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Protein and amino acids requirements for beef cattle

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INTRODUCTION

Proteins are molecules that play several functions in the animal body, contributing to the composition of structural tissues, enzymes, hormones, hormonal receptors, and genetic material (Boye et al., 2012). Dietary protein can be divided into two main portions for ruminant animals: rumen degradable protein (RDP) and rumen undegradable protein (RUP; NRC, 1985). In addition, metabolizable protein (MP) requirements are met by intestinal amino acids (AA) absorption. These AA come from dietary digestible RUP plus the true digestible microbial crude protein (Cervieri et al., 2001; Sinclair et al., 2014). Thereby, protein nutrition is one of the main factors that affect animal performance.

According to Pinto and Millen (2018), commercial feedlots in Brazil use high crude protein (CP) contents in diets of finishing animals (in some cases up to 15 % CP) as strategy to stimulate dry matter intake (DMI) and to reduce feedlot period. However, there is a positive correlation between protein intake and nitrogen excretion in the feces and urine (Sinclair et al., 2014), which contributes to environmental contamination. Menezes et al. (2016) showed that reducing CP levels in the diets of finishing cattle is possible without affecting animal performance besides reducing N excretion to environment. Moreover, unbalanced diets represent economic losses, once protein is considered the most expensive nutrient in beef cattle diets (Appuhamy et al., 2014; Russel et al., 1992). Additionally, toxic effects related to N excess may lead to fertility impairment (Rhoads et al., 2006). Thus, providing more accurate information on protein nutrition may contribute to making beef production systems more environmentally and financially sustainable.

In this context, nutritional models have tried to get as close as possible to the real nutritional requirements of animals. Using AA to formulate diets should allow the feeding of lower protein rations and may also be an alternative to maximize growth performance of ruminants. Therefore, in addition to revised equations for predicting protein requirements, predictive equations to estimate the net and metabolizable AA requirements of beef cattle are also available in the current edition of this publication.

PROTEIN REQUIREMENTS

Ruminant protein requirements are met through absorption in the small intestine of end products resulting from the digestion of nitrogenous compounds, especially the AA available for absorption. The sources of protein that reach the intestine of ruminants are microbial crude protein (MCP), dietary protein that did not suffer action of rumen microorganisms and endogenous protein; thus, ruminants present peculiarities in their protein nutrition (Bach et al., 2005). Amino acids from these sources that are absorbed in the intestine are named MP (ARC 1980).

Formulation based on CP intake can cause several estimation errors once this intake does not consider the biological value of CP as well as the efficiency of MCP synthesis per kg of digestible organic matter. The current systems of nutrient requirements for cattle evolved and recommended MP intake (MPI), accounting for the available protein absorbed as amino acids in the intestine. According to Santos (2006), the use of MP has encouraged and allowed advances in the knowledge of nutritional requirements, allowing animal productivity gains by optimizing the MCP in the rumen, adequacy of the RUP content and of the amount and quality of MP supplied by the animal, reduction of the losses of nitrogenous compounds to reduce the negative impact of the release of these compounds in the environment.

Protein requirements can be divided into protein required for maintenance (including the endogenous loss of nitrogen compounds through feces, urine, and scurf) and for growth (nitrogen compounds utilized for deposition of body tissues or secreted in milk), as will be explained separately in other sections of this chapter, allowing for a better understanding of the results obtained.

EVALUATION OF CRUDE PROTEIN REQUIREMENTS UTILIZING THE BR-CORTE (2016)

In the third edition of BR-CORTE (BR-CORTE, 2016), there was a considerable effort to improve and to ratify protein requirements for beef cattle. According to Galyean (2014), changes in nutrient requirements associated with sex, genetic groups, physiological status, and environment make establishing requirements more complex and this is a challenge for the committees that try to establish nutrient requirements. This highlights the importance of constantly updating the database and using environmental conditions and handling consistent with the tropics.

Menezes et al. (2016) observed overestimation of CP requirements by the BR-CORTE (2010) of 45.2, 23.5, and 11.2% in relation to the values of CP intake observed for finishing Nellore bulls submitted to diets containing 14, 12, and 10 % CP, respectively. Prados et al. (2015) worked with growing crossbred (Holstein × Zebu) bulls and observed overestimation of 27.5% in CP intake, with a predicted value of 1,200 g/d for CP requirements in relation to the observed intake of 870 g/d. Additionally, Amaral et al. (2014) observed predicted CP intake (1,580 g/d) 17% greater than the observed (1,348 g/d) for finishing crossbred (Holstein × Zebu) bulls while Costa e Silva et al. (2013) found overestimated values of CP intake of 16.75% in relation to the average of observed values for finishing Nellore bulls.

Thus, before generating new equations, the prediction of CP intake by the BR-CORTE (2010) was tested in the last edition (BR-CORTE, 2016). For that, 271 individual data of cattle from 8 studies were collected: Costa e Silva (2011), Souza (2013), Rufino (2014), Silva (2014), Menezes (2016), Prados (2016), Amaral (2016) and Zanetti (2017). The database included dissertations and theses that were concluded after 2010 and were not part of the database of the second edition of BR-CORTE (BR-CORTE, 2010).

The descriptive statistics of data of CP intake referring to the observed values in the studies and the values predicted by the BR-CORTE (2010) are shown in the Table 9.1, and these data were evaluated using the Model Evaluation System (MES; Tedeschi, 2006). The concordance correlation coefficient (CCC) allows us to evaluate the accuracy and precision of the estimates; as this value approaches 1, the estimates are more precise and accurate. The mean square error of prediction (MSEP) considers the magnitude of the errors associated with the estimates and the lower its value, the better the estimates. Furthermore, from the MSEP decomposition, the errors can be associated with mean bias, systematic errors, and random errors; a better estimate is associated with a greater percentage of random errors.

Table 9.1 - Regression analysis and descriptive statistics of observed values and predicted values by the BR-CORTE (2010) for dietary crude protein requirement, adapted from BR-CORTE (2016)

Item	Dietary crude protein	
	Observed value	Predicted value
Mean	1.01	1.13
Standard deviation	0.20	0.16
Maximum	1.74	1.67
Minimum	0.50	0.67
% overestimation	12.24	
P-value (H_0: a = 0 and b = 1)	<0.01	
CCC	0.61	
Cb	0.80	
Mean square error of prediction	0.0324	
Mean bias (%)	0.0153 (47.22%)	
Systematic error (%)	0.0001 (0.31%)	
Random error (%)	0.0170 (52.47%)	

The validation analysis showed that the intercept and slope differ from zero and 1, respectively (*P* <0.01), which indicates that the estimates of the BR-CORTE (2010) model were inappropriate (Figure 8.1). Moreover, CP requirements were overestimated by 12.24% in relation to the observed CP intake. In the error decomposition, 47.22% of the errors were associated with mean bias, showing a tendency towards CP overestimation. Diets with excess protein will result in high diet costs with increased N excretion. These results demonstrated that new adjustments in the estimates of protein requirements needed to be performed.

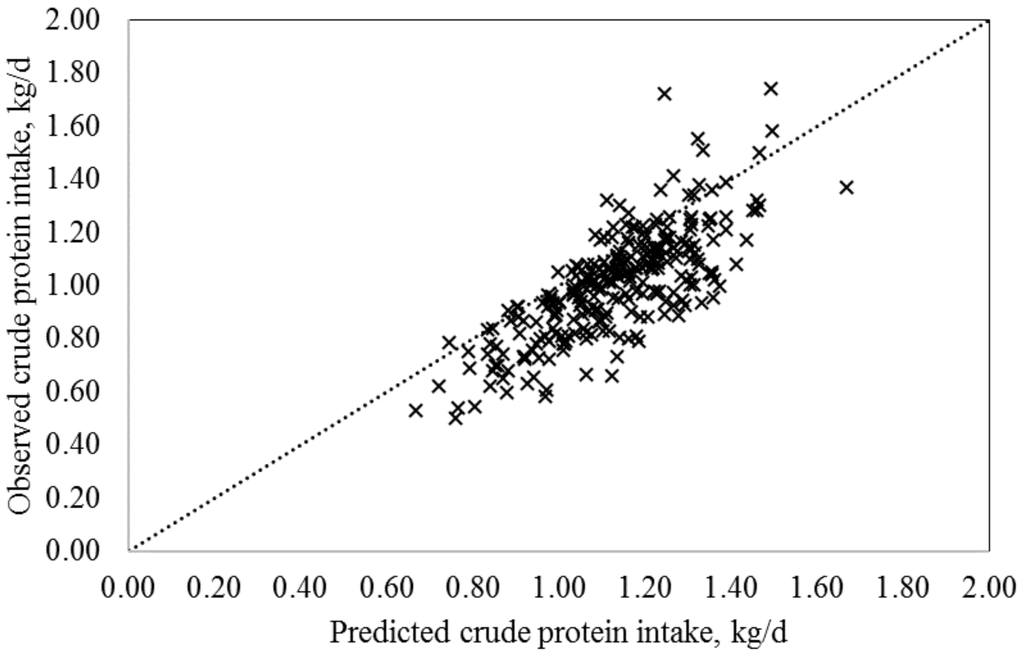

Figure 9.1 - Relationship between observed values and predicted values by the equation proposed by the BR-CORTE (2010) for crude protein intake, adapted from BR-CORTE (2016).

Diets with a protein content below the requirements of animals can affect productivity. However, diets with excess protein result in higher cost with feeding, and higher nitrogen excretion. Thus, knowledge of correct protein requirements is necessary to formulate diets to optimize animals' performance and contribute to the environment.

The results of the predicted CP intake highlight the need to adequate it to genetic, physiological, and environmental factors in Brazil. Then, in the third BR-CORTE edition (BR-CORTE, 2016), protein requirements were adjusted with the inclusion of new variables for MCP and data of animals with different body weights, gender, and genetic groups.

BR-CORTE (2016) DATABASE

In the third edition of BR-CORTE (BR-CORTE, 2016), a database was developed using 32 studies conducted under Brazilian conditions from 1991 to 2016: Galvão (1991), Jorge (1993), Paulino (1996), Ferreira (1997), Véras (2000), Silva (2001), Veloso (2001), Putrino (2002), Tedeschi et al. (2002), Paulino (2002), Backes (2003), Leonel (2003), Martins (2003), Chizzotti (2004), Moraes (2006), Paulino (2006), Marcondes (2007), Paixão (2008), Sales (2008), Porto (2009), Machado (2009), Marcondes (2011), Souza (2011), Costa e Silva (2011), Paula (2012), Rotta (2012), Amaral (2012), Prados (2012), Rodrigues (2014), Costa e Silva (2015), Silva (2015), and Menezes (2016). Among the data presented, 767 animals were raised in feedlot system and 148 in grazing system. In relation to the genetic group, 406 animals were Zebu cattle, 212 animals were crossbred beef cattle, and 149 animals were crossbred dairy cattle (Tables 9.2, 9.3, and 9.4, respectively). For animals raised on pasture, the descriptive statistics can be seen in Table 9.5.

