu\ (mg/d) = EBG \times (1.25 \times EBW^{0.33}),$$

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, hence as per 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 DM. The NRC (2000) recommends 10 mg/kg DM dietary Cu in beef cattle. However, these recommendations did not consider the amount of Cu supplied in the basal diet but only that used for supplementation. Costa e Silva et al. (2015a) evaluated the composition of the basal diet and found that the average dietary Cu requirements for Nellore cattle were 9.53 mg/kg DM and this BR-CORTE edition supports this recommendation for Zebu cattle. Nevertheless, Prados (2016) compared diets with (5.85 mg/kg DM) and without Cu supplementation and found no difference in animal performance.

Iron

Iron (Fe) is an important component of various proteins that participate in 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 Fe supply 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 DM was adequate for animal growth and anemia prevention. Based on the data from Costa e Silva et al. (2015a) and Zanetti (work in progress), the net Fe requirements for maintenance and the true retention coefficient are 2.9 mg/kg BW and 73.4%, respectively, in beef cattle (Figure 9.8).

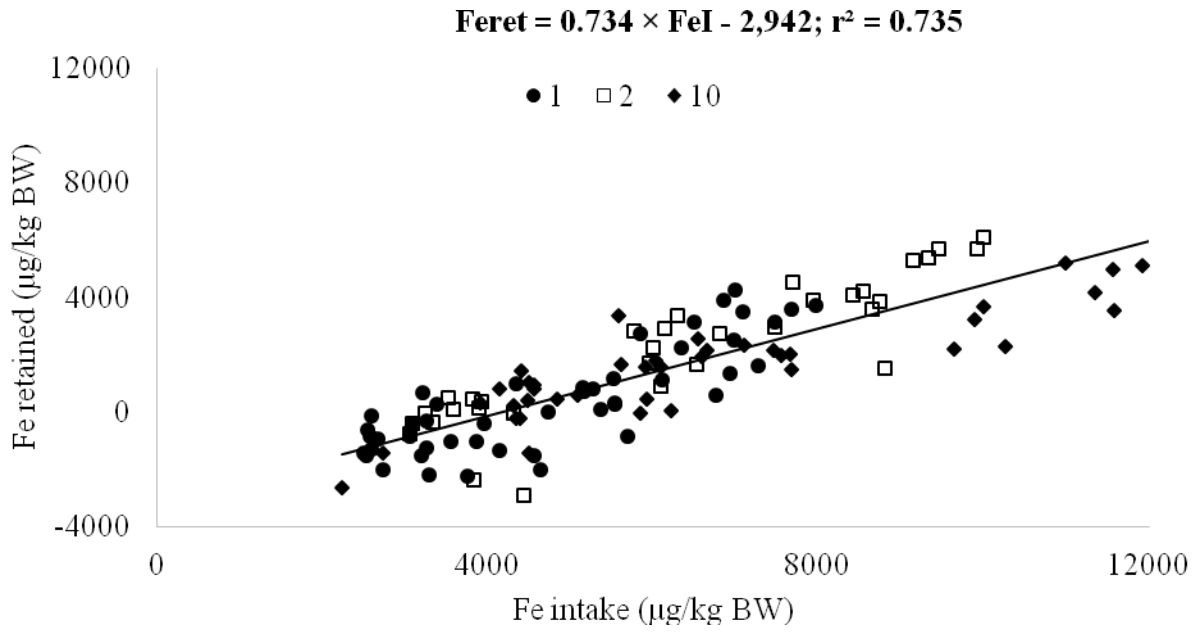

Figure 9.8 - Relationship between Fe retained (Feret) and Fe intake (FeI) in beef cattle. Data from Costa e Silva et al. (2015a - 1 and 2) and Zanetti (work in progress – 10).

For the NRGFe, the equation suggested by Zanetti (work in progress) was used:

$$NRGFe\ (mg/d) = EBG \times (10.4 \times EBW^{0.24}),$$

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 than the rate of animal growth. However, the NRC (2000) suggests that as the animal grows, the relative requirements would decrease, because blood volume does not increase proportionally to BW.

The NRC (2000) recommended 50 mg/kg DM as the Fe dietary requirement. We suggest a comparatively higher average of 166 mg/kg DM. However, we highlight that the 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 in relation to the presence of other microminerals in the diet. Some studies (Bentley and Phillips, 1951; Rojas et al, 1965; DiCostanzo et al, 1986) reported Mn levels were associated with reproductive aspects but did not affect animal performance. Schroeder et al. (1966) recommended 20 to 25 mg/kg DM of Mn for good skeletal development.

The net Mn requirements for maintenance and the retention coefficient were 184.9 µg/kg BW and 43.9%, respectively (Figure 9.9). The NRC (2001) suggests 2 µg/kg BW and 75% as the net Mn requirements 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 independent of its dietary concentration and that it is primarily absorbed in the small intestine. Sathler (2015) evaluated the partial absorption coefficients in the rumen, small intestine, and large intestine 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 microminerals resulted in an absorption coefficient 15% lower than the diet containing microminerals without macrominerals. However, this author verified that Mn absorption in the small intestine using the treatment with all minerals was greater compared to treatment without macrominerals, without differences in the total apparent absorption coefficient.

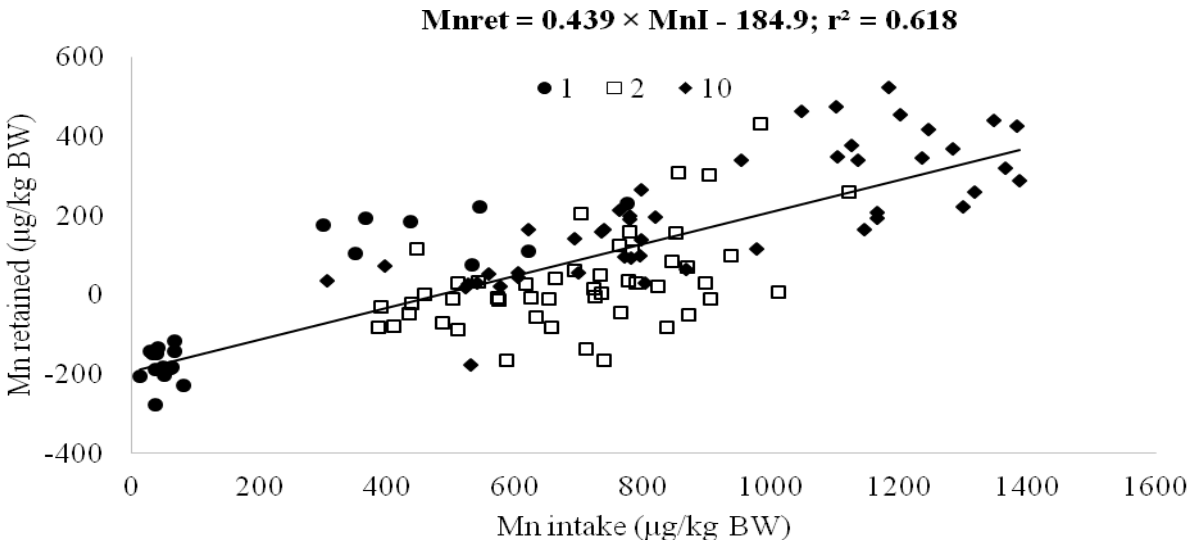

Figure 9.9 - Relationship between Mn retained (Mnret) and Mn intake (MnI) in beef cattle. Data from Costa e Silva et al. (2015a - 1 and 2) and Zanetti (work in progress – 10).

For the NRGMn, Costa e Silva et al. (2015a) suggested the following equation:

$$NRGMn\ (mg/d) = EBG \times (0.07 \times EBW^{0.80}),$$

where EBG is the empty body gain (kg/d) and EBW is empty body weight (kg).

The NRC (2000) recommended 20 mg/kg DM dietary Mn requirement and this was adopted by the BR-CORTE (2010). Hartmans (1974) fed cows 2.5 to 3.5 years of age with diets containing 16 to 21 mg/kg DM and did not observe Mn deficiency symptoms or improved animal performance. Possibly, the supply of Mn was above the requirements for optimal performance. Costa e Silva et al. (2015a) estimated dietary Mn requirements as 9.59 mg/kg DM and showed that similar animal performance was achieved when 10 mg/kg DM was supplied.

Selenium

The Se concentration in animals depends on the dietary Se amount, 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 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 Se requirements for maintenance and the retention coefficient, we used the recommendations of Costa e Silva et al. (2015a) of 3.72 µg/kg BW and 48.7%, respectively (Figure 9.10). This retention coefficient value is higher than that of 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 the 40 to 50% range established by the NRC (2001).

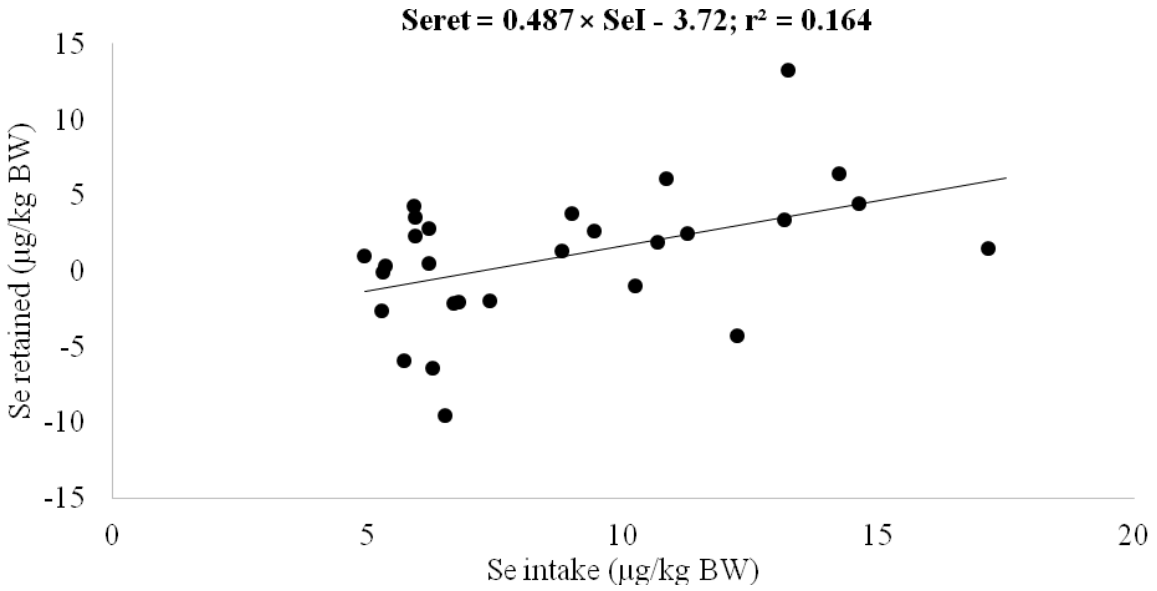

Figure 9.10 - Relationship between Se retained (Seret) and Se intake (SeI) in beef cattle. Data from Costa e Silva et al. (2015a - 1).

For the 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 empty body weight (kg).

Thus, we can infer 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 DM (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 DM as the dietary Se requirements. However, Costa e Silva et al. (2015a) estimated 0.57 mg/kg DM as the dietary Se requirements. Moreover, this value is higher than that recommended by the CSIRO (2007) and NRC (2001) of 0.05 and 0.30 mg/kg DM, 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, and, therefore, we recommend that further studies are required before the dietary requirements can be 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 microminerals (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 the Zn endogenous losses and estimated 12 µg/kg BW as the net Zn requirements for maintenance. Weigand and Kirchgessner (1982) estimated the net Zn requirements for maintenance in lactating cows as 53 µg/kg BW. Furthermore, the ARC (1980) and the NRC (2001) estimated the net Zn requirements for maintenance as 55 µg/kg BW, while the CSIRO (2007) recommended 45 µg/kg BW. However, experiments conducted in tropical conditions and, therefore, adopted in the dataset of this BR-CORTE edition, suggest that the net Zn requirement for maintenance is 334.4 µg/kg BW (Figure 9.11), which is more than the above mentioned recommendations.

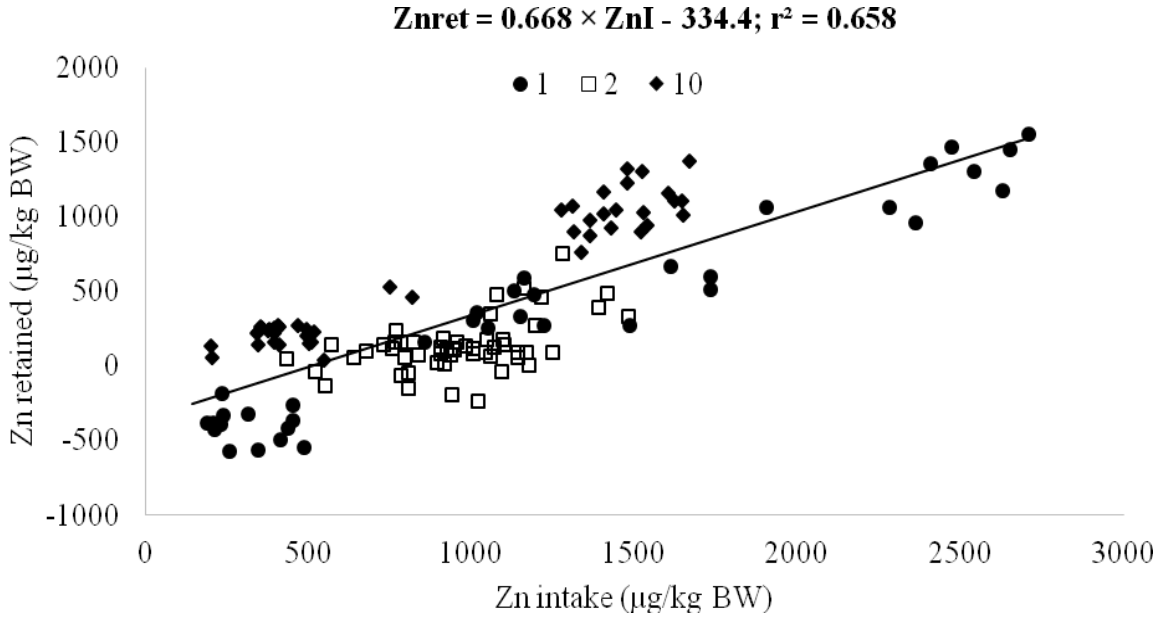

Figure 9.11 - Relationship between Zn retained (Znret) and Zn intake (ZnI) in beef cattle. Data from Costa e Silva et al. (2015a - 1 and 2) and Zanetti (work in progress – 10).

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 66.8%

retention coefficient (Figure 9.11). Miller and Cragle (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 microminerals, Zn was primarily absorbed in the rumen (approximately 43.7% of the Zn intake) and large intestine (an average 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 independent of dietary Ca. Nevertheless, Prados (2016) verified lower Zn concentration in the liver when there was Ca supplementation in the diet that could be due to the interaction between Ca and Zn, decreasing Zn absorption.

For the NRGZn, Costa e Silva et al. (2015a) recommended the following equation:

$$NRGZn\ (mg/d) = EBG \times (1.16 \times EBW^{0.86}),$$

where EBG is the empty body gain (kg/d) and EBW is empty body weight (kg).

The ARC (1980) suggested that 16 to 31 mg Zn/kg BW can be incorporated into body tissue for each kilogram of BW gain. The NRC (2000) considered the dietary Zn requirements as 30 mg/kg DM, while the CSIRO (2007) recommended 11.6 mg/kg DM. 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 DM as the dietary Zn requirements in Nellore cattle.

Cobalt

Co is the precursor of vitamin B12, which is associated with energy metabolism; although, the amount of dietary Co that is converted to vitamin B12 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, 86.8% was estimated as the true retention coefficient (Figure 12) showing that only 13.2% of 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 9.12).