PROTEIN REQUIREMENTS FOR MAINTENANCE

The demand of protein for maintenance of cattle is equal to the endogenous nitrogen losses through feces, urine, and scurf (NRC, 2000). In the first edition of BR-CORTE (BR-CORTE, 2006), the value of 2.69 g/BW$^{0.75}$ was adopted as the net protein required for maintenance (NPm; Véras et al., 2007). Bulls, steers, and heifers were fed four dietary CP levels (7, 10, 13 and 15%). Thus, gender did not affect the relationship between retained nitrogen and nitrogen intake (Figure 9.2). NPm (2.69 g/BW$^{0.75}$) was obtained multiplying the intercept of the regression between retained nitrogen on nitrogen intake (0.4313) by 6.25.

Table 9.2 - Descriptive statistics for Zebu cattle raised in feedlot and used to determine protein requirements, adapted from BR-CORTE (2016)

Item	N[1]	Mean	SD[2]	Maximum	Minimum
Bulls					
Initial shrunk body weight (kg)	214	290	58.3	438	151
Final shrunk body weight (kg)	227	408	73.1	592	215
Initial empty body weight (kg)	215	257	52.5	358	130
Final empty body weight (kg)	227	366	66.7	549	191
Average daily gain (kg/d)	162	0.99	0.40	2.66	-0.04
Empty body gain (kg/d)	214	0.99	0.40	1.87	-0.01
Retained energy (Mcal/d)	207	4.28	2.44	14.2	-0.58
Retained protein (g/d)	207	177	76.9	412	-29.1
Metabolizable protein intake (g/d)	159	700	213	1,263	195
Steers					
Initial shrunk body weight (kg)	123	287	57.1	399	110
Final shrunk body weight (kg)	123	367	80.1	520	125
Initial empty body weight (kg)	123	253	51.9	352	95.2
Final empty body weight (kg)	123	331	74.2	469	113
Average daily gain (kg/d)	110	0.71	0.40	1.41	-0.18
Empty body gain (kg/d)	123	0.67	0.37	1.32	-0.21
Retained energy (Mcal/d)	123	3.62	2.07	7.47	-0.02
Retained protein (g/d)	123	93.1	64.1	242	-122
Metabolizable protein intake (g/d)	48	651	255	1,143	159
Heifers					
Initial shrunk body weight (kg)	82	218	53.1	342	129
Final shrunk body weight (kg)	82	273	73.1	437	131
Initial empty body weight (kg)	82	192	50.1	297	111
Final empty body weight (kg)	82	247	70.2	397	115
Average daily gain (kg/d)	53	0.67	0.42	1.27	-0.12
Empty body gain (kg/d)	82	0.54	0.37	1.25	-0.13
Retained energy (Mcal/d)	82	2.49	2.02	8.22	-0.21
Retained protein (g/d)	81	74.0	62.3	196	-35.6
Metabolizable protein intake (g/d)	69	470	158	741	151

[1]N = number of observations; [2]SD = standard deviation.

Table 9.3 - Descriptive statistics for crossbred beef cattle raised in feedlot and utilized to determine protein requirements, adapted from BR-CORTE (2016)

Item	N[1]	Mean	SD[2]	Maximum	Minimum
Bulls					
Initial shrunk body weight (kg)	133	313	47.4	435	198
Final shrunk body weight (kg)	145	460	73.6	585	248
Initial empty body weight (kg)	133	264	37.9	366	173
Final empty body weight (kg)	145	404	68.4	499	222
Average daily gain (kg/d)	133	1.10	0.37	1.93	-0.08
Empty body gain (kg/d)	131	1.05	0.36	1.98	-0.05
Retained energy (Mcal/d)	133	3.89	1.70	8.76	-0.41
Retained protein (g/d)	133	156	69.7	384	-90.8
Metabolizable protein intake (g/d)	108	738	221	1,409	428
Steers					
Initial shrunk body weight (kg)	41	355	41.4	434	260
Final shrunk body weight (kg)	41	447	73.7	552	265
Initial empty body weight (kg)	41	312	48.8	385	205
Final empty body weight (kg)	41	409	70.2	506	238
Average daily gain (kg/d)	41	0.93	0.62	1.72	-0.36
Empty body gain (kg/d)	41	0.99	0.58	1.64	-0.09
Retained energy (Mcal/d)	41	5.41	2.74	9.53	0.75
Retained protein (g/d)	41	139	96.3	276	-49.3
Metabolizable protein intake (g/d)	35	704	200	918	272
Heifers					
Initial shrunk body weight (kg)	38	271	33.5	331	194
Final shrunk body weight (kg)	38	364	85.2	494	187
Initial empty body weight (kg)	38	241	36.8	311	150
Final empty body weight (kg)	38	327	74.0	443	175
Average daily gain (kg/d)	38	0.86	0.66	1.75	-0.31
Empty body gain (kg/d)	38	0.80	0.58	1.73	-0.18
Retained energy (Mcal/d)	38	4.00	2.61	7.65	-0.48
Retained protein (g/d)	37	125	92.2	297	-69.7
Metabolizable protein intake (g/d)	33	623	233	985	213

[1]N = number of observations; [2]SD = standard deviation.

Table 9.4 - Descriptive statistics for crossbred dairy cattle raised in feedlot and used to determine protein requirements, adapted from BR-CORTE (2016)

Item	N[1]	Mean	SD[2]	Maximum	Minimum
Bulls					
Initial shrunk body weight (kg)	81	297	103	494	150
Final shrunk body weight (kg)	93	412	126	661	169
Initial empty body weight (kg)	123	263	70.7	415	131
Final empty body weight (kg)	135	379	103	600	150
Average daily gain (kg/d)	81	1.34	0.64	2.64	0.02
Empty body gain (kg/d)	120	1.32	0.62	2.74	0.05
Retained energy (Mcal/d)	120	5.33	2.96	12.7	-0.67
Retained protein (g/d)	120	188	118	414	-181
Metabolizable protein intake (g/d)	125	698	271	1,417	118
Steers					
Initial shrunk body weight (kg)	48	325	34.7	453	216
Final shrunk body weight (kg)	48	388	53.1	575	254
Initial empty body weight (kg)	48	268	29.1	363	185
Final empty body weight (kg)	48	342	48.3	510	247
Average daily gain (kg/d)	48	0.77	0.55	1.70	-0.21
Empty body gain (kg/d)	48	0.93	0.38	2.00	0.02
Retained energy (Mcal/d)	48	3.93	1.63	9.00	0.51
Retained protein (g/d)	20	78.3	73.5	210	-110
Metabolizable protein intake (g/d)	28	920	255	1,410	458
Heifers					
Initial shrunk body weight (kg)	20	258	38.6	347	196
Final shrunk body weight (kg)	36	311	56.7	431	215
Initial empty body weight (kg)	36	195	43.3	298	115
Final empty body weight (kg)	36	276	54.2	403	192
Average daily gain (kg/d)	20	0.68	0.36	1.23	-0.04
Empty body gain (kg/d)	36	0.87	0.38	1.67	0.05
Retained energy (Mcal/d)	36	3.98	1.74	7.79	0.73
Retained protein (g/d)	36	100	70.4	240	-52.9
Metabolizable protein intake (g/d)	15	853	186	1,155	570

[1]N = number of observations; [2]SD = standard deviation.

Table 9.5 - Descriptive statistics for Zebu cattle raised on pasture and used to determine protein requirements, adapted from BR-CORTE (2016)

Itens	N[1]	Mean	SD[2]	Maximum	Minimum
Bulls					
Initial shrunk body weight (kg)	128	190	87.4	409	74.0
Final shrunk body weight (kg)	128	335	84.6	519	140
Initial empty body weight (kg)	128	163	72.0	337	63.3
Final empty body weight (kg)	128	292	75.6	463	118
Average daily gain (kg/d)	128	0.56	0.19	0.95	-0.15
Empty body gain (kg/d)	128	0.45	0.19	0.90	-0.10
Retained energy (Mcal/d)	127	1.12	1.01	4.14	-0.83
Retained protein (g/d)	108	87.0	32.4	156	14.5
Metabolizable protein intake (g/d)	84	459	163	893	189
Steers					
Initial shrunk body weight (kg)	20	317	59.8	409	226
Final shrunk body weight (kg)	20	363	66.9	484	243
Initial empty body weight (kg)	20	261	49.3	337	186
Final empty body weight (kg)	20	299	57.5	405	193
Average daily gain (kg/d)	20	0.57	0.33	0.95	-0.15
Empty body gain (kg/d)	20	0.47	0.29	0.90	-0.10
Retained energy (Mcal/d)	20	1.15	1.07	2.35	-0.83
Retained protein (g/d)	18	65.4	37.1	134	14.5
Metabolizable protein intake (g/d)	-	-	-	-	-

[1]N = number of observations; [2]SD = standard deviation.

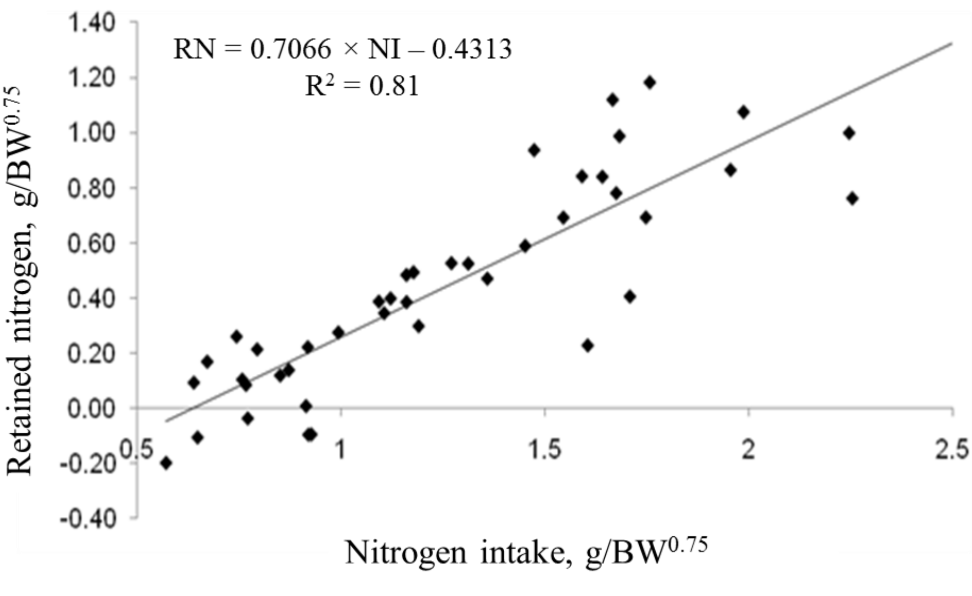

Figure 9.2 - Relationship between retained nitrogen (RN) and nitrogen intake (NI), expressed as $g/BW^{0.75}$. Adapted from Véras et al. (2007).

The AFRC (1993) adopted the value of 2.30 $g/BW^{0.75}/d$ for NPm, which was obtained through the sum of the basal requirements of endogenous nitrogen and losses by scurf and hair. The INRA (1988) and Smuts (1935) adopted values of 3.25 $g/EBW^{0.75}/d$ and 3.52

g/BW$^{0.75}$/d for NPm, respectively, which were obtained through experiments involving nitrogen balance.

In this context, Ezequiel (1987) obtained the metabolizable protein required for maintenance (MPm) of 1.72 and 4.28 g/BW$^{0.75}$/d for Nellore and Holstein steers, respectively. Costa e Silva et al. (2015) estimated MPm as 1.28 g/BW$^{0.75}$/d of growing Nellore steers and heifers. Furthermore, Valadares et al. (1997), considering the sum of fecal endogenous losses (estimated by regression between absorbed nitrogen and nitrogen intake) and urinary endogenous losses (obtained by regression between urinary nitrogen excretion and nitrogen intake), calculated the MPm of 4.13 g/BW$^{0.75}$/d.

To convert NPm to MPm, BR-CORTE (2006) utilized the factor of 0.667, obtained from the relationship between retained nitrogen and absorbed nitrogen (Figure 9.3), which is close to the recommendation of the NRC (1985) of 0.67. Utilizing this efficiency and considering an NPm of 2.69 g/BW$^{0.75}$, MPm was estimated as 4.03 g/BW$^{0.75}$. Thus, BR-CORTE (2006) recommended the use of 4 g/BW$^{0.75}$/d as the MPm.

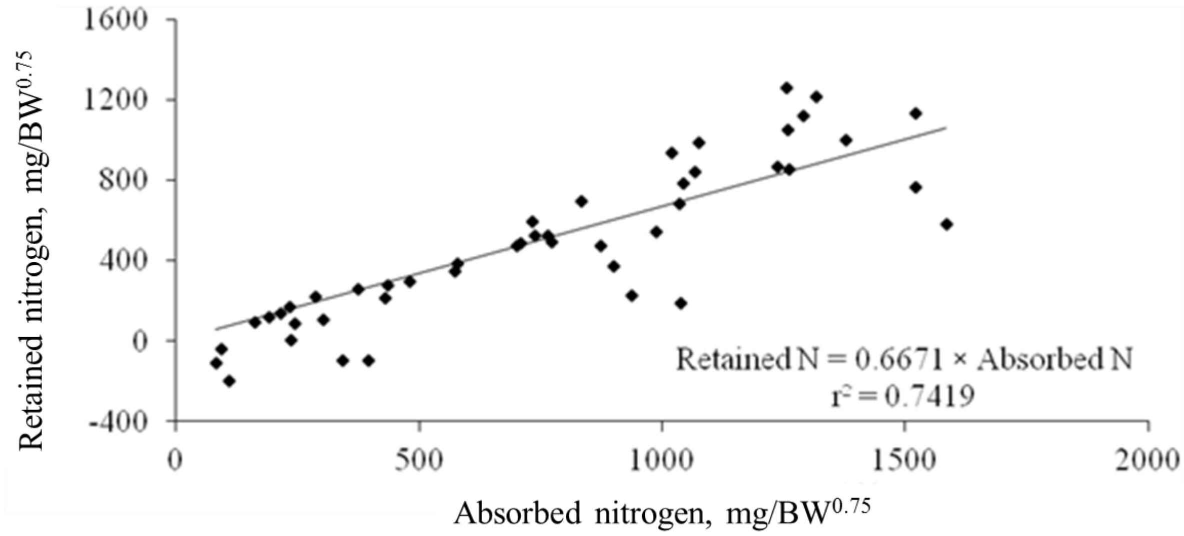

Figure 9.3 - Relationship between retained nitrogen and absorbed nitrogen. Adapted from Véras et al. (2007).

The NRC (2000) adopted the value of 3.8 g/BW$^{0.75}$, obtained by Wilkerson et al. (1993), as the MPm. This value was calculated by the division of the intercept (242) of the regression between MPI (g/d) and average daily gain (ADG; kg/d) of animals, by the average of metabolic body weight of the animals (63.44) in the database, which were fed 45 different protein sources with the number of animals varying from 3 to 30 per protein source. The same value was obtained by Susmel et al. (1993) in experiments involving nitrogen balance. Similarly, the NASEM (2016) recommended for MPm the value of 3.8 g/SBW$^{0.75}$.

In the second edition of BR-CORTE (BR-CORTE, 2010), MPI was correlated with ADG and empty body gain (EBG) to estimate MPm. The two equations estimated MPm values close to that proposed in the first edition of BR-CORTE (BR-CORTE, 2006): 4.0 g/BW$^{0.75}$, which was maintained in the BR-CORTE (2010).

Initially, to convert CP intake for MPI of the database, MCP synthesis should be estimated through the equation proposed in Chapter 3 ($MCP = -53.07 + 304.9 \times CPI + 90.8 \times TDNI - 3.13 \times TDNI^2$). After MCP synthesis is known, the requirements of RDP can be estimated. Furthermore, the BR-CORTE (2010) considered the efficiency of the use of degraded N for microbial N as 90%, so 10% of net N losses were considered in the rumen. Then, the requirements of RDP (g/d) were calculated as 1.11 × MCP. However, the inefficiency of this process, represented by the factor 1.11, was removed (for more details, see section "Considerations regarding nitrogen compound recycling"); thereby, the requirements of RDP are considered equal to MCP synthesis. Additionally, RUP intake was estimated by the difference between CP and RDP intakes. Therefore, MPI can be obtained from the following equation: MPI = (MCP × 0.64) + (RUP/0.80).

In the third edition of BR-CORTE (BR-CORTE, 2016), the same methodology of the BR-CORTE (2010) to estimate MPm was utilized, where MPI was correlated with EBG. After evaluations, the effect of production system was observed, suggesting that MPm must be estimated separately for animals raised on pasture and in feedlot. Moreover, effects of the genetic group and sex were tested for animals raised in feedlot and no effect was observed, allowing the development of only one equation for animals raised in feedlot (Figures 9.4 and 9.5; Table 9.5).

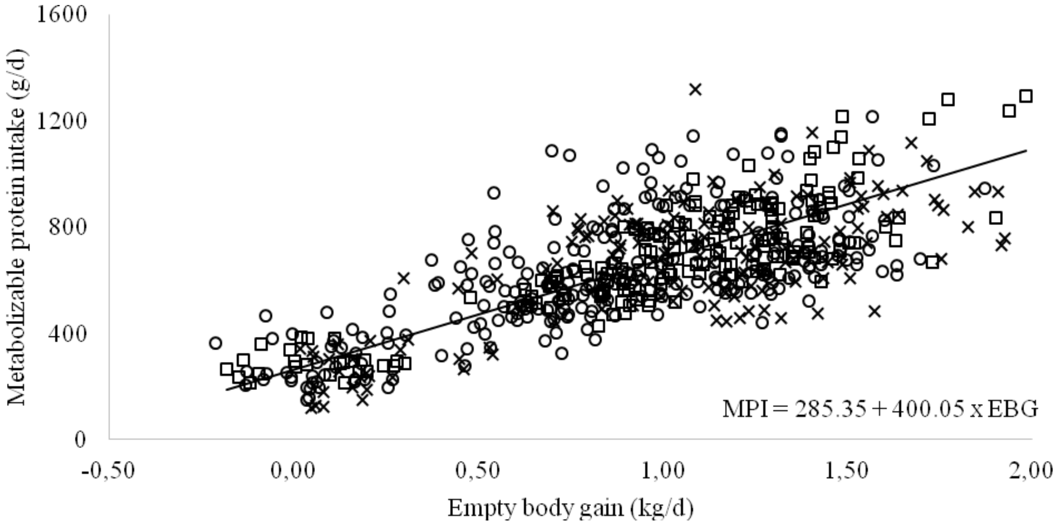

Figure 9.4 - Relationship between metabolizable protein intake and empty body gain of animals raised in feedlot. Symbols represent data from Zebu cattle (○), crossbred beef cattle (□), and crossbred dairy cattle (×).

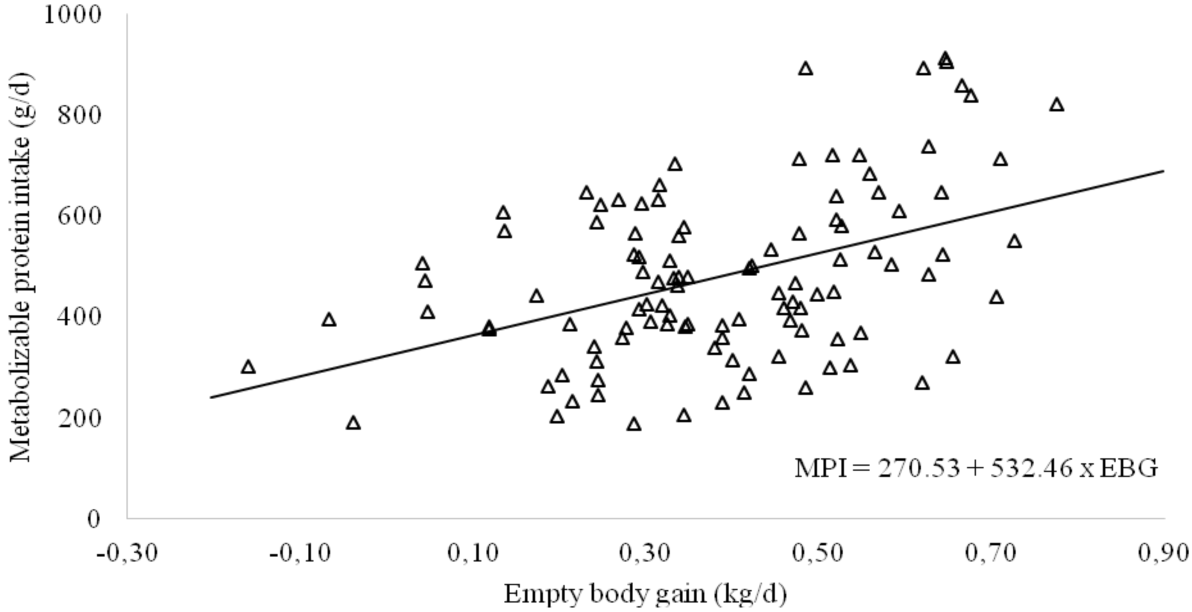

Figure 9.5 - Relationship between metabolizable protein intake and empty body gain of animals raised on pasture.