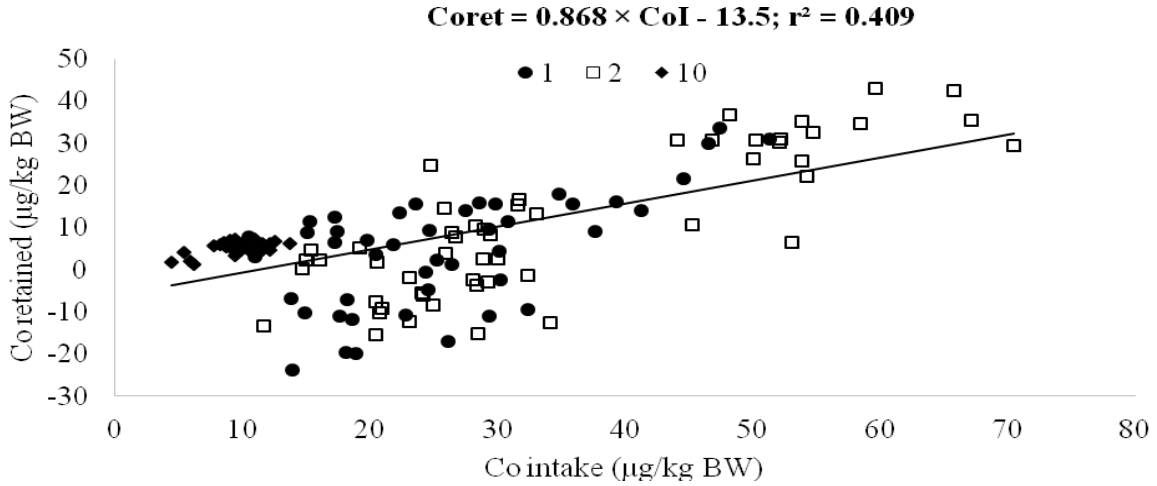

Figure 9.12 - Relationship between Co retained (Coret) and Co intake (CoI) in beef cattle. Data from Costa e Silva et al. (2015a - 1 and 2) and Zanetti (work in progress - 10).

NRGCo was based on the equation suggested by Zanetti (work in progress):

$$NRGCo\ (mg/d) = EBG \times (0.045 \times EBW^{-0.023}),$$

where EBG is the empty body gain (kg/d) and EBW is empty body weight (kg).

Thus, the NRGCo decreases as the EBW increases, although at an almost constant rate. Smith (1987) suggested 0.11 mg/kg DM as the dietary Co requirements, and this was adopted by the NRC (2000 and 2001). The BCNRM (2016) recommends 0.15 mg/kg DM. 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 requirements was 0.63 mg/kg DM, considering the retention coefficient and the Co contents of the feeds.

Chromium

In previous BR-CORTE editions, the recommendations for the net Cr required for maintenance 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 as 22.9 µg/kg BW and 78.4%, respectively (Figure 9.13).

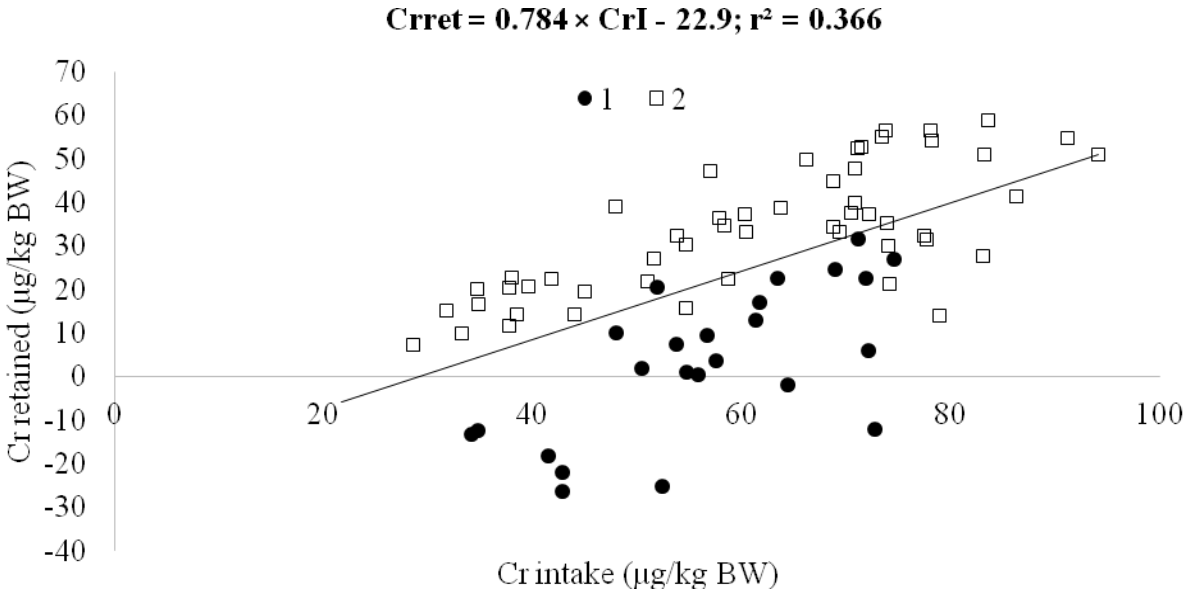

Figure 9.13 - Relationship between Cr retained (Crret) and Cr intake (CrI) in beef cattle. Data from Costa e Silva et al. (2015a - 1 and 2).

Moreover, Costa e Silva et al. (2015a) estimated the NRGCr and suggested the following equation:

$$NRGCr\ (mg/d) = EBG \times (0.23 \times EBW^{0.61}),$$

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 who received 0.3 mg/kg DM. Additionally, some studies (Butting et al., 1994; Kegley and Spears, 1995) evaluated Cr supplementation in calves and suggested that 0.4 mg Cr/kg DM inclusion increases glucose clearance rate. The NRC (2000) adopted this recommendation of 0.4 mg/kg DM as the dietary Cr requirements 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 DM.

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 evidence of the direct and indirect production of thiomolybdates in ruminal contents of cattle remain inconclusive. Thus, there is a need to verify the influence of changes in the dietary Cu supply on the presence of soluble thiomolybdates in the rumen fluid and the Cu and Mo concentrations and distributions in blood plasma. The NRC does not provide the dietary Mo requirements because Mo deficiencies are rarely observed. Zanetti (work in progress) established the endogenous losses and the retention coefficient for Mo as 3.27 μg/kg BW and 49.7%, respectively (Figure 9.14).

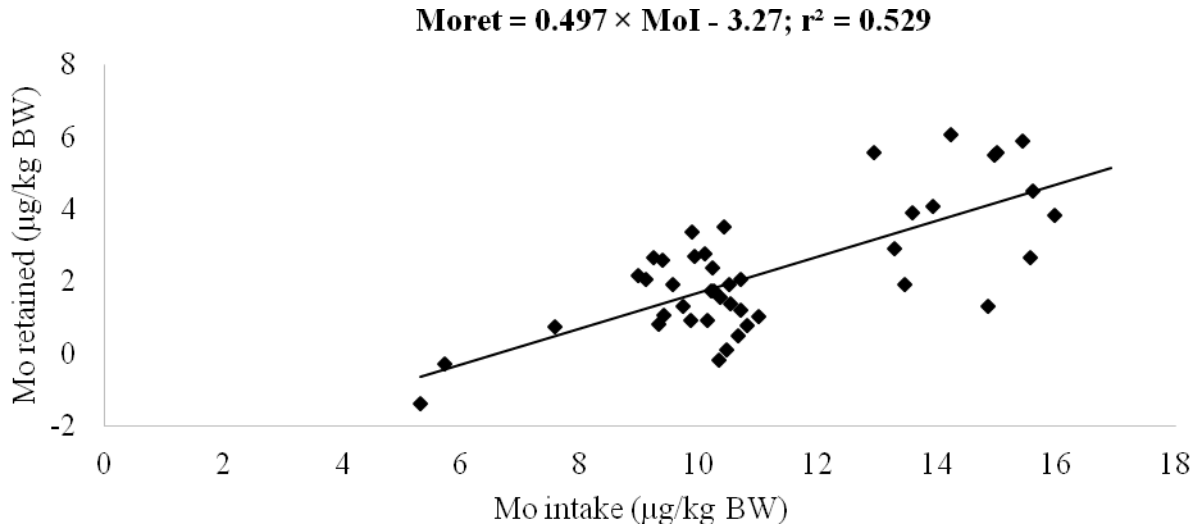

Figure 9.14 - Relationship between Mo retained (Moret) and Mo intake (MoI) in beef cattle. Data from Zanetti (work in progress - 10).

Additionally, Zanetti (work in progress) estimated the NRGCo and suggested the following equation:

$$NRGMo\ (mg/d) = EBG \times (0.0035 \times EBW^{0.406}),$$

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 regulate 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 I requirements 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 that the recommendations from the NRC (2000) of 0.5 mg/kg DM should be adopted.

TOXICITY

When provided in high amounts, some inorganic elements can cause several adverse health issues in cattle. For the formulation of rations, we recommend that maximum dietary mineral levels should be fixed at 120% of the dietary requirements, to guarantee a mineral balance in the diet without harmful absorption and avoiding unnecessary losses. However, in practical conditions, this balance is not always possible. The toxic mineral values obtained from the literature are presented in Table 9.11.

Table 9.11 - Maximum tolerable concentrations of minerals for beef cattle

Macromineral	Toxic level	Micromineral	Toxic level
Calcium[1]	44 g/kg DM	Copper[4]	40 mg/kg DM
Potassium[4]	20 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]	25 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] BCNRM (2016).

TABLES OF MINERAL REQUIREMENTS FOR BEEF CATTLE

Based on the estimated net requirements for maintenance and NRG as well as the true retention coefficient, dietary mineral requirements were calculated (Table 9.12). The recommended dietary mineral requirements are shown in Tables 9.13 and 9.14.

Table 9.12 - Summary of the recommendations for calculation of dietary macromineral and micromineral requirements for beef cattle

Mineral	Net requirements for maintenance	True 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: $NRGCa = EBG \times (147 \times EBW^{-0.50})$	462
			Crossbred cattle: $NRGCa = EBG \times (66.0 \times EBW^{-0.32})$	453
P	13.5	67.8	Zebu cattle: $NRGP = EBG \times (38.6 \times EBW^{-0.36})$	445
			Crossbred cattle: $NRGP = EBG \times (25.4 \times EBW^{-0.25})$	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	$NRGS = EBG \times (0.03 \times EBW^{0.8900})$	-
Mineral	µg/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	$NRGFe = EBG \times (14.0 \times EBW^{0.24})$	-
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.

Therefore, considering a 400 kg Nellore bull with ADG of 1.0 kg/d, the dietary requirements of macrominerals and micro elements can be calculated:

$SBW = 0.88 \times BW^{1.0175} = 0.88 \times 400^{1.0175} = 390.9$ kg
$EBW = 0.8126 \times SBW^{1.0134} = 0.8126 \times 390.9^{1.0134} = 344$ kg
$EBG = 0.963 \times ADG^{1.0151} = 0.963 \times 1.0^{1.0151} = 0.963$ kg

• **Calcium** (Table 9.13)**:**
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** (Table 9.13)**:**
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** (Table 9.13)**:**
Maintenance: $5.9 \times BW = 5.9 \times 400 = 2{,}360$ mg = 2.36 g/d
Growth: $EBG \times (0.3466 \times EBW^{0.0113}) = 0.963 \times (0.3466 \times 344^{0.0113}) = 0.357$ g/d
Total net requirements = maintenance + growth = 2.36 + 0.357 = 2.717 g/d
Dietary requirements = total net requirements/retention coefficient = 2.717/0.355 = 7.65 g/d

• **Sodium** (Table 9.13)**:**
Maintenance: $6.3 \times BW = 6.3 \times 400 = 2{,}511$ mg = 2.52 g/d
Growth: $EBG \times (5.594 \times EBW^{-0.2998}) = 0.963 \times (5.594 \times 344^{-0.2998}) = 0.935$ g/d
Total net requirements = maintenance + growth = 2.52 + 0.935 = 3.455 g/d
Dietary requirements = total net requirements/retention coefficient = 3.455/0.371 = 9.31 g/d

• **Potassium** (Table 9.13)**:**
Maintenance: $23.5 \times BW = 23.5 \times 400 = 9{,}400$ mg = 9.40 g/d
Growth: $EBG \times (0.9463 \times EBW^{0.1216}) = 0.963 \times (0.9463 \times 344^{0.1216}) = 1.854$ g/d
Total net requirements = maintenance + growth = 9.40 + 1.854 = 11.254 g/d
Dietary requirements = total net requirements/retention coefficient = 11.254/0.484 = 23.25 g/d

• **Sulfur** (Table 9.13)**:**
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 = 12.15 g/d

• **Copper** (Table 9.14)**:**
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** (Table 9.14)**:**
Maintenance: 2,942 × BW = 2,942 × 400 = 1,176.800 µg = 1,177 mg/d
Growth: EBG × (10.4 × $EBW^{0.24}$) = 0.963 × (10.4 × $344^{0.24}$) = 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** (Table 9.14)**:**
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** (Table 9.14)**:**
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** (Table 9.14)**:**
Maintenance: 334.4 × BW = 334.4 × 400 = 133,760 µg = 133.76 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 = 133.76 + 169.6 = 303.4 mg/d
Dietary requirements = total net requirements/retention coefficient = 303.4/0.668 = 454.2 mg/d

• **Cobalt** (Table 9.14)**:**
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** (Table 9.14)**:**
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** (Table 9.14)**:**
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

Table 9.13 - Dietary macromineral (Ca, P, Mg, Na, K, and S; g/d) requirements of Zebu and crossbred cattle for different body weights and weight gains

Body weight (kg)	Weight gain (kg/d)	Zebu cattle						Crossbred cattle				
		Ca	P	Mg	Na	K	S	Ca	P	Mg	Na	K
200	0.50	13.62	8.27	3.82	4.94	11.45	4.46	14.86	8.94	3.74	5.28	11.45
	1.00	23.33	12.64	4.32	6.52	13.22	6.27	25.82	14.00	4.17	7.21	13.22
	1.50	33.11	17.05	4.83	8.11	15.01	8.09	36.87	19.10	4.60	9.15	15.00
250	0.50	13.62	8.92	4.65	5.69	13.93	5.54	15.12	9.66	4.55	6.11	14.01
	1.00	22.27	12.95	5.15	7.16	15.75	7.76	25.31	14.43	4.96	8.01	15.91
	1.50	30.99	17.01	5.66	8.64	17.59	10.00	35.57	19.25	5.36	9.92	17.84
300	0.50	13.89	9.66	5.48	6.46	16.39	6.61	15.57	10.44	5.36	6.94	16.54
	1.00	21.76	13.42	5.99	7.85	18.26	9.23	25.16	14.99	5.75	8.81	18.58
	1.50	29.70	17.22	6.50	9.25	20.14	11.88	34.83	19.59	6.14	10.71	20.62
350	0.50	14.33	10.45	6.31	7.24	18.86	7.67	16.14	11.26	6.18	7.77	19.08
	1.00	21.60	14.00	6.82	8.57	20.76	10.69	25.25	15.64	6.55	9.63	21.21
	1.50	28.93	17.59	7.33	9.91	22.68	13.74	34.43	20.05	6.93	11.51	23.36
400	0.50	14.89	11.28	7.14	8.04	21.32	8.73	16.78	12.11	7.00	8.60	21.60
	1.00	21.67	14.66	7.65	9.31	23.25	12.15	25.50	16.34	7.36	10.45	23.83
	1.50	28.52	18.07	8.16	10.60	25.20	15.59	34.29	20.61	7.72	12.31	26.07
450	0.50	15.53	12.13	7.98	8.84	23.77	9.78	17.48	12.98	7.82	9.44	24.12
	1.00	21.91	15.37	8.48	10.07	25.74	13.59	25.87	17.09	8.17	11.27	26.43
	1.50	28.35	18.63	9.00	11.31	27.72	17.43	34.33	21.22	8.52	13.12	28.77

Table 9.14 - Dietary micromineral (Cu, Fe, Mn, Se, Zn, Co, Cr, and Mo; mg/d) requirements of beef cattle for different body weights and weight gains

Weight gain (kg/d)	Body weight (kg)						
	200	250	300	350	400	450	500
				Copper			
0.50	30.41	37.26	44.07	50.85	57.60	64.33	71.04
1.00	34.90	42.11	49.23	56.28	63.28	70.25	77.18
1.50	39.43	46.99	54.42	61.76	69.01	76.21	83.36
				Iron			
0.50	825	1,026	1,228	1,429	1,631	1,832	2,033
1.00	848	1,051	1,254	1,456	1,659	1,861	2,063
1.50	871	1,075	1,280	1,482	1,687	1,890	2,092
				Manganese			
0.50	88.8	111	133	155	177	198	220
1.00	93.5	116	139	162	184.9	208	230
1.50	98.2	122	146	170	193	217	240
				Selenium			
0.50	2.26	2.63	3.00	3.38	3.75	4.13	4.50
1.00	3.01	3.36	3.73	4.09	4.46	4.83	5.20
1.50	3.76	4.10	4.46	4.82	5.18	5.54	5.91
				Zinc			
0.50	168	208	248	287	326	365	403
1.00	237	293	347	401	454	507	560
1.50	307	378	447	516	584	651	718
				Cobalt			
0.50	3.13	3.91	4.69	5.47	6.24	7.02	7.80
1.00	3.15	3.93	4.71	5.49	6.26	7.04	7.82
1.50	3.18	3.95	4.73	5.51	6.29	7.06	7.84
				Chromium			
0.50	9.03	10.97	12.88	14.76	16.61	18.45	20.28
1.00	12.28	14.72	17.08	19.38	21.65	23.87	26.07
1.50	15.57	18.49	21.31	24.05	26.72	29.34	31.91
				Molybdenum			
0.50	1.34	1.68	2.01	2.34	2.67	3.00	3.33
1.00	1.37	1.71	2.04	2.37	2.71	3.04	3.37
1.50	1.40	1.74	2.07	2.41	2.74	3.08	3.41

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10

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:

$$CTB = MT + PREG \quad \text{Eq. 10.1}$$

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 × 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 × 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 d 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 pre-natal 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 10.1 (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 bulk 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 d 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:

$$DMIpreg\ (g/SBW) = DMInp - 0.02 \times (TG - 135) \quad \text{Eq. 10.2}$$

$$DMIpreg\ (kg/d) = DMInp - (SBW \times 0.00002 \times (TG - 135)) \quad \text{Eq. 10.3}$$

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. 10.2 and in g/d for Eq. 10.3), 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).

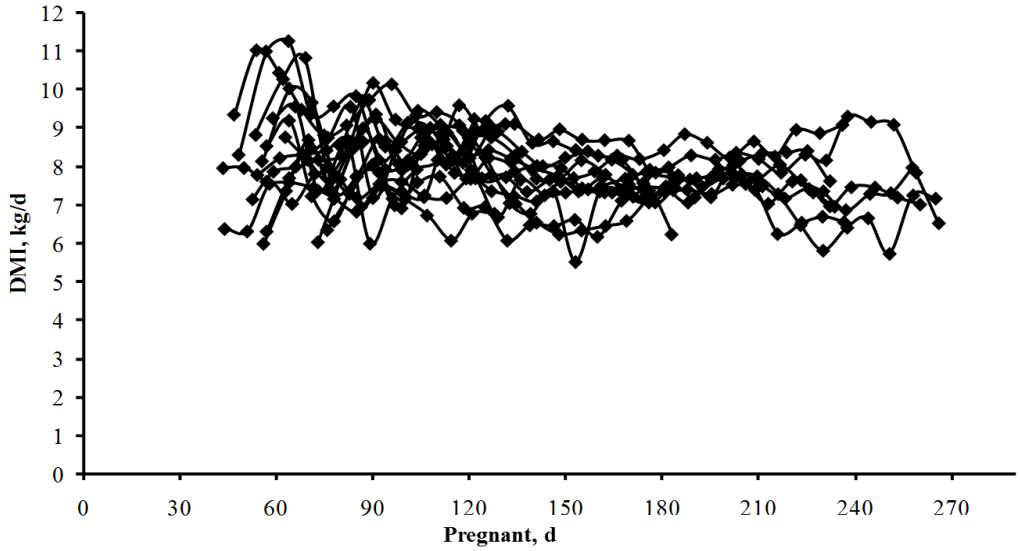

Figure 10.1 - Relationship between dry matter intake and days pregnant in Zebu cows.

REQUIREMENTS FOR MAINTENANCE

Energy requirement for maintenance

The net energy requirements for maintenance (NEm, kcal/EBW$np^{0.75}$/d) were estimated from the ratio between heat production (HP, kcal/$EBW^{0.75}$/d) and metabolizable energy intake (MEI, kcal/$EBW^{0.75}$/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):

$$HP = 85.9 \times \exp^{(MEI \times 0.0028)}$$

Eq. 10.4

The NEm value corresponds to the intercept of Eq. 10.4, representing the quantity of heat produced in absolute fasting. Further based on Eq. 10.4, 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:

$$NEm\ (kcal/d) = 85.9 \times EBW^{0.75}$$

Eq. 10.5

$$MEm\ (kcal/d) = 120 \times EBW^{0.75}$$

Eq. 10.6

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 7 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):

$$MEm\ (kcal/d) = 130 \times EBW^{0.75}$$

Eq. 10.7

where EBW = empty body weight (kg).

The MEm value established for open and pregnant Zebu cows in this edition of the BR-CORTE (Eq. 10.7) 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 7). 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 open 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; BCNRM, 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 11), the MEm value presented for open or pregnant cows is 4% lower. A compilation of the of studies carried out by the BCNRM (BCNRM, 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 10.1). 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 BCNRM, 2016).

Table 10.1 - 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]$SBW = 0.8084 \times BW^{1.0303}$ (see Chapter 1); [2]$SBW = 0.96 \times BW$ (NRC); [3]$EBW = 0.8424 \times SBW^{1.0122}$ (see Chapter 1); [4]$EBW = 0.851 \times SBW$ (NRC); [5]$EMm = 1.30 \times EBW^{0.75} / 1000$; [6]$EMm = 1.26 \times BW^{0.75} / 1000$. 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. 10.8. Based on Eq. 10.8, 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 8, MPm, g/d = $3.9 \times SBW^{0.75}$). Due to the small numerical difference, the same MPm value is also suggested for Zebu cows (Eq. 10.9).

$$MPI\ (g/d) = 3.93 \times SBW^{0.75} + 2.63 \times RP_{MT} \quad \text{Eq. 10.8}$$

$$MPm\ (g/d) = 3.9 \times SBW^{0.75} \quad \text{Eq. 10.9}$$

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:

$$NEg\ (Mcal/d) = 3.82 \times EBGnp^{1.07} \times BCS^{0.35} \quad \text{Eq. 10.10}$$

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. 10.10, 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. 10.10 is shown in Table 10.2.

Table 10.2 - 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	0.1.9	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 10.2 is usually larger for growing animals (Chapter 7) for BCS $\geq$ 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/BCNRM System (BCNRM, 2016), considering the BCS variations. According to the BCNRM (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 BCNRM 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. 10.11:

$$MEg\ (Mcal/d) = NEg/0.53 \quad \text{Eq. 10.11}$$

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:

$$NPg\ (g/d) = 307 \times EBGnp - 34 \times NEg \quad \text{Eq. 10.12}$$

where EBGnp = non-pregnant empty body weight gain (kg) and NEg = net energy requirement for gain (Mcal/d).

An example of applying Eq. 10.12 is presented in Table 10.3. 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. 10.12 and Table 10.3 show that the larger the BCS, the smaller the proportional daily protein gain that reaches negligible values with BCS > 6.

Table 10.3 - 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 0.27 (Gionbelli et al., work in progress). Thus the metabolizable energy required for maternal tissue weight gain (MPg, g/d) for adult Zebu cows can be calculated according to Eq. 10.13:

$$MPg\ (g/d) = NPg/0.27 \quad \text{Eq. 10.13}$$

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. 10.14

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 (BCNRM, 2016) for pregnancy with the same estimated calving weight, the requirements estimated for gestation in Zebu cows are about 30% lower (Figure 10.2).

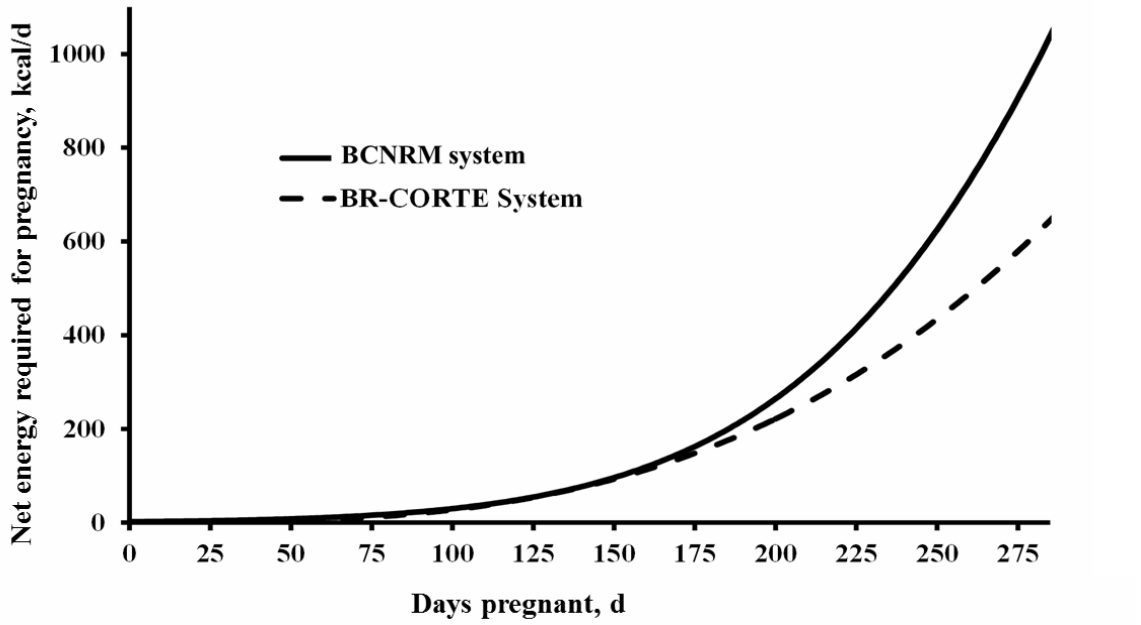

Figure 10.2 - Net energy requirements for pregnancy of an Angus-Hereford cow carrying a calf with estimated 32 kg calving weight (continuous line, BCNRM 2016) and of a Zebu cow carrying a calf with estimated 32 kg calving weight (dotted line, BR-CORTE 2016).

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 BCNRM System (based on a mean of results from studies involving sheep and cattle). Thus MEpreg should be calculated as follows:

$$MEpreg\ (Mcal/d) = NEpreg/0.12 \quad \text{Eq. 10.15}$$

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 3.5 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. 10.14 and Eq. 10.15, 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. 10.14 to estimate the net energy requirements for pregnancy.

$$NPpreg\ (g/d) = CBW \times 0.0000001773 \times TG^{2.945} \quad \text{Eq. 10.16}$$

where CBW = mean calf birth weight of the herd (kg) and TG = days pregnant.

The Figure 10.3 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 0.27 (Gionbelli et al., work in progress). Thus, the metabolizable protein requirement for pregnancy can be calculated as:

$$MPpreg\ (Mcal/d) = NPpreg/0.27 \quad \text{Eq. 10.17}$$

where NPpreg = net protein requirement for pregnancy (g/d).

The metabolizable protein requirement for pregnancy calculated according to Eq. 10.16 and Eq. 10.17 for a 500 kg Zebu cow carrying a calf with 32 kg estimated calving weight, at 285 d pregnant, is 356 g/d, that corresponds to 88% of the protein requirement for maintenance of the same cow (MPm = 405 g/d). Considering the last 90 d of pregnancy, the mean MPpreg requirement for the same cow is 235 g/d, which corresponds to an average increase in protein requirement of 58%, 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).

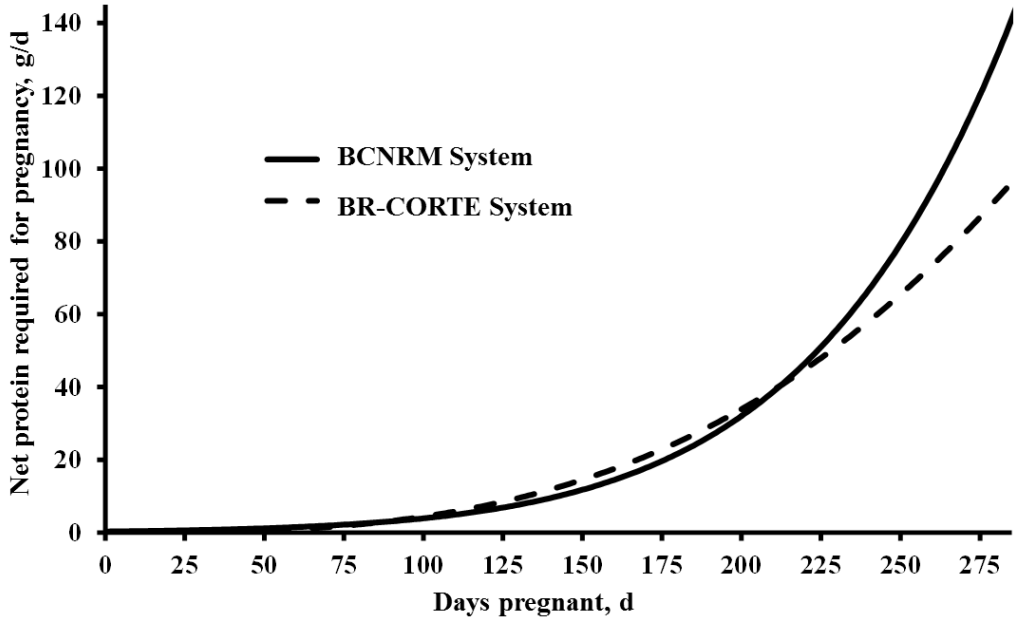

Figure 10.3 - Net protein requirements for pregnancy of an Angus-Hereford cow carrying a calf with estimated 32 kg calving weight (continuous line, BCNRM 2016) and a Nellore cow carrying a calf with estimated 32 kg calving weight (dotted line, BR-CORTE 2016).

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 10.4). 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.

Table 10.4 - Selection of scientific studies published in the last five 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

$$MEtotal = MEm + MEg \quad \text{Eq. 10.18}$$

Pregnant cows

$$MEtotal = MEm + MEg + MEpreg \quad \text{Eq. 10.19}$$

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. 10.20, Eq. 10.21, or Eq. 10.22). When the energetic concentration of the diet is not known, Eq. 10.23 should be used:

$$[ME] = 0.9147 \times [DE] - 0.2227 \quad \text{Eq. 10.20}$$

$$[DE] = \frac{0.2227 + [ME]}{0.9147}$$

Eq. 10.21

$$ME / DE = 0.65 + 0.44 \times TDN - 0.24 \times TDN^2$$

Eq. 10.22

$$DE = ME / 0.82$$

Eq. 10.23

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. 10.20 and Eq. 10.21 are derived from the ME and DE ratio obtained in diets of pregnant and open adult Zebu cows (Figure 10.4). Eq. 10.22 is a variation on the previous equations, considering 1 kg de TDN = 4.4 Mcal of DE. Eq. 10.23 represents the standard value of the DE to ME conversion efficiency used historically by the feeding systems (BCNRM 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* 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.

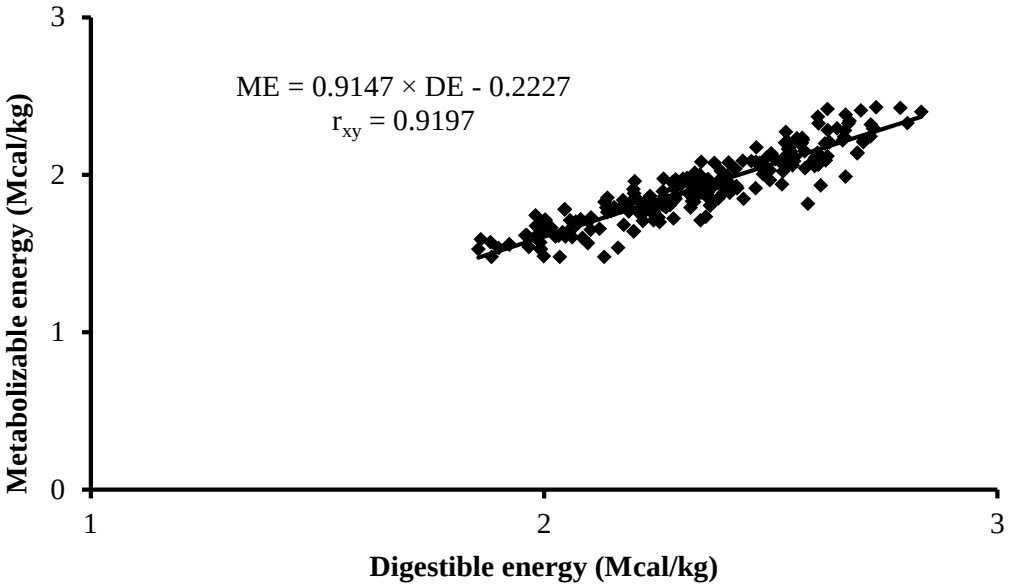

Figure 10.4 - Metabolizable energy and digestible energy ratio in adult Zebu cows (Gionbelli et al., work in progress).

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

$$MPtotal = MPm + MPg$$

Eq. 10.24

Pregnant cows

$$MPtotal = MPm + MPg + MPpreg$$

Eq. 10.25

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 8). 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):

$$MCP\ (g/d) = -53.07 + 304.9 \times CPI + 90.8 \times TDNI - 3.13 \times TDNI^2 \quad \text{Eq. 10.26}$$

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 8):

$$RUP\ (g/d) = (MPtotal - (MCP \times 0.64))/0.80 \quad \text{Eq. 10.27}$$

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 111 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, a 7.3% increase over the maintenance requirements (4.5% for energy and 10% for protein). This point was chosen because it is the time when the energy or protein requirements come to represent more than 10% 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 10.5 and Table 10.5.