Table 9.5 - Metabolizable protein required for maintenance of beef cattle raised on pasture and in feedlot adapted from BR-CORTE (2016)

System	Equation	$EBW^{0.75}$	MPm
Feedlot	MPI = 285.35 + 400.05 × EBG	72.0	3.96
Pasture	MPI = 270.53 + 532.46 × EBG	62.7	4.31

MPI = metabolizable protein intake (g/d); EBG = empty body gain (kg/d); $EBW^{0.75}$ = metabolic empty body weight (kg); MPm = metabolizable protein required for maintenance (g/$EBW^{0.75}$).

In the BR-CORTE (2010), the value obtained to estimate MPm for Nellore and crossbred cattle was 3.91 g/$EBW^{0.75}$. This value was close to that obtained in the third edition of BR-CORTE (BR-CORTE, 2016), which was maintained in the current edition (3.96 g/$EBW^{0.75}$) for cattle raised in feedlot. For pasture, the value estimated in the third edition of BR-CORTE (BR-CORTE, 2016) and kept in the current edition for MPm was 4.31 g/$EBW^{0.75}$, which was lower than that observed in the second edition of BR-CORTE (BR-CORTE, 2010; 4.87 g/$EBW^{0.75}$). In both cases, converting these values in terms of shrunk body weight (SBW), the estimates are 3.6 and 3.9 g/$SBW^{0.75}$ for animals raised in feedlot and on pasture, respectively. The value obtained for animals raised in feedlot was lower than those values recommended by the NASEM (2016) and the BR-CORTE (2010) which were 3.8 g/$SBW^{0.75}$ and 4.0 g/$BW^{0.75}$, respectively. Moreover, it is noteworthy that cattle raised on pasture required approximately 8.0% more MPm than those raised in feedlot.

In this context, the committee decided to maintain the values of 3.6 and 3.9 g/$SBW^{0.75}$ for MPm recommended in the last edition of BR-CORTE (BR-CORTE, 2016) for cattle raised in feedlot and on pasture, respectively.

PROTEIN REQUIREMENTS FOR GROWTH

The determination of body composition in animals is important for evaluating the nutritional value of feedstuffs and for studies evaluating animal growth (Boin et al., 1994), because it allows researchers to estimate the protein required for animal growth. The main body chemical components of cattle are water, protein, fat, and minerals. According to Ferreira et al. (1999), animal maturity is characterized by an increase in body fat content. Young animals have greater proportion of water and protein and lower fat content so that the concentrations of protein, ash, and water decreases with age and finishing. The NRC (2000) reported that body fat and protein contents present quadratic behavior in relation to body weight (BW) with inverse relationships: fat content increases, and protein content decreases as body weight increases.

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

Differences in the protein required for growth are attributed to variations in the composition of body gain (Garret et al., 1959; Geay, 1984). Protein required for growth is greater for late-maturity bulls than early-maturity steers (Geay, 1984). Boin (1995) observed greater protein content per kilogram of EBG for Nellore bulls in relation to Nellore steers. According to Geay (1984), net protein (NP) requirements tend to be less important compared to the requirements of energy for growing early cattle, such as Angus and Hereford, because there is lower retention of energy as protein (12 to 15%). This type of animal meets their protein requirements using mainly AA from microbial fermentation (Geay, 1984). Most studies indicate reduced net protein required for growth (NPg) as BW increases (Lana et al., 1992; Pires et al.; 1993; Fontes, 1995; Paulino, 1999, Cavalcante et al., 2005, Amaral et al., 2014).

In the first edition of BR-CORTE (BR-CORTE, 2006), NPg was estimated from regression equations of retained protein (RP), retained energy (RE), and ADG, and three equations were obtained as a function of gender for Zebu cattle raised in feedlot. In the second edition of BR-CORTE (BR-CORTE, 2010), a similar model to that proposed by the NRC (2000) was utilized, in which RP was correlated with RE and EBG. In the third edition (BR-CORTE, 2016), 10 different equations to predict NPg (Table 9.6) were recommended, considering the effects of production system (feedlot and pasture), genetic group (Zebu, crossbred beef and dairy cattle), and gender (bulls, steers, and heifers).

Table 9.6 - Equations used to estimate net protein required for the growth of animals raised on pasture and in feedlot of different genetic groups and gender, adapted from BR-CORTE (2016)

System	Genetic group	Gender	Equation
Feedlot	Zebu cattle	Bulls	NPg = 210.09 × EBG – 10.01 × RE
		Steers	NPg = 153.13 × EBG – 2.53 × RE
		Heifers	NPg = 193.90 × EBG – 12.16 × RE
	Crossbred beef cattle	Bulls	NPg = 281.77 × EBG – 27.66 × RE
		Steers	NPg = 219.94 × EBG – 12.04 × RE
		Heifers	NPg = 174.65 × EBG – 3.14 × RE
	Crossbred dairy cattle	Bulls	NPg = 171.43 × EBG – 3.08 × RE
		Steers	NPg = 236.36 × EBG – 19.84 × RE
		Heifers	NPg = 206.58 × EBG – 15.39 × RE
Pasture	Zebu cattle	Bulls	NPg = 181.43 × EBG – 2.88 × RE

NPg = net protein required for growth (g/d); EBG = empty body gain (kg/d); RE = retained energy (Mcal/d).

Development of a new equation to estimate the requirements of net protein for growth (NPg)

Costa e Silva et al. (2020) developed a new model to estimate NPg for cattle raised under Brazilian conditions. Briefly, a meta-analysis was performed using data obtained from 23 studies performed in Brazil from 1997 to 2016 (Costa e Silva et al., 2020). The database comprised 492 animals finished in feedlots and 60 animals raised and finished on pastures, totaling 552 observations that encompassed bulls, steers, and heifers of different genetic groups (Zebu, Crossbred beef cattle, and Crossbred dairy cattle). The general model adjusted was:

$$NPg = 176.01 \times EBG - 6.239 \times RE$$

where NPg = net protein requirements for growth (g/d), EBG = empty body gain (kg/d), and RE = retained energy (Mcal/d).

However, models using EBG and RE as predictive variables, which do not allow adjustments regarding BW when an animal reaches physiological maturity, may lead to overparameterization of NPg prediction, increasing the complexity of calculations. Aiming simplify the calculation of NPg for animals of different genetic groups and gender, authors decided to replace the RE variable of the general NPg equation with the equation used to estimate net energy requirements for growth (NEg). NEg equation, which was previously proposed in the BR-CORTE (2016), utilizes the equivalent empty body weight (EQEBW) as a predictive variable that allows estimating RE for any BW, regardless of gender and genetic group ($RE = 0.061 \times EQEBW^{0.75} \times EBG^{1.035}$). Thus, after replacing the RE predictive variable by the NEg equation, the new model obtained was: $NPg = 176.01 \times EBG - 6.239 \times 0.061 \times EQEBW^{0.75} \times EBG^{1.035}$. This new model for predicting NPg can be simplified as:

$$NPg = 176.01 \times EBG - 0.381 \times EQEBW^{0.75} \times EBG^{1.035}$$

where NPg = net protein requirements for growth (g/d), EBG = empty body gain (kg/d), and EQEBW = equivalent empty body weight (kg). In this context, utilizing the EQEBW as a predictive variable allows estimating the RE for any BW, regardless of gender and genetic group (Marcondes et al., 2016). Therefore, the use of EQEBW in models might simplify and can even improve the accuracy and precision of NPg estimates.

Moreover, these authors also evaluated the new equation proposed and compared to current models devised by international nutrient requirements system committees (ARC, 1980; BR-CORTE, 2016; NASEM, 2016) to predict NPg using an independent database. Model evaluation was performed using data from five independent experiments totaling 177 observations encompassing bulls and steers of different genetic groups (Zebu, crossbred beef cattle and crossbred dairy cattle). As a result, the BR-CORTE (2016) and NASEM (2016) equations did not correctly estimate NPg and were not recommended for estimating NPg for cattle in Brazilian production scenarios.

Nevertheless, the new approach (Costa e Silva et al., 2020) and the ARC (1980) presented both precision and accuracy. Furthermore, the inclusion of EQEBW in the new approach (Costa e Silva et al., 2020) improved the estimation of NPg, which presented superior reproducibility and accuracy when compared to the current models evaluated. Therefore, the committee recommends the use of the equation proposed by Costa e Silva et al. (2020) to predict NPg ($NPg = 176.01 \times EBG - 0.381 \times EQEBW^{0.75} \times EBG^{1.035}$) in the current edition of BR-CORTE.

Efficiency of the use of metabolizable protein

To convert NP to MP requirements, the partial efficiency of the use of metabolizable protein for growth (*k*) must be estimated. MP contains the digestible rumen undegradable protein (dRUP) and the digestible true microbial crude protein (dtMCP) which represent the amount of AAs that reach the small intestine to be absorbed.

Among the international systems for nutrient requirements of beef cattle, the NRC (1984) reported the mean biological value of AA absorbed by cattle as 66%, a value obtained by Zinn and Owens (1983). Then, based on this study and others, the NRC (1985) adopted values of 50 and 65% for *k*, being these values based on the biological value of protein and on the value of an ideal mixture AA (Oldham, 1987). Oldham (1987) also suggested an efficiency of 85% for all physiological functions as a value reflecting the efficiency of conversion of an ideal mixture of AA. As this fact does not occur in practice, the real efficiency normally is lower than this value.

According to the British system (AFRC, 1993), the efficiency of the use of an ideal mixture of AA named *kaai*, is a characteristic that is inherent to the animal. However, this system recognized that, in practice, lower values than the real efficiency have been found. These efficiencies are basically dependent on the mixed quality of AA in the dRUP and the proportion between dRUP and dtMCP that reaches the small intestine. Therefore, the AFRC (1993) considers fixed values for the efficiency of the use of MP as follows: 100% for maintenance, 59% for growth, 85% for pregnancy and 68% for lactation.

Due to the high quality of the mixture of AA of MCP, the biological value of MCP is high, and therefore, the proportion of MCP that reaches the small intestine could alter the efficiency of the use of MP (NRC, 2000). However, the French system (INRA, 1988) considers that as body weight increases, *k* decreases. This decreasing efficiency was confirmed by Ainslie et al. (1993) and Wilkerson et al. (1993), with data from animals with body weight varying from 150 to 300 kg. In this context, the NRC (2000) adopted the equation proposed by Ainslie et al. (1993) to estimate *k* for animals from 150 to 300 kg BW, as follows:

$$k = 83.4 - (0.114 \times \text{EQEBW})$$

Thus, an animal with 150 kg EQEBW will have a *k* value equal to 0.663, while a 300kg animal will have efficiency of 0.492. The NRC (2000) recommended the equation above only for animals with EQEBW lower than 300 kg; while for heavier animals, the NRC (2000) suggested the fixed value of 0.492, from the previous version (NRC, 1984). Also, we highlight that the protein required for growth is relatively low when animals achieve body weight of approximately 400 kg.

Data from Brazil reported *k* values of 33.3% (Costa e Silva et al., 2013) and 34.4% (Menezes et al., 2016) for growing and finishing Nellore cattle, respectively. Nevertheless, Zanetti et al. (2016) and Silva et al. (2016) obtained values of *k* equal to 26.72 and 25.2% for Holstein × Zebu steers and heifers, respectively. However, Mariz et al. (2018) have described an average value for *k* of 40% for Nellore and Angus × Nellore bulls. Several factors such as age, body composition, and feeding conditions can affect *k* (Blaxter et al., 1966; Garrett, 1980; Gionbelli et al., 2012, Marcondes et al., 2013).

The first edition of BR-CORTE (BR-CORTE, 2006) utilized the recommendations of the NRC (2000) for *k*, whose k value was considered the slope obtained from the regression between RP and MPI. On the other hand, the BR-CORTE (2010) evaluated RP as a function of MPI (Figure 9.6) and found no effect of genetic group or gender on *k*, and the equation adopted was:

$$\text{RP} = -2.223 + 0.4691 \times \text{MPI}$$

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

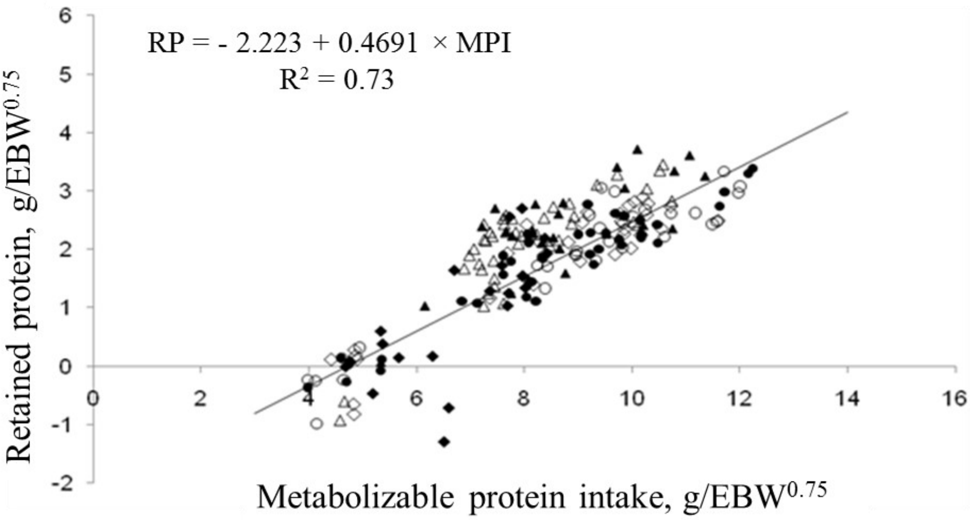

Figure 9.6 - Relationship between retained protein and metabolizable protein intake. Symbols represent data from bulls (▲, Δ), steers (◊, ♦), and heifers (○, ●). Solid points represent Nellore and empty point represent crossbred *Bos taurus indicus* × *Bos taurus taurus* cattle.

From this equation, the value estimated for *k* was 46.9% for Zebu and crossbred cattle. This estimated value was similar to 49.2% recommended by the NRC (2000). In addition, the same value estimated for *k* for animals raised in feedlot was adopted for grazing animals in the second edition of BR-CORTE (BR-CORTE (2010) due to the limited data available in such conditions. In the third edition of BR-CORTE (BR-CORTE, 2016), a similar equation was adjusted; the value obtained was 47.4% (Figure 9.7) for animals raised on pasture and in feedlot. Also, the amount of data from animals raised on pasture was small, preventing us from evaluating the effect of the production system on *k*.

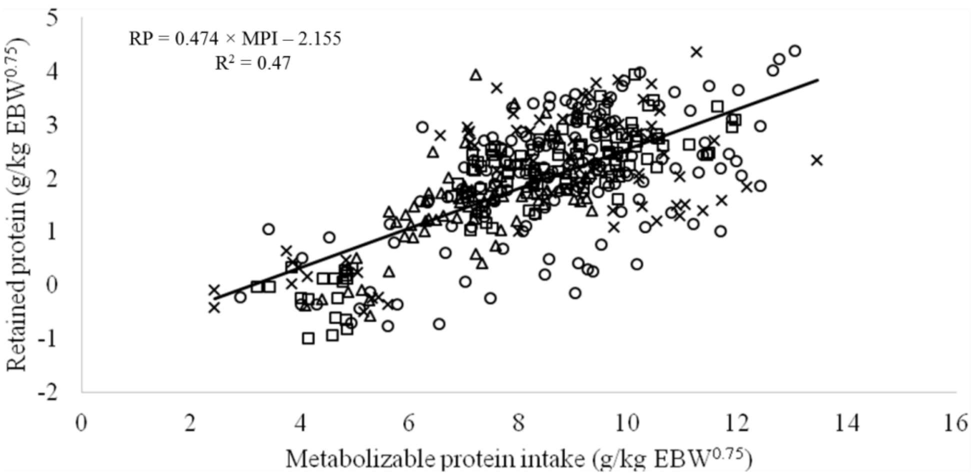

Figure 9.7 - Relationship between retained protein (RP) and metabolizable protein intake (MPI) of animals raised in feedlot. Symbols represent data from Zebu cattle (○),crossbred beef cattle (□), crossbred dairy cattle (×), and animals raised on pasture (Δ).

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

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

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

where EQEBW = equivalent empty body weight.

This equation recommended in the second edition of BR-CORTE (BR-CORTE, 2010) was kept in the current edition. However, in the second edition of BR-CORTE (BR-CORTE, 2010), the committee recommended this equation to be utilized for animals that present SBW < 350 kg. As the value of *k* increased for adult animals (46.9 vs. 47.4%) from the second (BR-CORTE, 2010) to the third edition (BR-CORTE, 2016) of BR-CORTE, the recommendation would be the use of this equation for animals with SBW < 340 kg. Therefore, considering an animal with 150 kg EQEBW, using the equation, the efficiency might be 67%. This estimated value is similar to 66% which was suggested by the NRC (2000). Additionally, as the animal grows, the estimated *k* value decreases up to SBW equals to 340 kg. After this value of SBW, *k* might be constant and equal to 47.4%. The NRC (2000) and NASEM (2016) considered the value of 49.2% for *k* for animals with BW greater than 300 kg.

MCP can be calculated by considering the recommendation presented in Chapter 3, where MCP synthesis was calculated as a function of CPI and total digestible nutrients intake (TDNI) as follows:

$$MCP\,(g/d) = -53.07 + 304.9 \times CPI + 90.8 \times TDNI - 3.13 \times TDNI^2$$

where CPI = crude protein intake (kg/d) and TDNI = total digestible nutrients intake (kg/d). Thus, the requirements of RDP can be calculated from recommendations of the current edition, where MCP synthesis equals to RDP requirements: RDP = MCP. While the requirements of RUP can be obtained by the following equation: RUP = (Total metabolizable protein – (MCP × 0.64))/0.80. To obtain CP requirements, RDP and RUP requirements should be added. It is noteworthy that the values used for MCP true digestibility and RUP digestibility in the small intestine were recently confirmed by Mariz et al. (2018), who estimated MCP true digestibility and RUP digestibility as approximately 80%., evaluating Nellore and Angus × Nellore cannulated bulls in the rumen and ileum,

CONSIDERATIONS REGARDING NITROGEN COMPOUND RECYCLING

Urea recycling from liver to rumen and salivary glands is one of the peculiarities that involves ruminant physiology and nutrition and represents an evolutionary advantage for these animals, allowing their survival in periods of dietary protein restriction (lower than 7%; Lazzarini et al., 2009; Sampaio et al., 2010). According to Batista et al. (2016), providing ammonia for rumen microorganisms, urea recycling affects the amount of N available in the rumen provided directly from the diet. Therefore, the nutrient systems should consider recycled N to estimate protein requirements of the animals. Considering such aspects, the current edition of the North America system (NASEM, 2016) considers urea recycling for the rumen as:

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

where N urea = N recycled for rumen as urea (g/d); CP = dietary crude protein content (% DM); NI = nitrogen intake (g/d). Thereby, the NASEM (2016) aims to bring CP requirements closer to the real with the use of N recycling in the calculations, allowing diet formulation that optimize animal performance, reduce economic losses, and avoid environment contamination. Up to the second edition of BR-CORTE (BR-CORTE, 2010), nitrogen recycling was not considered in the calculations of protein requirements, which may have contributed to the overestimation of the recommendation of CP in cattle diets.