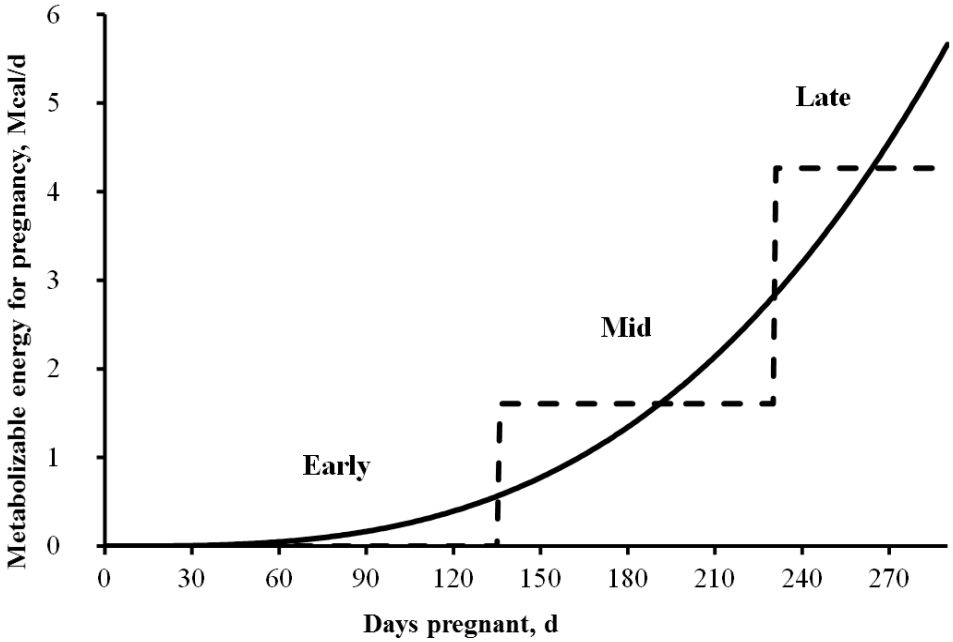

Figure 10.4 - Metabolizable energy requirements for pregnancy of an adult Zebu cow (500 kg BW carrying a calf with estimated 32 kg calving weight) divided into three pregnant periods (early, mid and late). The continuous line represents the requirements calculated daily and the dotted line represents the mean requirements to be considered in each period.

Table 10.5 - 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 10.6. 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 11 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 10.6 - 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 11)**	**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 10.6 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:

$$PX = 135 + CCI - LACT \quad \text{Eq. 10.28}$$

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. 10.28, 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 9 of this edition of the BR-CORTE should be adopted. For pregnant cows, an increase of 12 and 33% in the mineral requirements is suggested during mid- and late pregnancy. These values are based on the mean increase in energy requirements that occurs as a function of pregnancy. Thus the mineral requirements for open and pregnant Zebu cows can be calculated according to Table 10.7.

Table 10.7 - 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 × 1.12
Late pregnancy (231 d pregnant to calving)	Maintenance × 1.33

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11

Nutrient requirements for lactating beef cows and their calves

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INTRODUCTION

Brazil has approximately 200 million cattle (ANUALPEC, 2015), with around of 65 million being cows (females aged above three years). In addition, most of these cows are from Zebu cattle (*Bos taurus indicus*) and their crosses, responsible for the supply of all animals for the beef production chain.

In beef cattle production, the breast-feeding phase is important for the beef 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 beef cows (Calegare, 2004). Moreover, 70% of the energy required for beef production is utilized for functions involved with cow maintenance (Ferrell and Jenkins, 1985). Thus, approximately 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 beef production program based on the areas currently utilized for livestock, which are mandatorily based on reduction of the production cycle. Thereby, the production systems have intensified to reduce the age of animals 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 becomes essential for adequate planning and technology used to reach production targets established in the system.

During the breast-feeding phase, the correct measurement of milk yield (MY) becomes indispensable because this parameter represents the amount of nutrients that the 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 nutrient requirements of these animals. Milk yield can be measured directly and indirectly; the most common methods are manual milking (Gifford, 1953), weighing calves before and after suckling (Knapp and Black, 1941), mechanical milking after oxytocin use (Anthony et al., 1959), and evaluation of the deuterium monoxide content of milk (Freetly et al., 2006). Then, beyond an understanding of the DMI for animals, MY will influence calf performance and consequently body weight (BW) at weaning. In this context, the second edition of the BR-CORTE utilized the recommendation of Henriques et al. (2011) which evaluated different models to estimate MY of lactating Nellore cows. However, the equation was not validated under tropical conditions.

The metabolizable energy intake (MEI) that does not incur changes in energy in the body will influence the dietary energy required for maintenance, meaning that this parameter is considered a characteristic with moderate to high heritability (Carstens et al., 1988). Thereby, energy inefficiency, from 60 to 70% of the total energy required for maintenance of the animals (Bottje and Carstens, 2009), has been attributed to protein turnover, ion pumps (Na^+ and 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.

The energy requirements of the animal correspond to the sum of the needs for maintenance and production, which can be divided into energy required for growth, lactation, and pregnancy (Webster, 1979).

However, few studies (Fonseca, 2012a; 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 nutrient requirements of calves, the amount of energy and protein secreted by milk can be determined, which allows estimating the moment that milk does not provide enough nutrients and, thus, the exact moment for calf supplementation.

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 Zebu cows and their calves.

DRY MATTER INTAKE OF LACTATING BEEF COWS

The last edition of the BR-CORTE (2010) utilized the constant value of 2.39% BW for DMI of lactating Zebu cows during the first six months of lactation suggested by Fonseca (2009). However, the use of constant values does not estimate DMI of lactating cows accurately because the nutrient requirements of these animals reduce when lactation advances. Thereby, Costa e Silva (2015) evaluated five models to estimate the DMI (g/kg BW) of Nellore cows during the seven-month lactation period and observed that the adjusted equation using the model proposed by Wilmink (1987) added to the average daily gain (ADG) provided better estimates (Figure 11.1).

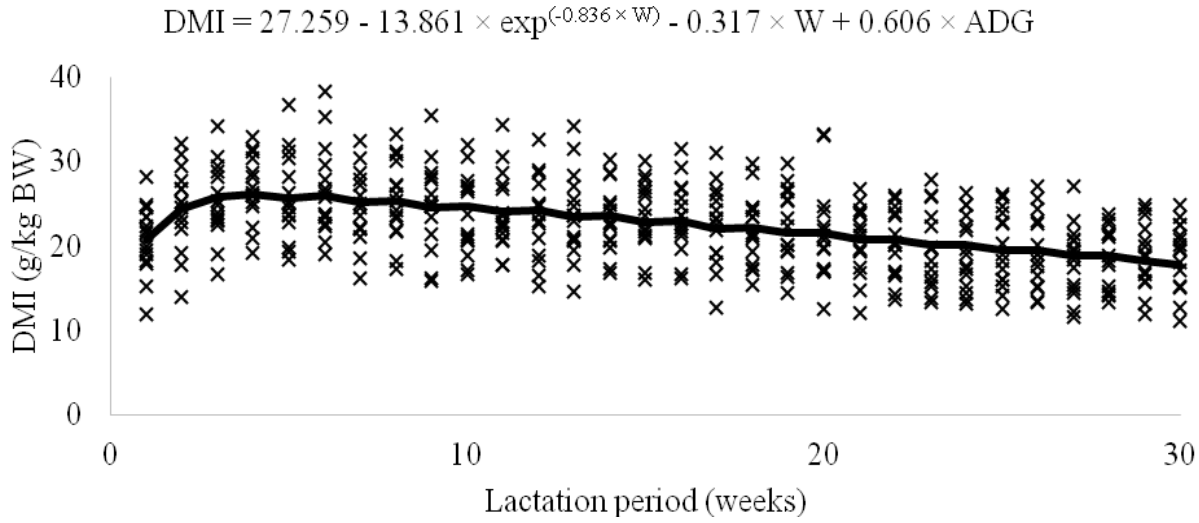

Figure 11.1 - Dry matter intake (g/BW) of Zebu cows during the lactation period.

Thus, the equation proposed by Costa e Silva (2015) was:

$$DMI\ (g/BW) = 27.259 - 13.861 \times \exp^{(-0.836 \times W)} - 0.317 \times W + 0.606 \times ADG,$$

where: DMI = dry matter intake, W = week of lactation, ADG = average daily gain (kg/d).

Considering the recommendation of BR-CORTE (2010), only values predicted in the beginning of lactation from the equation proposed by Costa e Silva (2015) are close to the mean recommended by the BR-CORTE (2010). However, when the last 4 weeks of lactation are considered, the difference between the recommendation of the BR-CORTE (2010) and the values predicted by the equation of Costa e Silva (2015) was 1.5 kg/d (6.0 *vs.* 7.5 kg/d).

Furthermore, Costa e Silva (2015) verified that the equation using the model proposed by Wilmink (1987) added to ADG correctly estimated the DMI of lactating Zebu cows raised on pasture from an independent database that contained a total of 120 observations (Table 11.1).

Table 11.1 - Descriptive statistics of the independent database utilized to evaluate the prediction equations for dry matter intake (DMI) and milk yield of beef cows

Study	Item	n	Mean	SD[1]	Maximum	Minimum
Lopes (2012)	Week of lactation	-	26.5	5.45	37.0	12.0
	Milk yield	143	6.97	1.58	9.99	4.24
	Total DMI	32	11.8	2.35	17.0	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 of lactation	-	28.1	6.38	40.0	12.0
	Milk yield	170	7.00	1.36	9.87	4.21
	Total DMI	60	12.9	1.45	16.7	9.94
	Body weight	60	450	51.6	567	362
	Average daily gain	60	0.20	0.09	0.40	-0.04
Márquez (2013)	Week of lactation	-	27.3	8.63	41.0	10.0
	Milk yield	61	6.49	1.64	9.40	3.37
	Total DMI	28	15.5	3.04	22.9	8.49
	Body weight	28	499	44.6	595	428
	Average daily gain	28	0.05	0.11	0.28	-0.17
Lopes (2015)	Week of lactation	-	8.05	2.65	12.0	3.00
	Milk yield	37	8.47	1.46	10.8	5.79

[1] SD = standard deviation; Adapted from Costa e Silva (2015).

After evaluations, Costa e Silva (2015) observed that the intercept and slope of the equation were not different from 0 and 1, respectively. Moreover, the mean square error of the prediction was close to zero, with this error being associated with random errors (92.1%; Table 11.2). Thus, in this edition of BR-CORTE is recommended that total DMI of lactating beef cows could be estimated from the following equation:

$$DMI\ (g/kg\ BW) = 27.259 - 13.861 \times \exp^{(-0.836 \times W)} - 0.317 \times W + 0.606 \times ADG.$$

MILK YIELD AND COMPOSITION OF BEEF COWS

The second edition of the BR-CORTE was based on the study developed by Henriques et al. (2011), suggesting an equation to estimate the milk yield of Zebu cows. These authors evaluated five models and recommended that the model described by Jenkins and Ferrell (1984) modified by Detmann (personal communication) was the best model that adjusted data. However, due to the lack of a model developed for Zebu cattle, the equation suggested by Henriques et al. (2011) was adopted:

$$MY = 5.9579 + 0.4230 \times W \times \exp^{(0.1204 \times W)},$$

where MY = milk yield and W = week of lactation. Nevertheless, Costa e Silva (2015) evaluated five models available in the literature to estimate the MY of Zebu cows during the seven-months lactation. In this study, the cows received a high-roughage diet (85% on DM basis) to simulate a diet at pasture receiving supplementation. Thereby, the equation that presented the better estimates was that adjusted using the model proposed by Cobby and Le Du (1978; Figure 11.2).

Table 11.2 - Mean (kg) and descriptive statistics for the relationship between observed and predict values of dry matter intake (DMI) and milk yield of lactating beef cows and DMI of roughage and concentrate of suckling beef calves

Item	Total DMI for cows		Milk yield				DMI of roughage and concentrate for calves	
	OBS[1]	Wilmink (1987) with ADG[2]	OBS[1]	Cobby and Le Du (1978)[3]	BR-CORTE (2010)[4]	NRC (1996)[5]	OBS[1]	BR-CORTE (2016)[6]
Mean	12.1	11.7	7.04	7.05	6.5	3.49	2.51	2.34
SD[7]	2.28	1.36	1.57	0.58	0.32	1.98	0.64	0.34
Maximum	17.0	14.0	10.8	8.57	7.25	8.00	3.99	3.37
Minimum	7.95	8.94	3.37	5.98	6.08	0.83	0.99	1.35
R	-	0.38	-	0.39	0.15	0.15	-	0.44
CCC[8]	-	0.33	-	0.65	0.14	0.13	-	0.33
Regression								
Intercept								
Estimate	-	4.49	-	-0.42	-5.29	5.97	-	0.55
SE	-	2.88	-	0.88	1.45	0.15	-	0.29
P-value[9]	-	0.13	-	0.64	< 0.001	< 0.001	-	0.054
Slope								
Estimate	-	0.65	-	1.06	1.9	0.31	-	0.85
SE	-	0.25	-	0.12	0.22	0.04	-	0.12
P-value[10]	-	0.16	-	0.63	< 0.001	< 0.001	-	0.24
MSEP[11]	-	4.68	-	2.09	2.47	16.6	-	0.40
Mean bias	-	0.15	-	0.00	0.30	12.6	-	0.04
Systematic bias	-	0.22	-	0.01	0.08	1.86	-	0.002
Random errors	-	4.31	-	2.08	2.09	3.79	-	0.35

[1]OBS = observed values; [2]Wilmink (1987) with ADG = values predicted by the equation generated from the model proposed by Wilmink (1987) added to average daily gain (ADG); [3]Cobby and Le Du (1978) = values predicted by the equation generated from the model proposed by Cobby and Le Du (1978); [4]BR-CORTE (2010) = values predicted by the equation suggested by Valadares Filho et al. (2010); [5]NRC (1996): milk yield = week/(0.3911 × $\exp^{(0.1176 \times week)}$); [6]BR-CORTE (2016) = values predicted by the equation proposed by Costa e Silva (2015); [7] SD = standard deviation; [8]CCC = concordance correlation coefficient; [9]H_0: $\beta_0 = 0$; [10]H_0: $\beta_1 = 1$; [11]MSEP = mean square error of prediction.

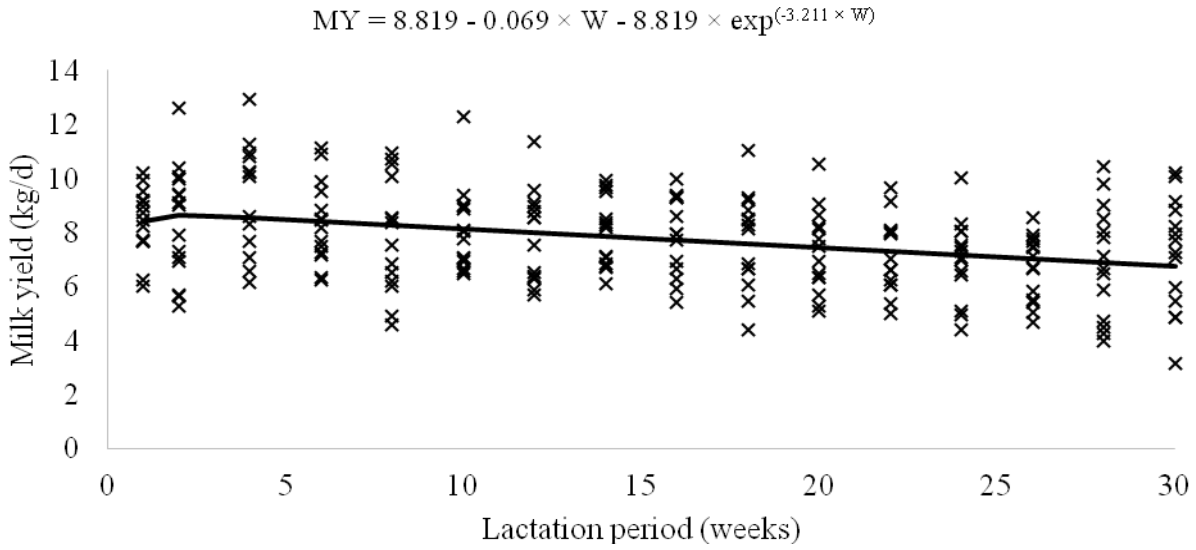

Figure 11.2 - Relationship between milk yield and week of lactation for lactating Zebu cows.

Furthermore, Costa e Silva (2015) evaluated whether the equations proposed by the BR-CORTE (2010), NRC (1996), and Cobby and Le Du (1978), correctly estimated the MY of Nellore cows raised on pasture of *Urochloa spp*. For that, an independent database was developed that contained 411 observations from 4 experiments conducted in the Beef Cattle sector of the Animal Science Department at *Universidade Federal de Viçosa* (Table 11.1).

After evaluation, Costa e Silva (2015) verified that the equation suggested by the model proposed by Cobby and Le Du (1978) had the better estimate as it was the unique equation that correctly estimated the MY of Nellore cows, presenting greater CCC (0.65) and lower mean square error of prediction (2.09), with 99.5% of this error being associated with random errors (Table 11.2). Thus, in this edition of BR-CORTE (2016) suggests the following equation to estimate milk yield of beef cows:

$$MY = 8.819 - 0.069 \times W - 8.819 \times \exp^{(-3.211 \times W)}.$$

The BR-CORTE (2010) utilized data from Fonseca (2009) to milk composition of Nellore cows. However, this recommendation discarded the variation that occurs through lactation in the concentration of milk components, considering only an average for each component during the entire lactation period. Moreover, mineral composition of the milk of Nellore cows was not presented in the last edition of the BR-CORTE (2010).

Then, Costa e Silva et al. (2015a) evaluated the milk composition of multiparous Nellore cows and verified that the percentage of total solids, lactose, and fat do not vary while protein increases through lactation. Thus, these authors suggested that the milk composition of Nellore cows would have an average percentage of 15.0% total solids, 4.59% lactose, and 5.61% fat, while protein would increase from 3.6%, at the beginning of lactation until 112 days, to 3.9%, at 7 months of lactation. The values were close to those recommended by the last edition of the BR-CORTE (2010), with an exception for fat content (5.61 *vs.* 3.88%). These greater values found by Costa e Silva et al. (2015a) can be attributed to a greater supply of roughage provided in the diet which possibly stimulated acetate production and thus caused a greater amount of substrate for *de novo* fat synthesis in the mammary gland. Furthermore, Costa e Silva et al. (2015a) also evaluated mineral milk composition of Zebu cows and considered that the average concentrations would be 1.11% Ca, 0.76% P, 0.20% Na, 0.25% S, 2.29 ppm Co, 3.20 ppm Cr, 29.9 ppm Fe, and 1.40 ppm Mn (Table 11.3).

Table 11.3 - Milk composition of Zebu cows during lactation

Component	Days of lactation							SEM	*P*-value
	28	56	84	112	140	168	196		
Total solids (%)	14.5	14.7	14.8	14.9	15.1	15.4	15.6	0.40	0.13
Protein (%)	3.57^{c}	3.50^{c}	3.54^{c}	3.62^{c}	3.75^{b}	3.87^{a}	3.94^{a}	0.10	<0.001
Lactose (%)	4.58	4.66	4.63	4.62	4.60	4.52	4.48	0.10	0.05
Fat (%)	5.20	5.44	5.58	5.53	5.65	5.90	5.98	0.40	0.44
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)	2.32^{ab}	2.58^{a}	1.99^{b}	2.20^{ab}	2.48^{ab}	2.16^{ab}	2.28^{ab}	0.20	0.03
Cr (ppm)	3.19	3.33	3.24	3.03	3.28	3.27	3.05	0.20	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 last edition of the BR-CORTE (2010) recommended the constant value of 2.35% BW for total DMI of suckling Zebu calves during the first six months of age; 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 Zebu calves during the breast-feeding phase. Also, knowing milk intake from the MY of cows and multiplying it by its DM content, we can obtain DMI from milk. Thereby, from the sum of DMI of milk and solid feedstuffs, we can access the total DMI of calves during the breast-feeding period. Thus, in this edition of the BR-CORTE, the following equation proposed by Costa Silva (2015) was adopted to estimate dry matter intake 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 5 experiments conducted on pasture (Table 11.4), this equation was evaluated, resulting in the correct estimate of DMI of roughage and concentrate of suckling beef calves (Table 11.2). So, this equation is recommended by this edition of BR-CORTE (2016).

Table 11.4 - Descriptive statistics of the independent database utilized to predict dry matter intake of roughage and concentrate of suckling beef calves

Study	Item	n	Mean	SD[1]	Maximum	Minimum
Lopes (2012)	Age (d)	-	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 (d)	-	192	33.2	245	120
	DMI of concentrate	62	0.46	0.20	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 (d)	-	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 (d)	-	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 (d)	-	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

[1] SD = standard deviation

ENERGY REQUIREMENTS FOR LACTATING BEEF COWS

The calculations utilized for nutrient requirements of lactating Zebu cows and their calves followed the same recommendations suggested in previous chapters. Due to the lack of experiments using lactating beef cows and their calves since the last edition of the BR-CORTE, in 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:

$$EBW = 0.8507 \times SBW^{1.0002},$$

and the relationship between empty body gain (EBG) and ADG was considered as 0.936. Accordingly explained in the chapter of energy requirements for beef cattle, heat production (HP) 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 expressed as kcal/EBW$^{0.75}$/d and MEI = metabolizable energy intake (kcal/EBW$^{0.75}$/d). Thus, from the previous equation, when MEI is equivalent to zero, we can obtain the value of 97.8 kcal/EBW$^{0.75}$/d, that is the net energy required for the maintenance of lactating Zebu cows.

The NRC (1996) stablished the NEm for beef cattle as 77 kcal/EBW$^{0.75}$/d, obtained from the data of Lofgreen and Garret (1968). Also, this system recommended discounts of 10% for Zebu cattle and an increase of 20% for lactating beef cows. Therefore, adopting these recommendations, the net energy required for the maintenance of lactating Zebu cows, according to the 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 last edition of the BR-CORTE, in 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), of 97.8 kcal/EBW$^{0.75}$/d.

Therefore, due to the lack of information for this animal category, BR-CORTE (2016) recommended the use of the value of 97.8 kcal/EBW$^{0.75}$/d as the net energy required for the maintenance of lactating Nellore cows.

The metabolizable energy required for the maintenance (MEm) of lactating Zebu cows was obtained when the MEI was equal to heat production using the iterative process in the previously proposed equation, which resulted in the 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 × Red Polled × Pinzgauer), the MEm was estimated as 146 kcal/BW$^{0.75}$/d and the efficiency of the use of ME for maintenance was 72%. Nevertheless, Calegare et al. (2007) estimated the MEm as 141.3 kcal/BW$^{0.75}$/d for lactating Nellore cows, being this value close to that observed by Fonseca (2009).

The energy loss related to body reserve mobilization 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 who 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 the mean value of 4.3 Mcal/BW loss. This value is below those recommended by other nutrient requirement systems that utilized *Bos taurus* cattle as a baseline for the calculations which could explain the differences between them (Table 11.5). The efficiency of the use of energy from body reserve mobilization for MY obtained by Freetly et al. (2006) was 78%, while the AFRC (1993) and the CSIRO (2007) considered this efficiency as 84%.

Table 11.5 - 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 increased control for important variables such as metabolizable energy intake to be obtained, which is utilized for calculations of the estimates.

Thereby, we believe that there is an underestimation of the energy obtained for the maintenance of animals maintained in feedlot, because it is not considered an extra energy expense that would be observed for animals raised on pasture. In an extensive situation, 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 heart beats 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 total energy production, respectively (Brosh et al., 2010). Thus, researches evaluating the increase in requirements for maintenance that grazing activities can cause in the breast-feeding herd might be conducted in Brazil to improve the understanding of variations on energy efficiency of the animals (Kelly et al., 2010).

The net energy required for growth (NEg) of lactating Nellore cows were calculated from equation described by Fonseca (2009):

$$NEg = EBG \times (1.0076 \times EBW^{0.2389}),$$

where NEg = net energy required for growth (Mcal/d), EBG = empty body gain (kg/d), and EBW = empty body weight (kg). The efficiency of the use of metabolizable energy (ME) for growth (*kg*) of lactating Nellore cows was 0.44, equivalent to the slope of the equation from relationship between RE (kcal/EBW$^{0.75}$/d) and MEI (kcal/EBW$^{0.75}$/d) described in Figure 11.3. Flatt et al. (1967), evaluating lactating Holstein cows, found the value of 0.64 for *kg*. If a retained energy equal to zero is considered, the requirements of ME for maintenance of beef lactating cows would be estimated as 140.1 kcal/EBW$^{0.75}$/d, which is a value close to that obtained by the iterative process (Figure 11.3).

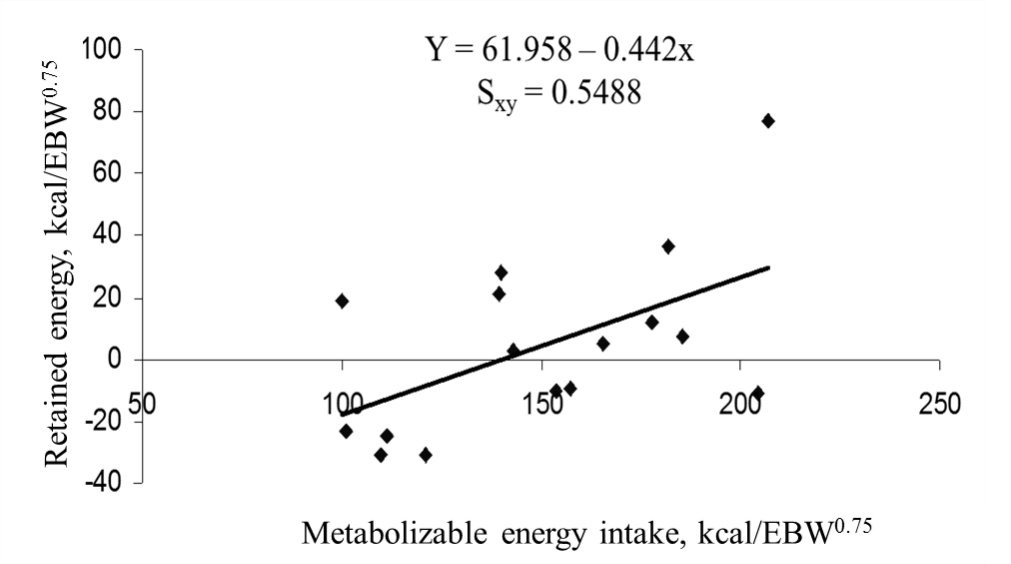

Figure 11.3 - Retained energy as a function of metabolizable energy intake. Adapted from Fonseca et al. (2012).

The net 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 (k_l) equal to *km* (BCNRM, 2016) of 0.72, the requirements of ME for lactation (ME_l) are 1.04 Mcal/kg milk.

In addition, the 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 Costa e Silva et al. (2015a)

of 3.69% CP, 4.59% lactose, and 5.61% fat, the requirement of NE for lactation, using the equation proposed by NRC (2001): NE_l (Mcal/kg milk) = 0.0929 × % fat + 0.0547 × % protein + 0.0395 × % lactose, is 0.904 Mcal/kg milk. Moreover, ME_l can be calculated as 1.26 Mcal/kg milk (0.904/0.72), which is higher than that found by Fonseca (2009), possibly due to the greater fat content in the milk found by Costa e Silva et al. (2015a). Alternatively, if there is no complete milk composition, or when there is only knowledge of the fat content of milk, the equation from NRC (2001) can be used: NE_l (Mcal/kg milk) = 0.36 + 0.0969 × % fat.

To convert ME to TDN was considered, first to convert ME to DE (for more details, see Chapter 6): 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 0.38 kg/kg milk when ME_l is 1.26 Mcal/kg milk.

ENERGY REQUIREMENTS FOR SUCKLING BEEF CALVES

The conversion of SBW for empty body weight (EBW) of suckling 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 of data from the study of Fonseca et al. (2012b), the requirements of ME for the maintenance of suckling calves was not estimated in the last edition of the BR-CORTE; 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 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 efficiency of the use of MEg were utilized, with *kg* = 0.69 for milk intake and *kg* = 0.57 for solid feedstuffs intake according to the recommendations of the NRC (2001). Then, in the period from 0 to 90 days of age, the *kg* of 0.66 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 feedstuffs consumed by calves in the respective periods (Fonseca, 2009).

The 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 this edition of the BR-CORTE (for more details, see Chapter 8) 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 obtained using the recommendation suggested by the BR-CORTE (2016):

$k = 47.4\%$.

The protein required for lactation is based on the amount of protein secreted in the milk. From the equation presented to estimate milk yield, the amount of protein produced in the milk can be estimated. The NRC (2001) suggests an equation to calculate the requirements of metabolizable protein for lactation (MP_l):

$MP_l\ (g/d) = CPmilk/0.67 \times 1000$

where CPmilk = true protein presented in the milk (kg/d), and 0.67 = efficiency of the use of metabolizable protein for lactation.

The average of CP content in the milk of Zebu cows obtained by Costa e Silva et al. (2015a) was 3.69%; this CP content was multiplied by the percentage of true protein in milk (AFRC, 1993), which is 95%, resulting in the value of 3.50% or 35.0 g of true protein per kilogram of 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 the animals, and feeding frequency (Schroeder and Titgemeyer, 2008). Due to the lack of a consistent value, we considered the efficiency of the use of metabolizable protein for lactation to be 0.67 (NRC, 2001), which resulted in the value of 52.3 g metabolizable protein (MP) per kilogram of milk, corresponding to the requirements of MP for lactation. This value is greater than 44.8 g MP per kilogram of milk presented for a milk with 3.15% CP (AFRC, 1993; NRC, 2001). Therefore, we recommend that the requirements of MP for lactating beef cows might be 52.3 g/kg milk.

The microbial crude protein synthesis (MCP) was calculated considering the recommendation presented in the Chapter 3, where microbial CP synthesis was calculated as a function of the intakes of crude protein (CPI) and total digestible nutrients (TDNI) 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 = total digestible nutrients intake (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 8):

$RDP = MCP$,

where the requirements of rumen undegradable protein (RUP) were obtained from the following equation:

$RUP = (\text{Total metabolizable protein} - (MCP \times 0.64))/0.80$.

So, the requirements of crude protein 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 in this edition of the BR-CORTE for animals raised on pasture (for more details, see Chapter 8):

$MPm = 3.9 \times SBW^{0.75}$.

The net 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 the Chapter 3, in which microbial synthesis was calculated as a function of the intakes of crude protein (CPI) and total digestible nutrients (TDNI).

However, calves, when consuming milk, present reflex for the formation of an esophageal groove, causing milk to go directly into the abomasum without suffering the action of microorganisms in the rumen. In this case, considering that protein and energy from milk to get MCP would not be the most correct. Thus, for suckling calves, we recommend 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 recommend the use of the following equation:

$MCP\ (g/d) = -53.07 + 304.9 \times (\text{total CPI} - \text{CPImilk}) + 90.8 \times (\text{total TDNI} - \text{TDNImilk}) - 3.13 \times (\text{total TDNI} - \text{TDNImilk})^2$,

where total CPI = total crude protein intake in the diet (kg/d), CPImilk = crude protein intake from milk (kg/d), total TDNI = total digestible nutrients intake in the diet (kg/d), and TDNImilk = total digestible nutrients intake from milk (kg/d).

For calculation of CPImilk, the milk yield of cows might be quantified and multiplied by the crude protein content of the milk. For TDN, initially, the contents of protein, lactose and fat in the milk might be quantified. According to the publication of Maynard et al. (1979), which states that the digestibility of milk constituents is 0.98 (carbohydrates), 0.95 (fat) and from BCNRM (2016) of 0.95 (protein), we considered the sum of the digestible constituents of the milk to account for the TDN intake from milk as shown in the following equation:

$TDNImilk = MY \times ((\%\ CP \times 0.95 + \%\ lactose \times 0.98) + (2.25 \times \%\ fat \times 0.95))$.

Considering the mean milk composition from the study of Costa e Silva et al. (2015a) as 3.69% CP, 4.59% lactose, and 5.61% fat, the TDN content of this milk would be approximately 20% on a natural basis or 138% on a dry matter basis of the milk (20/0.145).

However, considering that calves with a BW lower 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 of the BR-CORTE adopted the same recommendation as the last edition of the BR-CORTE in 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 of the BR-CORTE, for which microbial protein synthesis is equal to the RDP requirements (for more details, see Chapter 8):

$RDP = MCP$,

where the requirements of rumen undegradable protein (RUP) were obtained from the following equation:

$RUP = (\text{total metabolizable protein} - (MCP \times 0.64))/0.80$.

To obtain the crude protein 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 the maintenance and

retention coefficient of lactating beef cows and suckling calves, these estimates were calculated according to recommendations presented in Chapter 9 about the mineral requirements for beef cattle. With regard to the net requirements of macrominerals (Ca, P, Mg, Na, and K) for growth, the amounts of each mineral present in the animal's body were regressed as a function of EBW from the following model:

$$Mi = a \times EBW^{b},$$

where Mi = the amount of each macromineral (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 the growth of lactating beef cows and suckling calves were calculated from the following model:

$$Y = a \times b \times EBW^{b-1},$$

which Y = net requirements of each mineral for growth (g/d), EBW = empty body weight (kg).