However, Batista et al. (2016), evaluating low quality forage (5.0% CP on DM basis) or diets containing ruminal protein infusion to meet 100% RDP requirements and from 0 to 150% RUP requirements, found that 22% of the total microbial N in the control diet was from urea recycling, while in supplemented diets this incorporation was 10%. Furthermore, evaluating diets with different CP contents (9, 11, 13, and 15% on DM basis) and considering RDP content, the amount of RDP intake and microbial nitrogen (MN) synthesis obtained for each dietary CP level, Prates (2015) verified that the efficiency of the uptake of rumen degradable N intake as MN varied from 120% to 90.28% for diets with 9% and 15% CP, respectively. Thus, the amount of recycled N incorporated into microbial N was approximately 20% in the diet with 9% CP, decreasing to 10% in the diet containing 11% CP, and approximately zero for the diet with 13% CP. This author observed a net N loss in the rumen close to 10% for the diet containing 15% CP. Thus, considering the data described above, N recycling for rumen might contribute with 10 to 20% of microbial N, in diets varying from 5 to 13% CP. These values are lower than those calculated by the equation suggested by the NASEM (2016).

Although recognizing the importance of N recycling, the BR-CORTE committee does not recommend any value to account for this process, as so far only Batista et al. (2016) effectively measured urea recycling using animals fed low-quality forage and N infusions under tropical conditions. However, despite not recommending any value for N recycling, the committee considers that the amount of N compounds recycled into rumen could compensate the inefficiency of degradable N utilization. Nevertheless, the committee suggests that if the user desires to compute N recycling, values from 5% to 10% would be appropriate for conventional diets.

PRACTICAL EVALUATION OF CRUDE PROTEIN LEVELS IN BEEF CATTLE DIETS

Two studies were developed to evaluate the effect of reducing crude protein levels in the diets of beef cattle. In Study 1 (Menezes et al., 2019), animals were weaned, and the growing/finishing phase was conducted in a feedlot, in which static and oscillating levels of 10.5, 12.5, and 14.5 % CP in the diet DM were tested. In Study 2 (Menezes et al., 2016), animals were weaned, allocated on pasture for one year following a finishing phase in feedlot. In this case, levels of 10, 12, and 14% CP on the diet DM were evaluated.

Study 1

Forty-two young bulls (initial BW of 260 ± 8.1 kg; age of 7 ± 1.0 months) were fed *ad libitum* and were randomly assigned to receive one of the six diets with different CP concentrations for 140 d: 10.5 (LO), 12.5 (MD), or 14.5% CP in the diet DM (HI), and LO to HI (LH), LO to MD (LM), or MD to HI (MH) oscillating CP at a 48-h interval for each feed. Dry matter intake, growth performance, and carcass traits were not affected ($P > 0.05$) by dietary CP content or oscillating dietary CP (Table 9.7), suggesting that oscillating CP diets were not detrimental to bull performance.

On the other hand, results on N balance were more variable. Overall, bulls fed the HI CP diet presented greater N intakes and excretions than those fed the MD or LO CP diets. Moreover, bulls fed the HI and MD CP diets had greater N retained than those fed low (LO CP diet). Differences were also observed among oscillating dietary CP treatments and the MD static treatment, where greater N intake and excretions were observed for bulls fed LH and MH in comparison to those receiving MD treatment; whereas bulls fed LM showed lower N intake and urinary N excretion than those fed MD. Furthermore, bulls receiving the MD diet retained more N than those fed LM and MH CP diets.

Table 9.7 - Growth performance and carcass traits of Nellore bulls fed different crude protein levels [Adapted from Menezes et al. (2019)]

Item[1]	Treatment[2]						SEM[3]	Contrasts[4]				
	LO	MD	HI	LH	LM	MH		Linear	Quadratic	M × LH	M × LM	M × MH
Animal performance												
Dry matter intake (kg/d)	7.71	7.62	7.29	7.54	7.51	7.62	0.21	0.27	0.33	0.51	0.77	0.77
Initial SBW (kg)	276	275	279	275	274	277	9.09	0.75	0.95	0.85	0.92	0.93
Final SBW (kg)	440	447	433	455	445	448	14.1	0.46	0.98	0.8	0.71	0.67
ADG (kg)	1.17	1.25	1.13	1.32	1.23	1.25	0.06	0.15	0.79	0.51	0.34	0.35
Gain to feed ratio (G:F)	0.15	0.16	0.15	0.17	0.16	0.16	0.01	0.11	0.24	0.19	0.10	0.14
Carcass traits												
Cold carcass weight (kg)	261	266	258	271	262.2	268	8.43	0.53	0.92	0.93	0.69	0.56
Cold carcass dressing (%)	59.4	59.4	59.7	59.5	59	59.8	0.43	0.73	0.79	0.53	0.96	0.53
Fat thickness (mm)	4.9	3.9	3.2	4.0	3.8	5.1	0.50	0.41	0.06	0.11	0.16	0.77
N balance												
N intake (g/d)	135.2	149.7	197.6	171.9	143.8	165.9	2.38	<0.01	<0.01	0.02	<0.01	<0.01
Urine N (g/d)	67.7	85.5	116.1	92.8	71.2	90.7	2.39	<0.01	<0.01	0.33	<0.01	<0.01
Fecal N (g/d)	43.9	44.3	52.1	49.9	47.0	50.0	1.21	<0.01	0.01	0.07	0.81	<0.01
N retained (g/d)	23.8	29.0	29.1	29.9	26.4	27.3	1.16	0.96	0.01	0.13	<0.01	0.04

[1]SBW, shrunk body weight; ADG, average daily gain.
[2]LO, low (10.5% CP); MD, medium (12.5 % CP); HI, high (14.5% CP), LH, oscillating low (LO; 10.5% CP) to high (HI; 14.5% CP) every 48 h; LM, oscillating low (10.5%) to medium (MD; 12.5 % CP) every 48 h; MH, oscillating medium (12.5 % CP) to high (14.5% CP) every 48 h.
[3]SEM = standard error of the mean.
[4]Linear and quadratic contrasts compared 10.5, 12.5, and 14.5% CP; M vs. LH compared 12.5 vs. oscillating 10.5 to 14.5% CP every 48 h; M vs. LM compared 12.5 vs. oscillating 10.5 to 12.5% CP every 48 h; M vs. MH compared 12.5 vs. oscillating 12.5 to 14.5% CP every 48 h.

This study showed that reducing CP from 14.5 to 10.5% in diets or oscillating CP supply did not affect growth performance and carcass traits of growing Nellore bulls; but increasing diet CP content increased N intake, excretions, and retention. It is important to highlight that MD and HI diets presented similar N retention and MD diet showed an overall improvement on N intake, excretion, and retention when compared to the LH and MH oscillating dietary CP treatments.

It seems that although there is no adverse effect of feeding oscillating CP diets in relation to a static level of 12.5% CP, nor static low (10.5% CP) and high (14.5 % CP) levels on growth performance of young Nellore bulls; there may be undesirable increases in environmental N excretion when the average dietary CP content is increased. Thus, it appears plausible that diets containing 10.5 and 12.5% CP contents, or within this range should be indicated for finishing Nellore young bulls. This recommendation on dietary CP content may reach the requirements, reduce environmental impact related to N excretion, and avoid economic losses.

Study 2

Nellore bulls with an average age of 20 ± 1.0 months and initial BW of 330 ± 8.1 kg were used in this experiment. Bulls were divided into three groups and were randomly assigned to the treatments consisting of three levels of CP in the diets: 10, 12, and 14% of CP. The experiment lasted 112 days. Similar to Study 1, no effect of dietary CP levels was observed on animal performance or carcass traits of Nellore bulls finished in feedlot (Table 9.8).

Table 9.8 - Performance and carcass traits of finishing Nellore bulls fed three different crude protein content

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), CP levels influence ADG of growing animals, although the same behavior is not observed for finishing animals. This occurs because protein requirements reduce as the animals reach maturity (NRC, 2000), when they start depositing more fat, increasing fat:muscle ratio in the carcass.

Nevertheless, Brazilian feedlots normally adopt CP levels ranging from 11 to 15%, with mean values of 13.6% CP (Pinto and Millen, 2018), because higher CP levels stimulate intake and are related to high weight gain (Véras et al., 2007). However, Menezes et al. (2016) showed that DMI is not affected by dietary protein levels and the reduction of CP contents during the finishing phase contributes to the reduction of feeding costs. According to these authors, the excessive intake of CP in the diet of 14% CP in relation to 10% was 330 g/d, which is equivalent to 733 grams of soybean meal that could be saved per animal each day. Thus, the reduction of CP contents in diets is possible and viable, mainly during the finishing phase, which reduces feeding costs.

Based on these experiments, the current edition of BR-CORTE suggests that diets containing 10.5 and 12.5% CP contents, or within this range may be indicated if the aim is to produce young bulls in feedlots. In other respects, no difference in animal performance among Nellore bulls fed diets containing 10, 12 or 14% CP were detected when finishing more mature animals with initial BW of 330 kg (Menezes et al., 2016).

AMINO ACIDS REQUIREMENTS

Nutritional models for feeding protein have evolved from basic CP (NRC, 1976; ARC, 1965) to more complex systems based on RDP and RUP (ARC, 1980; INRA, 1988; NASEM, 2016; BR-CORTE, 2016). However, AA and not protein per se, are the required nutrients. Thus, it would be more appropriate to use AA instead of CP requirements to meet the cattle maintenance and production requirements when formulating diets. Furthermore, formulating diets utilizing the AA requirements may contribute to reducing protein content of beef cattle diets, without adversely affecting animal performance, resulting in reduction of protein intake, feed costs, and excreted N compounds to the environment.

Despite the considerable progress in modeling microbial protein synthesis (NASEM, 2016) and AA digestibility (Tamminga and Oldham, 1980; Mariz et al., 2018), there have been limited advances in intermediate metabolism of AA and especially in net AA requirements of ruminants (Tedeschi et al., 2015; Schwab and Broderick, 2017; Amaral et al., 2021). Thus, robust predictive models need to be developed to estimate net and metabolizable AA requirements of cattle, which allow balancing diets for both rumen microorganisms and the host animal.

Few measures of AA requirements for ruminants are available. In the CNCPS (O'Connor et al., 1993), the AA requirements of ruminants are based on NP requirement and AA profile in whole-body tissue (Titgemeyer and Loest, 2001). However, the efficiency in which absorbed AA are used for protein retention is difficult to access (NASEM, 2016), and there are few and contradictory estimates. According to the AFRC (1993), the efficiency of AA usage for gain was assumed to be 59% for all essential AA (EAA), while BR-CORTE (BR-CORTE, 2016) suggested 47.4% as efficiency of MP, which is near to that of 49% suggested in NASEM (2016). Despite these systems adopted the same values for efficiency for AA usage, recent evaluations showed that differences exist among individual AA (Titgemeyer et al., 1990; Löest et al., 2002; Batista et al., 2016).