Thus, the equations generated to estimate the net requirements of each mineral for growth considering each animal category are shown in the Table 11.6. Due to non-adjustment to data for Ca of lactating cows (Fonseca, 2009), the recommendation from Chapter 9 was used to estimate the net requirements for the growth of this mineral. Furthermore, due to the lack of recommendations for sulfur and microminerals for both animal categories (Fonseca, 2009), the equations described in the Chapter 9 were adopted.

Table 11.6 - Net requirements of macrominerals (Ca, P, Mg, Na, and K) 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: NRCa (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 from Chapter 9. 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 9).

TABLES OF THE NUTRIENT REQUIREMENTS OF LACTATING BEEF COWS AND THEIR CALVES

From estimates of the requirements of energy, protein, and macrominerals for growth of lactating beef cows and suckling calves, dietary requirements of the nutrients can be calculated. The equations utilized for the calculations of the nutrient requirements of lactating beef cows and suckling calves are shown in the Tables 11.7, 11.8, and 11.9, respectively, with the equation utilized to calculate microbial N described in Chapter 3, while the net requirements of macrominerals for maintenance, true retention coefficient, and dietary requirements of microminerals are described in Chapter 9.

Table 11.7 - Summary of the equations to estimate energy and protein requirements for lactating beef cows and their calves

Item	Equations		Unit
	Cows	Calves	
DMI	$27.259 - 13.861 \times \exp^{(-0.836 \times W)} - 0.317 \times W + 0.606 \times ADG$	$0.353 - 0.532 \times DMImilk + 0.01065 \times BW + 0.3497 \times ADG$	kg/d
MY	$8.819 - 0.069 \times W - 8.819 \times \exp^{(-3.211 \times W)}$	-	kg/d
SBW	$0.88 \times BW^{1.0175}$	-	kg
EBW	$0.8507 \times SBW^{1.0002}$	$0.962 \times SBW$	kg
EBG	$0.936 \times ADG$	$0.958 \times ADG$	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	$EBG \times (1.0076 \times EBW^{0.2389})$	$0.0932 \times EBW^{0.75} \times EBG^{0.9157}$	Mcal/d
kg	44	Milk = 69 Solids = 57	%
MEg	NEg/kg		Mcal/d
NE_l	0.75	-	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	$EBG \times (376.4 \times EBW^{-0.1839})$	$EBG \times (139.7 \times EBW^{0.0351})$	g/d
k	47.4	84.665 – 0.1179 × EQEBW	%
MP_l	52.3	-	g/kg milk
MPt	MPm + MPg + MP_l	MPm + MPg	g/d
CPImilk	-	MY × 0.0369	g/d
TDNImilk	-	MY × 0.20	kg/d
MCP	$-53.07 + 304.9 \times CPI + 90.8 \times TDNI - 3.13 \times TDNI^2$	SBW < 150 kg: 120 g/kg TDN SBW > 150 kg: $-53.07 + 304.9 \times (CPI - CPImilk) + 90.8 \times (TDNI - TDNImilk) - 3.13 \times (TDNI - TDNImilk)^2$	g/d
RDP	MCP		g/d
RUP	(MPt - (MCP × 0.64))/0.80		g/d
CP	RDP + RUP		g/d

Table 11.8 - Summary of the equations to estimate the net requirements of macrominerals (Ca, P, Mg, Na, K, and S) for growth (g/d) of lactating beef cows and their calves

Item	Equations	
	Cows	Calves
Ca	EBW < 462 kg: EBG × (147 × EBW$^{-0.50}$) EBW ≥ 462 kg: NRCa (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$^{-0.0636}$)
S	EBG × (0.03 × EBW$^{0.8900}$)	

[1]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 9).

Table 11.9 - Summary of the equations utilized for the calculation of dietary requirements of microminerals (Cu, Co, Cr, Fe, Mn, Mo, Se, and Zn) for beef cattle (Adapted from Chapter 9)

Mineral	Net requirements for maintenance	Retention coefficient	Net requirements for growth (NRG)[1]
	µg/kg body weight	%	mg/d
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 × (14.0 × 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$^{0.86}$)

[1]EBG = empty body gain (kg/d); EBW = empty body weight (kg).

Thereby, considering a 450-kg lactating beef cows in the 10th week of lactation with average daily gain of 0.2 kg/d, we have:

• DMI = 27.259 – 13.861 × exp$^{(-0.836 \times 10)}$ – 0.317 × 10 + 0.606 × 0.20 = 24.21 g/kg SBW
• DMI = 24.21 g/kg SBW × 441 kg = 10.68 kg/d
• MY = 8.819 – 0.069 × W – 8.819 × exp$^{(-3.211 \times W)}$ = 8.819 – 0.069 × 10 – 8.819 × exp$^{(-3.211 \times 10)}$ = 8.13 kg/d
• SBW = 0.88 × BW$^{1.0175}$ = 0.88 × 450$^{1.0175}$ = 441 kg
• EBW = 0.8507 × SBW$^{1.0002}$ = 0.8507 × 441$^{1.0002}$ = 375.3 kg
• EBG = 0.936 × ADG = 0.936 × 0.2 = 0.187 kg/d

- **Energy requirements** (Table 11.10):

• NEm = 97.8 × EBW$^{0.75}$ = 97.8 × 375.3$^{0.75}$ = 8,344 kcal/d = 8.34 Mcal/d
• MEm = 135.0 × EBW$^{0.75}$ = 135.0 × 375.3$^{0.75}$ = 11,511 kcal/d = 11.5 Mcal/d
• NEg = 1.0076 × EBW$^{0.2389}$ × EBG = 1.0076 × 375.3$^{0.2389}$ × 0.187 = 0.78 Mcal/d
• MEg = NEg/kg = 0.78/0.44 = 1.77 Mcal/d
• NE_l = 0.75 Mcal/kg milk = 0.75 × 8.13 = 6.10 Mcal/d
• ME_l = NE_l/k_l = 6.10/0.72 = 8.47 Mcal/d
• MEt = MEm + MEg + ME_l = 11.5 + 1.77 + 8.47 = 21.74 Mcal/d
• DE =(((MEt/DMI) + 0.3032)/0.9455) × DMI = (((21.74/10.68) + 0.3032)/0.9455) × 10.68 = 26.42 Mcal/d
• TDN = DE/4.4 = 26.42/4.4 = 6.00 kg/d

- Protein requirements (Table 11.10):

• $MPm = 3.9 \times SBW^{0.75} = 3.9 \times 441^{0.75} = 375.1$ g/d
• $NPg = 0.3764 \times EBW^{-0.1839} \times EBG = 0.3764 \times 375.3^{-0.1839} \times 0.187 = 0.0237$ kg/d = 23.70 g/d
• $MPg = NPg/k = 23.70/0.474 = 50.0$ g/d
• $MP_l = 52.3$ g/kg milk = 52.3 × 8.13 = 425.2 g/d
• $MPt = MPm + MPg + MP_l = 375.1 + 50.0 + 425.2 = 850.3$ g/d
• $MCP = -53.07 + 304.9 \times CPI + 90.8 \times TDNI – 3.13 \times TDNI^2 = -53.07 + 304.9 \times 1.213 + 90.8 \times 6.00 – 3.13 \times (6.00)^2 = 749$ g/d
• RDP = MCP = 749 g/d
• $RUP = (MPt – (MCP \times 0.64))/0.80 = (850.3 – (749 \times 0.64))/0.80 = 463.7$ g/d
• CP = RDP + RUP = 749 + 463.7 = 1,212.7 g/d

To obtain the concentration required of TDN and CP (% DM in the diet), the requirements of TDN (6.00 kg/d) and CP (1212.7 g/d) might be divided by the DMI of the animal.
• TDN (% DM in the diet) = TDN/DMI = 6.00/10.68 = 56.2%
• CP (% DM in the diet) = CP/DMI = 1.2127/10.68 = 11.4%

- Mineral requirements (Table 11.10):

• Calcium:
- Net requirements for maintenance = 11.7 × 450/1,000 = 5.27 g/d
- Net requirements for growth = $EBG \times (147 \times EBW^{-0.50}) = 0.187 \times (147 \times 375.3^{-0.50}) = 1.42$ g/d
- Net requirements for lactation = 1.1 g/kg milk = 1.1 × 8.13 = 8.94 g/d
- Dietary requirements = (Net requirements for maintenance + growth + lactation)/retention coefficient = (5.27 + 1.42 + 8.94)/0.568 = 27.52 g/d

• Phosphorus:
- Net requirements for maintenance = 13.5 × 450/1,000 = 6.08 g/d
- Net requirements for growth = $EBG \times (54.4 \times EBW^{-0.4484}) = 0.187 \times (54.4 \times 375.3^{-0.4484}) = 0.71$ g/d
- Net requirements for lactation = 0.77 g/kg milk = 0.77 × 8.13 = 6.26 g/d
- Dietary requirements = (Net requirements for maintenance + growth + lactation)/retention coefficient = (6.08 + 0.71 + 6.26)/0.678 = 19.25 g/d
Ca:P ratio = 27.52/19.25 = 1.43

• Magnesium:
- Net requirements for maintenance = 5.9 × 450/1,000 = 2.66 g/d
- Net requirements for growth = $EBG \times (1.4 \times EBW^{-0.3227}) = 0.187 \times (1.4 \times 375.3^{-0.3227}) = 0.039$ g/d
- Net requirements for lactation = 0.07 g/kg milk = 0.07 × 8.13 = 0.57 g/d
- Dietary requirements = (Net requirements for maintenance + growth + lactation)/retention coefficient = (2.66 + 0.039 + 0.57)/0.355 = 9.21 g/d

• Sodium:
- Net requirements for maintenance = 6.3 × 450/1,000 = 2.84 g/d
- Net requirements for growth = $EBG \times (1.4 \times EBW^{-0.0575}) = 0.187 \times (1.4 \times 375.3^{-0.0575}) = 0.186$ g/d
- Net requirements for lactation = 0.2 g/kg milk = 0.2 × 8.13 = 1.63 g/d
- Dietary requirements = (Net requirements for maintenance + growth + lactation)/retention coefficient = (2.84 + 0.186 + 1.63)/0.371 = 12.55 g/d

• Potassium:
- Net requirements for maintenance = 23.5 × 450/1,000 = 10.58 g/d
- Net requirements for growth = $EBG \times (3.1 \times EBW^{-0.2142}) = 0.187 \times (3.1 \times 375.3^{-0.2142}) = 0.163$ g/d
- Net requirements for lactation = 0.7 g/kg milk = 0.7 × 8.13 = 5.69 g/d

- Dietary requirements = (Net requirements for maintenance + growth + lactation)/retention coefficient = (10.58 + 0.163 + 5.69)/0.484 = 33.95 g/d

• Sulfur:
- Net requirements for maintenance = 10.4 × 450/1,000 = 4.68 g/d
- Net requirements for growth = EBG × (0.03 × $EBW^{0.89}$) = 0.187 × (0.03 × $375.3^{0.89}$) = 1.10 g/d
- Net requirements for lactation = 0.3 g/kg milk = 0.3 × 8.13 = 2.44 g/d
- Dietary requirements = (Net requirements for maintenance + growth + lactation)/retention coefficient = (4.68 + 1.10 + 2.44)/0.773 = 10.63 g/d

• Cobalt:
- Net requirements for maintenance = 13.5 × 450/1,000 = 6.08 mg/d
- Net requirements for growth = EBG × (0.045 × $EBW^{-0.023}$) = 0.187 × (0.045 × $375.3^{-0.023}$) = 0.007 mg/d
- Net requirements for lactation = 2.3 mg/kg milk = 2.3 × 8.13 = 18.70 mg/d
- Dietary requirements = (Net requirements for maintenance + growth + lactation)/retention coefficient = (6.08 + 0.007 + 18.70)/0.868 = 28.56 mg/d

• Copper:
- Net requirements for maintenance = 95.6 × 450/1,000 = 43.02 mg/d
- Net requirements for growth = EBG × (1.25 × $EBW^{0.33}$) = 0.187 × (1.25 × $375.3^{0.33}$) = 1.65 g/d
- Net requirements for lactation = 1.99 mg/kg milk = 1.99 × 8.13 = 16.18 g/d
- Dietary requirements = (Net requirements for maintenance + growth + lactation)/retention coefficient = (43.02 + 1.65 + 16.18)/0.735 = 82.79 mg/d

• Chromium:
- Net requirements for maintenance = 22.9 × 450/1,000 = 10.31 mg/d
- Net requirements for growth = EBG × (0.23 × $EBW^{0.61}$) = 0.187 × (0.23 × $375.3^{0.61}$) = 1.60 mg/d
- Net requirements for lactation = 3.2 mg/kg milk = 3.2 × 8.13 = 26.0 g/d
- Dietary requirements = (Net requirements for maintenance + growth + lactation)/retention coefficient = (10.31 + 1.60 + 26.0)/0.784 = 48.35 g/d

• Iron:
- Net requirements for maintenance = 2,942 × 450/1,000 = 1,324 mg/d
- Net requirements for growth = EBG × (14.0 × $EBW^{0.24}$) = 0.187 × (14.0 × $375.3^{0.24}$) = 10.86 mg/d
- Net requirements for lactation = 29.9 mg/kg milk = 29.9 × 8.13 = 243.1 mg/d
- Dietary requirements = (Net requirements for maintenance + growth + lactation)/retention coefficient = (1,324 + 10.86+ 243.1)/0.734 = 2,150 mg/d

• Manganese:
- Net requirements for maintenance = 184.9 × 450/1,000 = 83.21 mg/d
- Net requirements for growth = EBG × (0.07 × $EBW^{0.80}$) = 0.187 × (0.07 × $375.3^{0.80}$) = 1.50 mg/d
- Net requirements for lactation = 1.41 mg/kg milk = 1.41 × 8.13 = 11.46 mg/d
- Dietary requirements = (Net requirements for maintenance + growth + lactation)/retention coefficient = (83.21 + 1.50 + 11.46)/0.439 = 219.1 mg/d

• Zinc:
- Net requirements for maintenance = 334.4 × 450/1,000 = 150.5 mg/d
- Net requirements for growth = EBG × (1.07 × $EBW^{-0.07}$) = 0.187 × (1.07 × $375.3^{-0.07}$) = 0.13 mg/d
- Net requirements for lactation = 35.4 mg/kg milk = 35.4 × 8.13 = 287.8 mg/d
- Dietary requirements = (Net requirements for maintenance + growth + lactation)/retention coefficient = (150.5 + 0.13 + 287.8)/0.668 = 656.3 mg/d

Table 11.10 – Energy, protein, macrominerals and microminerals requirements for lactating beef cows

Requirements	Body weight (kg)								
	400			450			500		
ADG (kg/d)	0.10	0.20	0.30	0.10	0.20	0.30	0.10	0.20	0.30
DMI (kg/d)	9.44	9.46	9.49	10.6	10.7	10.7	11.8	11.9	11.9
Energy (Mcal/d)									
NEm		7.62			8.34			9.04	
MEm		10.5			11.5			12.5	
NEg	0.38	0.76	1.13	0.39	0.78	1.17	0.40	0.80	1.20
MEg	0.86	1.72	2.58	0.88	1.77	2.65	0.91	1.81	2.72
NE_l		6.10			6.10			6.10	
ME_l		8.47			8.47			8.47	
MEt	19.8	20.7	21.6	20.9	21.7	22.6	21.9	22.8	23.7
TDN (kg/d)	5.46	5.67	5.88	5.79	6.01	6.22	6.12	6.34	6.56
Crude protein (g/d)									
MPm		343			375			407	
NPg	12.1	24.2	36.3	11.8	23.7	35.5	11.6	23.2	34.8
MPg	25.5	51.1	76.6	25.0	50.0	75.0	24.5	49.0	73.5
MPl		425			425			425	
MPt	794	819	845	825	850	875	856	881	905
RDP	694	717	739	727	749	771	758	780	802
RUP	437	450	464	450	464	477	464	477	490
CP	1,131	1,167	1,204	1,177	1,213	1,248	1,222	1,257	1,292
Macrominerals (g/d)									
Ca	25.3	26.6	28.0	26.3	27.5	28.8	27.2	28.4	29.6
P	17.8	18.3	18.9	18.7	19.2	19.8	19.7	20.2	20.7
Mg	8.31	8.36	8.42	9.14	9.19	9.25	9.97	10.0	10.1
Na	11.4	11.7	11.9	12.3	12.5	12.8	13.1	13.4	13.6
K	31.4	31.5	31.7	33.8	33.9	34.1	36.2	36.4	36.5
S	9.18	9.81	10.5	9.92	10.6	11.3	10.7	11.4	12.2
Microminerals (mg/d)									
Co	27.8	27.8	27.8	28.5	28.5	28.6	29.3	29.3	29.3
Cu	75.1	76.2	77.3	81.7	82.8	83.9	88.2	89.4	90.5
Cr	45.8	46.8	47.7	47.3	48.4	49.4	48.9	50.0	51.1
Fe	1,942	1,949	1,956	2,142	2,150	2,157	2,343	2,350	2,358
Mn	196	198	199	217	219	221	239	240	242
Zn	631	631	631	656	656	656	681	681	681

*Considering a cow in the 10th week of lactation and milk yield of 8.13kg/d.