In this regard, Amaral et al. (2021) and Mariz et al. (2018) developed complementary studies, which 1) evaluated the AA content in empty body and estimated net requirements of AA and energy for weight gain of purebred (Nellore) and crossbred Angus × Nellore (A × N) bulls; 2) determined the apparent and true intestinal digestibility of total and individual AA and estimated the efficiency of whole-body AA retention from individual and total absorbed AA.

There is a deficiency of AA requirements data in the literature, especially for beef cattle. Moreover, data utilized for Amaral et al. (2021) and Mariz et al. (2018) were obtained in Brazilian production conditions. Therefore, the above-mentioned studies will serve as the basis of the net and metabolizable AA requirements incorporated into the current edition of this publication.

The content of each AA and CP (kg) in the empty body and the AA requirements were described in equations forms by Amaral et al. (2021). This database included data from 48 bulls (24 Nellore and 24 A × N) fed three dietary CP contents (100, 120 and 140 g CP/kg DM) in a comparative slaughter experiment. Considering that no differences were found between the genetic groups evaluated, a single equation was obtained to estimate the individual AA content in empty body and the net individual AA requirements for weight gain (g/kg EBG and g/100 g CP) for both Nellore and crossbred A × N bulls (Table 9.9).

Table 9.9 - Amino acids composition of crude protein in the empty body and the net amino acids requirements for gain of Nellore and crossbred Angus × Nellore bulls[1], adapted from Amaral et al. (2021)

Amino acid	Body composition (kg)	R^2	Net requirements for gain	
			g/kg EBG	g/100 g of CP
CP, g/d	$0.3501 \times EBW^{0.8942}$	0.96	$313.1 \times EBW^{-0.1058}$	100
Essential amino acids, g/100 g CP				
Arginine	$0.0368 \times EBW^{0.8369}$	0.94	$30.8 \times EBW^{-0.1631}$	$9.84 \times EBW^{-0.0573}$
Histidine	$0.0035 \times EBW^{1.0556}$	0.91	$3.69 \times EBW^{0.0556}$	$1.18 \times EBW^{0.1614}$
Isoleucine	$0.0102 \times EBW^{0.9369}$	0.93	$9.56 \times EBW^{-0.0631}$	$3.05 \times EBW^{0.0427}$
Leucine	$0.0239 \times EBW^{0.9003}$	0.95	$21.5 \times EBW^{-0.0997}$	$6.87 \times EBW^{0.0061}$
Lysine	$0.0167 \times EBW^{0.9536}$	0.93	$15.9 \times EBW^{-0.0464}$	$5.09 \times EBW^{0.0594}$
Methionine	$0.0059 \times EBW^{0.9197}$	0.88	$5.43 \times EBW^{-0.0803}$	$1.73 \times EBW^{0.0255}$
Phenylalanine	$0.0096 \times EBW^{0.9370}$	0.94	$8.98 \times EBW^{-0.0630}$	$2.87 \times EBW^{0.0428}$
Threonine	$0.0102 \times EBW^{0.9349}$	0.94	$9.54 \times EBW^{-0.0651}$	$3.05 \times EBW^{0.0407}$
Tryptophan	$0.0016 \times EBW^{0.9698}$	0.84	$1.57 \times EBW^{-0.0302}$	$0.50 \times EBW^{0.0756}$
Valine	$0.0099 \times EBW^{0.9751}$	0.90	$9.61 \times EBW^{-0.0249}$	$3.07 \times EBW^{0.0809}$
Non-essential amino acids, g/100 g CP				
Alanine	$0.0421 \times EBW^{0.8115}$	0.93	$34.2 \times EBW^{-0.1885}$	$10.9 \times EBW^{-0.0827}$
Aspartic	$0.0267 \times EBW^{0.8751}$	0.73	$23.4 \times EBW^{-0.1249}$	$7.46 \times EBW^{-0.0191}$
Cystine	$0.0016 \times EBW^{1.0111}$	0.85	$1.64 \times EBW^{0.0111}$	$0.52 \times EBW^{0.1169}$
Glutamic	$0.0416 \times EBW^{0.9058}$	0.91	$37.7 \times EBW^{-0.0942}$	$12.0 \times EBW^{0.0116}$
Glycine	$0.1134 \times EBW^{0.7291}$	0.84	$82.7 \times EBW^{-0.2709}$	$26.4 \times EBW^{-0.1651}$
Proline	$0.0632 \times EBW^{0.7550}$	0.86	$47.7 \times EBW^{-0.2450}$	$15.2 \times EBW^{-0.1392}$
Serine	$0.0189 \times EBW^{0.8491}$	0.95	$16.0 \times EBW^{-0.1509}$	$5.13 \times EBW^{-0.0451}$
Tyrosine	$0.0069 \times EBW^{0.9474}$	0.91	$6.53 \times EBW^{-0.0526}$	$2.09 \times EBW^{0.0532}$

[1]EBW = Empty body weight; EBG = Empty body gain.

The equations to estimate the net Lysine (Lys) and Methionine (Met) requirements (g/100 g of CP) reported by Amaral et al (2021) were: Lys = 5.09 × $EBW^{0.0594}$ and Met = 1.73 × $EBW^{0.0255}$. Considering a bull with EBW of 350 kg, the net Lys and Met requirements calculated by these equations were 7.20 and 2.01 g/100 g CP, respectively.

The equations to estimate the net Lys and Met requirements (g/kg EBG) reported by Amaral et al (2021) were: Lys = 15.9 × $EBW^{-0.0464}$ and Met = 5.43 × $EBW^{-0.0803}$. Silva et al. (2002) reported values of net requirement of Lys and Met for weight gain of Nellore bulls (EBG = 1 kg/d and BW = 350 kg) of 10.36 and 3.54 g/d, respectively. Similarly, the net requirements of Lys and Met for weight gain predicted for Holstein steers based on the AA body composition observed by Ainslie et al. (1993) were 10.71 and 3.69 g/d. The values obtained by these authors were close to those reported in the study by Amaral et al. (2021) of 12.15 and 3.39 g/d for the net requirement of Lys and Met, respectively.

To convert the individual and total net AA to metabolizable AA requirements, individual and total AA retention efficiencies must be estimated. Such efficiencies were estimated by Mariz et al (2018) through a linear regression between individual and total AA absorbed (g/d) and their respective whole-body retention (g/d). For this, Mariz et al. (2018) utilized data from two studies. In study 1, the intestinal digestibility and total and individual AA daily absorbed were estimated in a digestion trial (for more details, please check Mariz et al., 2018). Study 2 data were composed by the efficiency of individual and total AA utilization for whole-body protein retention previously described in Amaral et al. (2021) complementary study.

True intestinal digestibility of AA was obtained by a linear regression model fitted between the AA absorbed in the small intestine and their respective omasal flow. The intercept of the equation represented the endogenous losses, and the slope represented the true digestibility of the dietary AA (Table 9.10) or microbial AA (Table 9.11). The true intestinal digestibility of total AA was 75%, and the endogenous loss was 17.18 g/d. True digestibility of individual EAA varied from 72% for threonine to 86% to Met, while it varied from 67% for tyrosine to 85% to cystine for non-essential amino acids (NEAA). The true intestinal digestibility of Lys was 77%.

Table 9.10 - True intestinal digestibility of amino acids, adapted from Mariz et al. (2018)

Item	Equations[1]	TID[2]
Total amino acids	$\hat{Y} = -17.18 + 0.75X$	75
Essential amino acids	$\hat{Y} = -8.14 + 0.77X$	77
Non-essential amino acids	$\hat{Y} = -9.29 + 0.74X$	74
Essential amino acids		
Arginine	$\hat{Y} = -0.76 + 0.81X$	81
Histidine	$\hat{Y} = -0.47 + 0.83X$	83
Isoleucine	$\hat{Y} = -0.87 + 0.77X$	77
Leucine	$\hat{Y} = -1.78 + 0.79X$	79
Lysine	$\hat{Y} = -1.70 + 0.77X$	77
Methionine	$\hat{Y} = -0.38 + 0.86X$	86
Phenylalanine	$\hat{Y} = -1.21 + 0.78X$	78
Threonine	$\hat{Y} = -1.65 + 0.72X$	72
Tryptophan	$\hat{Y} = -0.56 + 0.82X$	82
Valine	$\hat{Y} = -1.69 + 0.76X$	76
Non- essential amino acids		
Alanine	$\hat{Y} = -1.97 + 0.74X$	74
Aspartic acid	$\hat{Y} = -1.08 + 0.81X$	81
Cystine	$\hat{Y} = -1.41 + 0.85X$	85
Glutamic acid	$\hat{Y} = -1.91 + 0.75X$	75
Glycine	$\hat{Y} = -2.59 + 0.71X$	71
Proline	$\hat{Y} = -2.23 + 0.73X$	73
Serine	$\hat{Y} = -1.30 + 0.76X$	76
Tyrosine	$\hat{Y} = -0.05 + 0.67X$	67

[1]$\hat{Y}$ = AA absorbed in small intestine (g/d); X = AA omasal flow.
[2]True intestinal digestibility.

The true intestinal digestibility of total microbial AA obtained in this study was 80% (Table 9.11), which is similar to the value of 80% adopted for microbial protein in some feeding systems such as NASEM (2016) and the previous edition of this publication (BR-CORTE, 2016). Nevertheless, when considering true intestinal digestibility of individual AA, these values varied substantially. Microbial arginine and tyrosine showed the highest values for true digestibility (arginine = 85% and tyrosine = 89%) among EAA and NEAA, respectively. The estimated intestinal digestibilities of microbial Lys and Met were 84 and 80%, respectively.

Table 9.11 - True intestinal digestibility of microbial amino acids, adapted from Mariz et al. (2018)

Item	Equations[1]	TID[2]
Total amino acids	$\hat{Y} = -21.27 + 0.80\ X$	80
Essential amino acids	$\hat{Y} = -10.87 + 0.82\ X$	82
Non-essential amino acids	$\hat{Y} = -10.62 + 0.79X$	79
Essential amino acids		
Arginine	$\hat{Y} = -1.34 + 0.85\ X$	85
Histidine	$\hat{Y} = -0.60 + 0.79\ X$	79
Isoleucine	$\hat{Y} = -1.97 + 0.83X$	83
Leucine	$\hat{Y} = -3.19 + 0.84\ X$	84
Lysine	$\hat{Y} = -0.60 + 0.84\ X$	84
Methionine	$\hat{Y} = -0.36 + 0.80\ X$	80
Phenylalanine	$\hat{Y} = -1.60 + 0.81\ X$	81
Threonine	$\hat{Y} = -0.67 + 0.79\ X$	79
Tryptophan	-	-
Valine	$\hat{Y} = -1.03 + 0.79\ X$	79
Non- essential amino acids		
Alanine	$\hat{Y} = -1.62 + 0.75\ X$	75
Aspartic acid	$\hat{Y} = -0.79 + 0.81\ X$	81
Cystine	$\hat{Y} = -0.43 + 0.70\ X$	70
Glutamic acid	$\hat{Y} = -3.20 + 0.76\ X$	76
Glycine	$\hat{Y} = -1.55 + 0.81\ X$	81
Proline	$\hat{Y} = -2.54 + 0.87\ X$	87
Serine	$\hat{Y} = -1.21 + 0.83\ X$	83
Tyrosine	$\hat{Y} = -0.87 + 0.89\ X$	89

[1]$\hat{Y}$ = AA absorbed in small intestine (g/d); X = AA omasal flow.
[2]True intestinal digestibility.