To exemplify the nutrient requirements of suckling beef calves, a 150-kg calf, son of the cow utilized in the previous example, was considered with ADG of 0.80 kg/d and consuming a diet consisted by 55% milk and 45% forage + concentrate on DM basis:

• DMImilk = MY × % DM milk = 8.13 × 0.145 = 1.18 kg/d
• DMIrc = 0.353 - 0.532 × DMImilk + 0.01065 × BW + 0.34965 × ADG = 0.353 – 0.532 × 1.18 + 0.01065 × 150 + 0.3497 × 0.80 = 1.60 kg/d
• $DMI_{total} = DMI_{rc} + DMI_{milk}$ = 1.60 + 1.18 = 2.78 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** (Table 11.11):
• $NEm = 70.3 \times EBW^{0.75} = 70.3 \times 144^{0.75}$ = 2.93 Mcal/d
• $MEm = 118.6 \times EBW^{0.75} = 118.6 \times 144^{0.75}$ = 4.94 Mcal/d
• $NEg = 0.0932 \times EBW^{0.75} \times EBG^{0.9157} = 0.0932 \times 144^{0.75} \times 0.77^{0.9157}$ = 3.04 Mcal/d
• kg = 55 × 0.69 + 45 × 0.57 = 0.64
• MEg = NEg/kg = 3.04/0.64 = 4.75 Mcal/d
• MEt = MEm + MEg = 4.94 + 4.75 = 9.69 Mcal/d
• DE = ME/0.96 = 9.69/0.96 = 10.1 Mcal/d
• TDN = DE/4.4 = 10.1/4.4 = 2.29 kg/d

- **Protein requirements** (Table 11.11):
• $MPm = 3.9 \times SBW^{0.75} = 3.9 \times 150^{0.75}$ = 167 g/d
• $NPg = 0.1397 \times EBW^{0.0351} \times EBG = 0.1397 \times 144^{0.0351} \times 0.77$ = 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 + 188.4 = 356.4 g/d
• CPImilk = MY × 0.0369 = 8.13 × 0.0369 = 0.300 kg
• TDNImilk = MY × 0.20 = 8.13 × 0.20 = 1.626 kg
• $MCP = -53.07 + 304.89 \times (CPI - CPImilk) + 90.79 \times (TDNI - TDNImilk) - 3.13 \times (TDNI - TDNImilk)^2 = -53.07 + 304.89 \times (0.459 - 0.300) + 90.79 \times (2.29 - 1.626) - 3.13 \times (2.29 - 1.626)^2$ = 73.8 g/d
• RDP = MCP = 73.8 g/d
• RUP = (MPt – (MCP × 0.64))/0.80 = (356.4 – (73.8 × 0.64))/0.80 = 385 g/d
• CP = RDP + RUP = 73.8 + 385 = 459 g/d

In the same way as for cows, to obtain the concentration required of TDN and CP (% DM in the diet), the requirements of TDN (2.29 kg/d) and CP (459 g/d) can be divided by DMI of the animal.

• TDN (% DM in the diet) = TDN/DMI = 2.29/2.78 = 82.4%
• CP (% DM in the diet) = PB/DMI = 0.459/2.78 = 16.5%

- **Mineral requirements** (Table 11.11):
• **Calcium:**
- Net requirements for maintenance: 11.7 × 150/1000 = 1.755 g/d
- Net requirements for growth = $EBG \times (54.8 \times EBW^{-0.3981}) = 0.77 \times (54.8 \times 144^{-0.3981})$ = 5.835 g/d
- Dietary requirements = (Net requirements for maintenance + growth)/retention coefficient = (1.755 + 5.835)/0.568 = 13.36 g/d

• Phosphorus:
- Net requirements for maintenance: 13.5 × 150/1000 = 2.025 g/d
- Net requirements for growth = EBG × (8.6 × $EBW^{-0.0371}$) = 0.77 × (8.6 × $144^{-0.0371}$) = 5.507 g/d
- Dietary requirements = (Net requirements for maintenance + growth)/retention coefficient = (2.025 + 5.507)/0.678 = 11.11 g/d
Ca:P ratio= 13.36/11.1 = 1.20

• Magnesium:
- Net requirements for maintenance: 5.9 × 150/1000 = 0.885 g/d
- Net requirements for growth = EBG × (0.4 × $EBW^{-0.0173}$) = 0.77 × (0.4 × $144^{-0.0173}$) = 0.282 g/d
- Dietary requirements = (Net requirements for maintenance + growth)/retention coefficient = (0.885 + 0.282)/0.355 = 3.29 g/d

• Sodium:
- Net requirements for maintenance: 6.3 × 150/1000 = 0.945 g/d
- Net requirements for growth = EBG × (1.2 × $EBW^{-0.0209}$) = 0.77 × (1.2 × $144^{-0.0209}$) = 0.833 g/d
- Dietary requirements = (Net requirements for maintenance + growth)/retention coefficient = (0.945 + 0.833)/0.371 = 4.79 g/d

• Potassium:
- Net requirements for maintenance: 23.5 × 150/1000 = 3.525 g/d
- Net requirements for growth = EBG × (1.5 × $EBW^{-0.0636}$) = 0.77 × (1.5 × $144^{-0.0636}$) = 0.842 g/d
- Dietary requirements = (Net requirements for maintenance + growth)/retention coefficient = (3.525 + 0.842)/0.484 = 9.02 g/d

We highlight that there are no studies that aimed to evaluate dietary requirements of S and microminerals for this animal category, being suggested the use of same recommendations from the Chapter 9.

Table 11.11 - Energy and protein requirements and dietary requirements of macrominerals (Ca, P, Mg, Na, and K) for suckling beef calves

Requirements	Body weight (kg)											
	100			150			200			250		
ADG (kg/d)	0.60	0.80	1.00	0.60	0.80	1.00	0.60	0.80	1.00	0.60	0.80	1.00
DMI (kg/d)	2.18	2.25	2.32	2.71	2.78	2.85	3.24	3.31	3.38	3.78	3.85	3.92
Energy (Mcal/d)												
NEm		2.16			2.93			3.63			4.29	
MEm		3.64			4.94			6.13			7.24	
NEg	1.72	2.24	2.75	2.34	3.04	3.73	2.90	3.77	4.63	3.43	4.46	5.47
MEg	2.61	3.40	4.17	3.65	4.75	5.83	4.60	5.99	7.35	5.55	7.22	8.86
MEt	6.26	7.04	7.81	8.59	9.69	10.8	10.7	12.1	13.5	12.8	14.5	16.1
TDN (kg/d)	1.48	1.67	1.85	2.03	2.29	2.55	2.54	2.87	3.19	3.03	3.42	3.81
Crude protein (g/d)												
MPm		123			167			207			245	
NPg	94.3	126	157	95.6	127	159	96.6	129	161	97.3	130	162
MPg	129	171	214	141	188	236	156	208	260	173	230	288
MPt	252	295	338	308	356	403	363	415	467	418	476	533
RDP	0.00	5.00	27.0	30.7	73.8	116	117	167	216	200	257	311
RUP	315	364	400	361	385	411	360	385	411	362	389	418
CP	315	369	427	392	459	527	478	552	627	563	646	729
Macrominerals (g/d)												
Ca	11.1	14.1	17.1	10.8	13.36	15.9	11.0	13.2	15.5	11.4	13.5	15.6
P	8.15	10.2	12.2	9.05	11.11	13.1	9.98	12.0	14.0	10.9	12.9	14.9
Mg	2.26	2.46	2.66	3.09	3.29	3.48	3.92	4.11	4.31	4.74	4.94	5.14
Na	3.39	3.95	4.51	4.22	4.79	5.34	5.06	5.62	6.17	5.90	6.46	7.01
K	6.19	6.63	7.08	8.58	9.02	9.45	11.0	11.4	11.8	13.4	13.8	14.2

[1]To convert NEg for MEg, the following kg were utilized as a function of body weight of the animals: 100 kg – 0.66, 150 kg – 0.64, 200 kg – 0.63, and 250 kg – 0.618; [2]Considering milk yield in the following weeks: 10th – 8.13 kg/d (100 kg BW); 19th – 7.51 kg/d (150 kg BW); 28th – 6.89 kg/d (200 kg BW); and 37th – 6.27 kg/d (250 kg BW).

SUPPLEMENTATION OF CALVES DURING BREAST-FEEDING PERIOD

From the information generated in the studies of Fonseca (2009) and Costa e Silva et al. (2015a), or so, considering the lactation curve of Nellore cows, the average milk composition, and according to nutrient requirements obtained for calves through breast-feeding phase, we will be able to estimate the moment when milk is not sufficient to provide 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 84 days of age, the milk does not provide all of the energy necessary for the calf which has an ADG close to 1 kg/d. However, protein becomes limiting only after the 20th week, approximately 140 days of age, which would be around from 70 to 100 days before weaning. Therefore, with the aim being for Nellore calves to maintain body weight gain close to 900 g/d until weaning, we recommend the use of multiple supplements via creep feeding after the third month of age, or then, to utilize cows with greater potential for milk yield (Table 11.12).

Table 11.12 - Milk yield of Nellore cows, availability of metabolizable energy (ME) and protein (MP) from milk, total requirements of ME and MP of suckling Nellore calves, and the need of milk to meet the ME requirements of calves according to the week of lactation and the body weight of the animals

W[1]	BW[2]	MY[3]	ME milk[4]	MP milk[5]	MEt[6]	MPt[7]	NM[8]
1	35.6	8.39	6.38	197	2.82	58.5	3.70
2	41.2	8.67	6.59	204	3.14	65.3	4.13
3	46.8	8.61	6.54	202	3.46	71.8	4.55
4	52.4	8.54	6.49	201	3.76	78.1	4.95
5	58.0	8.47	6.44	199	4.06	84.3	5.34
6	63.6	8.40	6.39	197	4.35	90.3	5.73
7	69.2	8.34	6.34	196	4.64	96.2	6.10
8	74.8	8.27	6.28	194	4.91	102	6.47
9	80.4	8.20	6.23	193	5.19	108	6.83
10	86.0	8.13	6.18	191	5.46	113	7.18
11	91.6	8.06	6.13	189	5.72	119	7.53
12	97.2	7.99	6.07	188	5.98	124	7.87
13	103	7.92	6.02	186	6.24	129	8.21
14	108	7.85	5.97	184	6.49	135	8.54
15	114	7.78	5.92	183	6.74	140	8.87
20	142	7.44	5.65	175	7.95	165	10.5

[1]W = week of lactation; [2] BW = body weight of calf, kg: considering body weight at birth of 30 kg and ADG of 0.80 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) of metabolizable energy of calf; [8]NM: need of milk (kg/d) to meet total requirements of ME of calf. Adapted from the BR-CORTE (2010).

The greater genetic capacity of cows leads to greater milk production, enabling an increase on weaning weight of calves. However, we should not disregard that the nutritional levels in the majority of pasture systems limits higher levels of milk yield (Paulino et al., 2012). Additionally, in the 3rd and 4th months of age, there are considerable changes through the gastrointestinal tract of the calf, and this is the period when this animal turns effectively ruminant (Porto et al., 2009), making it more dependent on pasture. However, these processes occur during the rainy-dry transition period in the most of Brazilian production 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 pasture tends to increase, causing 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 a creep feeding system is recommended. Creep feeding refers to the supply of additional feed for animals during the breast-feeding phase in a restricted area for calves (Paulino et al., 2012).

Studies regarding creep feeding in tropical conditions have consistently shown an increase in BW at weaning (Table 11.13), showing the importance of creep feeding to reduce the age at slaughter and the beginning of reproduction activity for 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 pasture, milk yield of cows, growth potential of calves, breed, sex, age of calves at weaning, and even the type of supplement and time of use of creep feeding influence animal performance.

Table 11.13 - Summary of data from studies about creep feeding

Study[1]	Experimental period (d)	Calf´s sex	Supplement intake (g/d)[2]	CP content in the supplement (g/kg)	ADG[3]	
					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 (2015)[4]	140	Male	1200	250	720	873
Almeida (2016)[4]	140	Female	800	250	642	732
Martins (2016)[4]	140	Male	1600	250	500	900

[1]Data processed; to access individual data, consult references.
[2]Mean intake of supplement from supplemented animals.
[3]ADG = average daily gain (g/d), NS = calves that received only mineral supplementation; or SUP = calves that received multiple supplements in a creep feeding system.
[4]Work in progress.

Then, when the limit imposed by genetics is obeyed, the lower pasture capacity and/or milk yield in meeting the nutritional requirements of calves, the greater will be the response to creep feeding, reflecting positively on the efficiency and profitability of this technique.

However, recommending the best level of supplementation (% BW) and the best CP content in the concentrate is difficult as this combination is inversely proportional; when the aim is to provide lower amounts of supplement, the CP content might be greater and the inverse is true. Therefore, the amount of supplement and CP content will depend directly on the aim of the production system.

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12

Environmental management and prediction of nitrogen and phosphorus excretion by 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 (BCNRM, 2016). The excretion distributed in well-managed pastures (extensive systems) represents little, if any, impact because the soil–plant system has the capacity to use and to retain the majority of the nutrients from manure. However, in drinking, rest or supplementation areas, there is an agglomeration of animals and soil compaction and the manure accumulated may represent an environmental problem. In feedlot, due the large concentration of animals, the large amounts of feces and urine that accumulate on pen surfaces can runoff into surface water, leaching into soil or volatilizing to 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 a role in meeting 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 compounds (N) and phosphorus (P), due to the pollution of soil and water and atmosphere for N.

True protein is the nutrient with the highest unit cost in beef cattle diets, and its inclusion in an unbalanced way in the diet results in increased production costs as well as increased excretion of nitrogen primarily in urine but also in feces (Cavalcante et al., 2005). Phosphorus is the mineral that contributes most to environmental pollution and is considered a significant 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 made with minimal if any 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 primary way of reducing environmental problems in the agriculture. Cole (2003) proposed the use of precision feeding, defined as the feeding management of cattle in order to do not decrease their performance but decrease the nutrient concentration in the diet and thus also reduce the nutrient excretion in the environment. A tool for the use of this management would be the appropriate formulation of diets to meet the nutritional requirements of cattle, reducing the excretion of polluting compounds without decrease animal performance.

Reduced nitrogen and phosphorus excretion can result in lower environmental impact and greater economic profit to the production system by reducing the use of nitrogen and phosphorus sources.

The development of control strategies is a complex issue but extremely important. The properly design of animal facilities,

avoiding the superficial runoff or infiltration to ground water is essential. In addition, management and composting of manure in intensive systems is a huge opportunity of generation of bio-fertilizers and/or bio-energy that minimize the environmental beef cattle of the activity and can create additional profits to the production system.

Thus, our objective was to develop equations that would be useful for the prediction of nitrogen and phosphorus excretion by beef cattle under tropical conditions.

EQUATIONS PROPOSED BY BCNRM (2016) EVALUATION

The BCNRM (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 BCNRM (2016), were tested for appropriateness for these database. 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
[BCNRM, 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 BCNRM (2016) were tested using the BR-CORTE (2016) database. For nitrogen excretion was used 751 individual data (Table 12.3) and for phosphorus excretion was used 178 individual data (Tables 12.8 and 12.10).

The equations for nitrogen excretion (Waldrip et al., 2013; Dong et al., 2014) use nitrogen intake as an independent variable. The BCNRM (2016) proposed an equation for predicting urinary N excreted using the nitrogen intake and dry matter intake as independent variables. The equations cited by BCNRM (2016) system do not correctly estimated excretion of nitrogen ($P < 0.05$; Table 12.1). 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 also due to genetic factors.

The proposed equation for P excretion (Geisert et al., 2010) did not correctly estimate the excretion of P for BR-CORTE data ($P < 0.05$; Table 12.1); however, a high CCC value was obtained. The lack of accuracy in estimating the excretion of P can be explained by genetic factors, because animals used by Geisert et al. (2010) differ from Zebu and crossbred animals used under tropical conditions.

Thus, is necessary to develop equations consistent with the environmental and genetic conditions in Brazil. Therefore, BR-CORTE (2016) generated new equations, based on a more robust database, and with a greater number of observations to estimate the 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 it assists in environmental issues and can identify management practices to reduce excretions.

Table 12.1 - 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)		BCNRM (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 by means of 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 feces, while the digested protein is converted into amino acids which can be used for animal tissue synthesis or oxidized for ATP production with consequent production of urea in liver, partially filtered in kidney and excreted in urine. Part of the urea may be recycled back to the gastrointestinal tract and assimilated by the microorganisms. However, a portion of the nitrogen in microorganisms is excreted in feces as a residue of microbial nitrogenous compounds (Satter et al., 2002).