The individual and total AA retention efficiencies estimated by Mariz et al. (2018) are described in Table 9.12. The intercept of the equation represented the endogenous losses, and the slope represented the AA retention efficiency.

The efficiency of utilization of total AA obtained in this study was 40%, whereas the efficiencies of utilization of EAA and NEAA were 38% and 42%, respectively.

Table 9.12 - The efficiency of individual absorbed amino acids to whole-body deposition, adapted from Mariz et al. (2018)

Item	Equations[1]	Efficiency (%)
Total amino acids	$\hat{Y} = -36.67 + 0.40\ X$	40
Essential amino acids	$\hat{Y} = -17.43 + 0.38\ X$	38
Non-essential amino acids	$\hat{Y} = -18.80 + 0.42\ X$	40
Essential amino acids		
Arginine	$\hat{Y} = -2.17 + 0.56\ X$	56
Histidine	$\hat{Y} = -1.42 + 0.62\ X$	62
Isoleucine	$\hat{Y} = -1.41 + 0.30\ X$	30
Leucine	$\hat{Y} = -3.36 + 0.30\ X$	30
Lysine	$\hat{Y} = -2.28 + 0.37\ X$	37
Methionine	$\hat{Y} = -0.37 + 0.58\ X$	58
Phenylalanine	$\hat{Y} = -1.57 + 0.31\ X$	31
Threonine	$\hat{Y} = -1.42 + 0.34\ X$	34
Tryptophan	$\hat{Y} = -0.18 + 0.39\ X$	39
Valine	$\hat{Y} = -2.55 + 0.40\ X$	40
Non-essential amino acids		
Alanine	$\hat{Y} = -1.25 + 0.35\ X$	35
Aspartic	$\hat{Y} = -3.65 + 0.26\ X$	26
Cystine	$\hat{Y} = -0.14 + 0.18\ X$	18
Glutamic	$\hat{Y} = -4.57 + 0.67\ X$	67
Glycine	$\hat{Y} = -0.68 + 0.63\ X$	63
Proline	$\hat{Y} = -0.40 + 0.43\ X$	43
Serine	$\hat{Y} = -1.16 + 0.31\ X$	31
Tyrosine	$\hat{Y} = -0.88 + 0.26\ X$	26

[1]$\hat{Y}$ = absorbed amino acid (g/d); X = whole-body amino acid retention.

Considering a bull with an EBW of 350 kg, the values for the metabolizable requirements of Lys and Met estimated based on the recommendations of Amaral et al. (2021) for net requirements of Lys (7.20 g/100 g CP) and Met (2.01 g/100 g CP) and their respective values of efficiency of use (Lys = 37%; Met = 58%) previously reported by Mariz et al. (2018) were: 19.47 and 3.47 g/100 g of CP, respectively.

It is noteworthy that Mariz et al. (2018) found differences in the retention efficiency of total and individual AA. Furthermore, arginine (56%), histidine (62%), and methionine (58%) showed the greatest estimates for retention efficiency among the EAA. For NEAA, glutamic acid (67%) and glycine (63%) showed the greatest estimates for retention efficiency. This discrepancy among AA suggests that there are differences in how efficiently the different AA are used for meat production. In this way, using a single coefficient for total AA utilization would not suit in the concept of precision feeding.

The above-mentioned studies (Amaral et al., 2021; Mariz et al., 2018) allow BR-CORTE users to estimate the EAA and NEAA requirements of beef cattle raised in tropical conditions. However, the unique features of the intermediate metabolism, in addition to the complex feed transformation during ruminal fermentation and the difficulties in determining the AA available for absorption in the duodenum, still pose a challenge to formulate diets based on AA requirements for cattle. Due to these challenges, the AA requirements estimates have been recommended as a guide and should be used according to the feeding system.

SUMMARY OF PROTEIN AND AMINO ACIDS REQUIREMENTS

The equations used to estimate protein requirements for Zebu, crossbred beef and dairy cattle are presented for different sexes, raised in feedlot or on pasture. in Tables 9.13 and 9.14. The metabolizable AA requirements for gain (g/kg EBG) are presented for different EBW in Table 9.15.

Table 9.13 - Summary of equations utilized to convert body weight and average daily gain for empty body weight and empty body gain of Zebu, crossbred beef cattle, and crossbred dairy cattle of three sexes, raised in feedlot or on pasture

Item	System	Genetic group	Gender	Equations	Unit
SBW		Zebu and Crossbred beef cattle		$0.8915 \times BW^{1.0151}$	kg
		Crossbred dairy cattle		$0.9247 \times BW^{1.0085}$	
EBW	Feedlot	Zebu cattle	Bulls	$0.8126 \times SBW^{1.0134}$	kg
			Steers	$0.6241 \times SBW^{1.0608}$	
			Heifers	$0.6110 \times SBW^{1.0667}$	
		Crossbred cattle	Bulls	$0.7248 \times SBW^{1.0314}$	
			Steers	$0.6586 \times SBW^{1.0499}$	
			Heifers	$0.6314 \times SBW^{1.0602}$	
	Pasture			$0.8507 \times SBW^{1.0002}$	
EBG				$0.9630 \times ADG^{1.0151}$	kg/d
EQEBW		Zebu cattle	Bulls	(EBW/517) × 517	kg
			Steers	(EBW/433) × 517	
			Heifers	(EBW/402) × 517	
		Crossbred beef cattle	Bulls	(EBW/560) × 517	
			Steers	(EBW/482) × 517	
			Heifers	(EBW/417) × 517	
		Crossbred dairy cattle	Bulls	(EBW/616) × 517	
			Steers	(EBW/532) × 517	
			Heifers	(EBW/493) × 517	

Table 9.14 - Summary of equations utilized to estimate protein requirements for beef cattle raised in feedlot or on pasture

Item	System	Equations	Unit
MPm	Feedlot	$3.6 \times SBW^{0.75}$	g/d
	Pasture	$3.9 \times SBW^{0.75}$	
NPg		$NPg = 176.01 \times EBG - 0.381 \times EQEBW^{0.75} \times EBG^{1.035}$	g/d
k		SBW < 340 kg: 84.665 – 0.1179 × EQEBW	%
		SBW > 340 kg: 47.4	
MPg		NPg/k	g/d
MPtotal		MPm + MPg	g/d
MCP		$-53.07 + 304.9 \times CPI + 90.8 \times TDNI - 3.13 \times TDNI^2$	g/d
RDP		MCP	g/d
RUP		(MPt - (MCP × 0.64))/0.80	g/d
CP		RDP + RUP	g/d

Thus, considering a 520-kg Nellore bull gaining 1.6 kg/d raised in feedlot:

- $SBW = 0.8915 \times BW^{1.0151} = 0.8915 \times 520^{1.0151} = 509.5$ kg
- $EBW = 0.8126 \times SBW^{1.0134} = 0.8126 \times 509.5^{1.0134} = 450.1$ kg
- $EBG = 0.963 \times ADG^{1.0151} = 0.963 \times 1.6^{1.0151} = 1.55$ kg/d
- EQEBW = (EBW/517) × 517 = (450.1/517) × 517 = 450.1 kg
- $MPm = 3.6 \times SBW^{0.75} = 3.6 \times 509.5^{0.75} = 386.1$ g/d
- $NPg = 176.01 \times EBG - 0.381 \times EQEBW^{0.75} \times EBG^{1.035} = 176.01 \times 1.55 - 0.381 \times 450.1^{0.75} \times 1.55^{1.035} = 214.2$ g/d
- k = 47.4%
- MPg = NPg/k = 214.2/0.474 = 451.9 g/d
- MP total = MPm + MPg = 386.1 + 451.9 = 838 g/d

• MCP = - 53.07 + 304.9 × CPI + 90.8 × TDNI – 3.13 × TDNI^2 = - 53.07 + 304.9 × 1.215 + 90.8 × 7.88 – 3.13 × 7.88^2 = 838.5 g/d
• RDP = MCP = 838.5 g/d
• RUP = [MPt – (MCP × 0.64)]/0.80 = [838 – (838.5× 0.64)]/0.80 = 376.7 g/d
• CP = RDP + RUP = 838.5 + 376.7 = 1215 g/d

Table 9.15 - Metabolizable amino acids requirements for gain of Nellore and crossbred Angus × Nellore bulls

Requirements	Utilization efficiency (%)[1]	Empty body weight (kg)			
		250	350	450	550
Essential amino acids (g/kg empty body weight gain)					
Arginine	56	22.35	21.16	20.31	19.65
Histidine	62	4.39	4.31	4.25	4.20
Isoleucine	30	22.59	22.11	21.76	21.49
Leucine	30	41.33	39.96	38.98	38.20
Lysine	37	33.26	32.75	32.37	32.07
Methionine	58	5.98	5.82	5.70	5.61
Phenylalanine	31	20.50	20.07	19.76	19.51
Threonine	34	19.50	19.08	18.77	18.53
Tryptophan	39	3.47	3.44	3.41	3.39
Valine	40	20.92	20.74	20.61	20.51
Non-essential amino acids (g/kg empty body weight gain)					
Alanine	35	34.51	32.39	30.89	29.74
Aspartic	26	45.16	43.30	41.96	40.92
Cystine	18	9.45	9.49	9.51	9.53
Glutamic	67	33.45	32.41	31.65	31.05
Glycine	63	29.41	26.85	25.08	23.76
Proline	43	28.72	26.45	24.87	23.68
Serine	31	22.43	21.32	20.53	19.92
Tyrosine	26	18.70	18.37	18.13	17.94

[1]Adapted from Mariz *et al.* (2018).

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