Most of the nitrogen consumed by beef cattle is excreted in feces and urine, and the loss of N by hair/scurf is of minor relevance. In manure, the nitrogen is present mostly 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 also 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 system with low quality of forage (low N supply) or feedlot diets excessive in nitrogen, due to overestimated animal's requirements or use of inconsistent requirement systems to the climate conditions and animals (genetic groups).

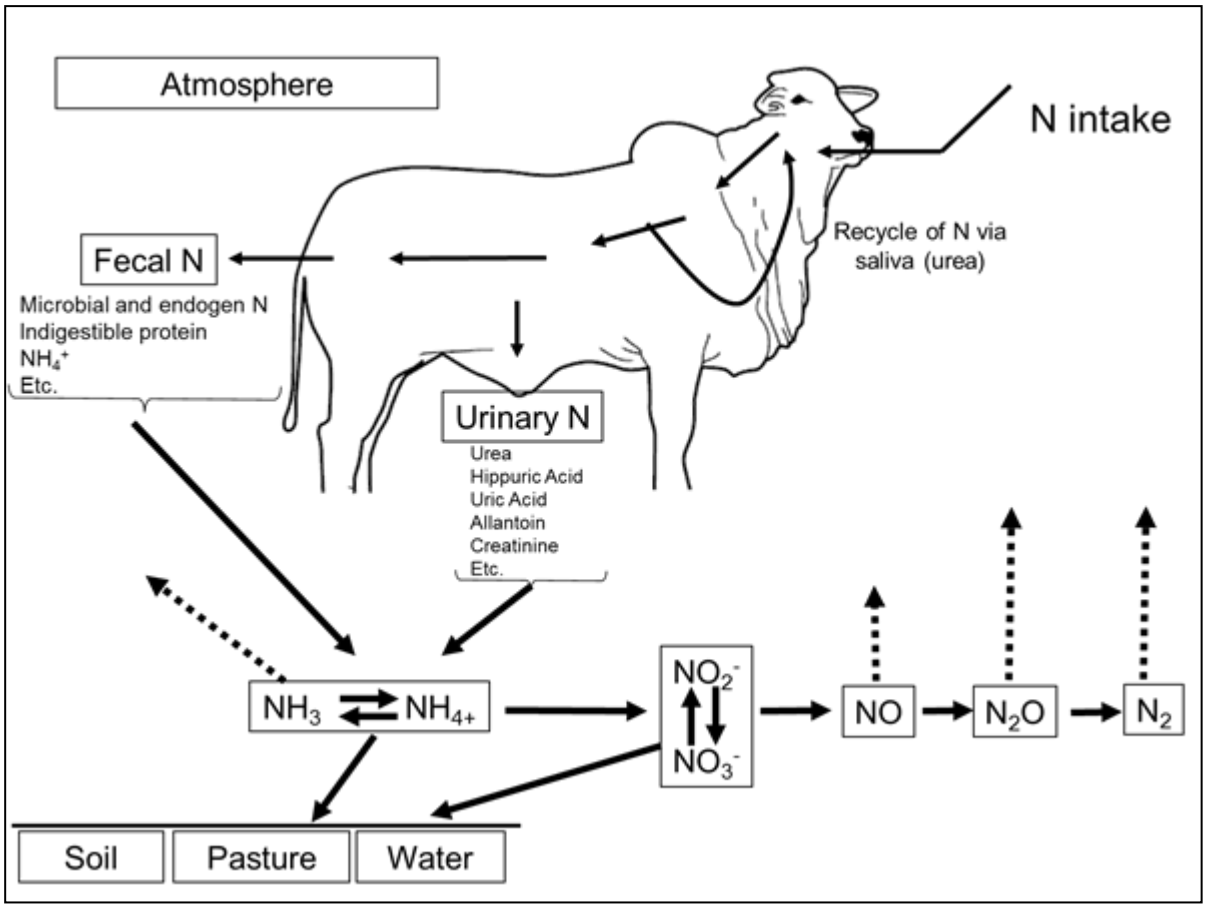
According to Menezes et al. (2016), nitrogen metabolism is affected by the levels of crude protein in the diet, and urinary and fecal N excretion increases linearly with protein intake. If protein contents in the diet are higher than the animal nutritional requirements, it results in an increase of N excretion, mainly via urine. Therefore, the reduction in 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 returns of producers.

The environmental concern about nitrogen is related to three main routes of this nutrient: losses as ammonia volatilization to the atmosphere, nitrate diffusion in soil and groundwater, and denitrification and nitrous

oxide emission in the atmosphere (Scheme 12.1). 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.

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 12.1. Summary of the nitrogen cycle.

According to IPCC (2006), the direct N_2O emissions from cattle excreta (without distinguishing between feces and urine) is 2% of the total N present in excreta. In indirect emissions, for each kg of excreta nitrogen deposited on the soil, 20% are volatilized and 30% leached. From the 20% volatilized, 1% is emitted in the form of N_2O, and from the 30% leached, 0.75% 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., 2016) 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 feces and urine found by the authors (0.7% of the nitrogen excreta) was lesser than 2% adopted by IPCC (2006).

Sordi et al. (2014) evaluated the N_2O emissions in the feces 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 (2006) 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. (2016), evaluating the effect of the addition of different quantities of cattle urine and feces 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.

The nitrogen in feces (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 12.2), 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 12.3.

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 12.3), 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 12.2 - 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 12.3 - 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, it was used the cross-validation method (leave-one-out) using the REG procedure in SAS to generate the parameters for nitrogen excretion prediction equations (Table 12.4). The solutions of the fixed effects of the prediction equations for N excretion via urine and feces with their respective coefficient of determination (R^2) are shown in Table 12.4. In both equations, there was a positive relationship between nitrogen intake and excretion, corroborating with other studies (Cole, 2003; Marini and Van Amburgh, 2003; Menezes et al., 2016).

For urinary N excretion, two equations were proposed, one based only on nitrogen intake and other one based on nitrogen intake and DMI. Predictions of N excretion proposed by Waldrip et al. (2013) and Dong et al. (2014), and used by BCNRM (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.

Table 12.4 - 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. 12.1)	Urinary N, g/d (Eq. 12.2)
Intercept	$2.549_{\pm 0.034}$	$3.262_{\pm 0.087}$	$3.819_{\pm 0.090}$
BW	$0.048_{\pm 0.0002}$	-	-
DMI	-	$3.680_{\pm 0.042}$	-
TDNI	$-3.469_{\pm 0.020}$	-	-
NI	$0.296_{\pm 0.0005}$	$0.177_{\pm 0.002}$	$0.344_{\pm 0.0008}$
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 12.5).

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 12.5 - 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 12.6. 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 12.6), 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 12.2) had greater accuracy and a lower mean square error of prediction (MSEP).

The similarity of predicted and observed nitrogen excretion is shown in Figure 12.1. The data are similarly disposed around the identical line (dotted line).

Table 12.6 - 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. 12.1)	Urinary N (Eq. 12.2)
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.

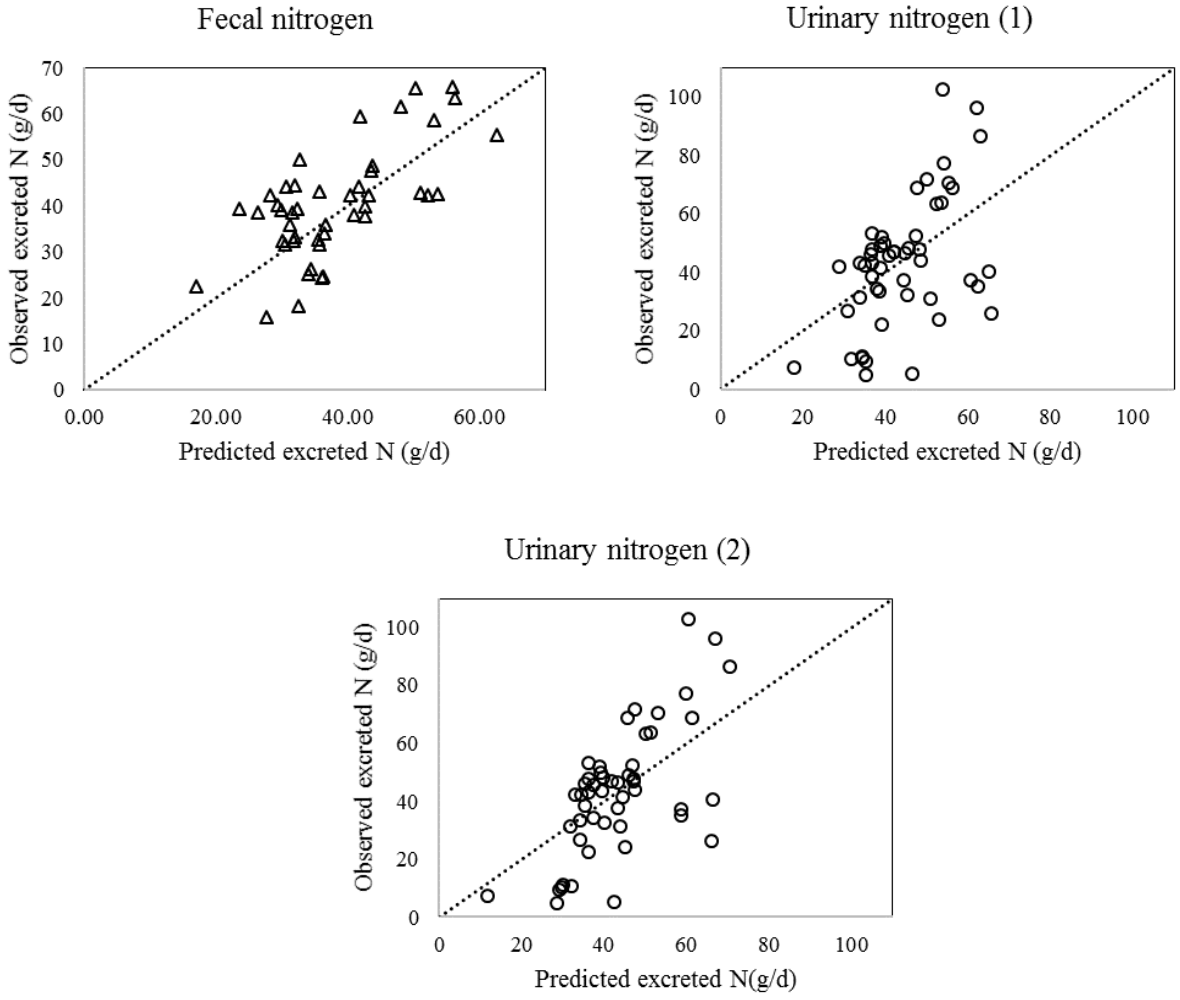


Figure 12.1 - Relationship between the observed values of fecal and urinary nitrogen excretion and those determined by the proposed equations. Predicted values are plotted on the X axis and the observed values are on the Y axis. The dotted line represents the ideal line (Y = X), intercept = 0 and slope = 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 12.2). 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.

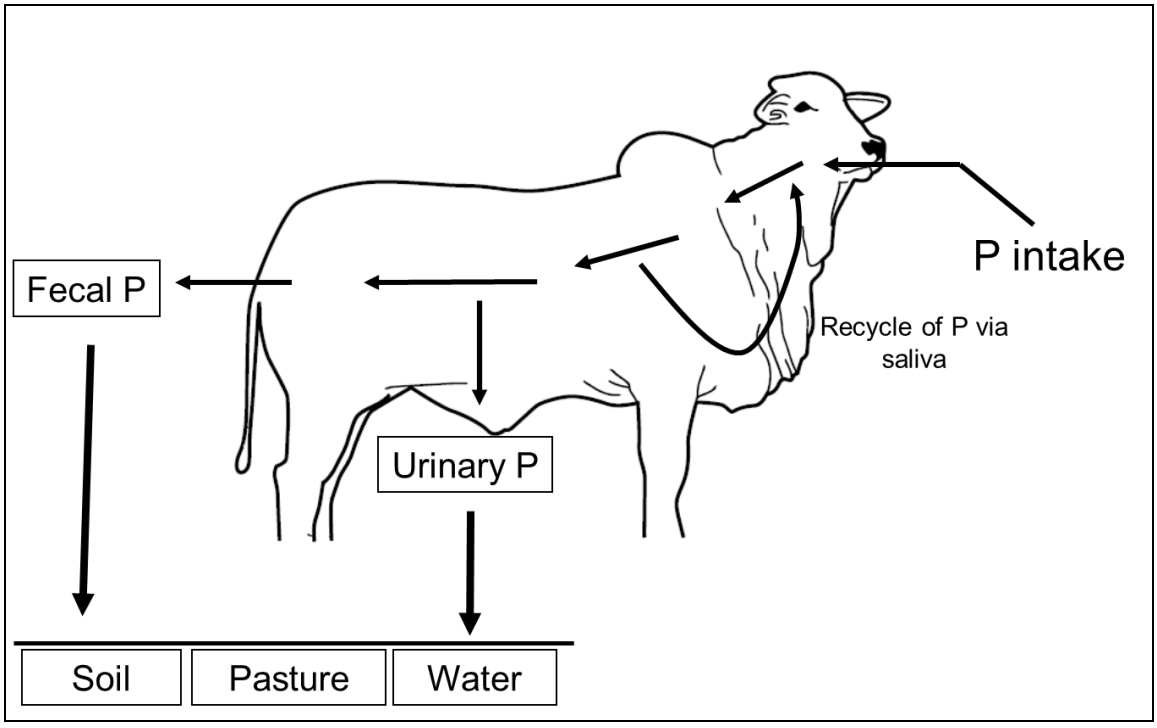
Phosphorus fractions in feces are: the phosphorus contained in diets that have not been solubilized; phosphorus derived from microorganisms and endogenous losses, and phosphorus intake above the requirements of the animal (in ruminants, the major portion is excreted in feces).

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 BCNRM (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 12.2. 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 12.7). 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 12.8.

The procedure for developing the equations was the same as previously presented for nitrogen.

Table 12.7 - 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 12.8, 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.

Table 12.8 - 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 12.9.

Table 12.9 - 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	$1.473_{\pm 0.043}$	$1.895_{\pm 0.044}$
BW	$-0.0019_{\pm 0.0002}$	$-0.0030_{\pm 0.0002}$
P intake	$0.482_{\pm 0.0035}$	$0.530_{\pm 0.0036}$
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 12.10), 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 12.10 - 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 12.11 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 12.11 - 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 12.2. The values are similarly disposed around the identical line (dotted line).

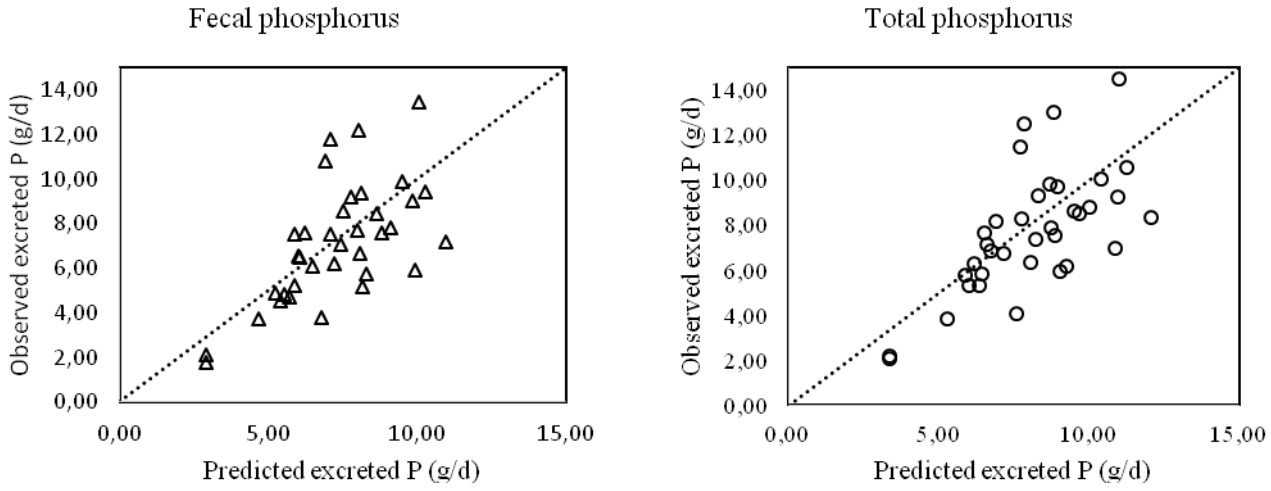


Figure 12.2 - Relationship between the observed values of phosphorus excretion and those determined by the proposed model. Predicted values are plotted on the X axis and the observed values are on the Y axis. The dotted line represents the ideal line (Y = X), intercept = 0 and slope = 1.

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 reduce the environmental impact of livestock farming.

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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