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Nutrient requirements of lactating beef cows and their calves

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INTRODUCTION

In beef cattle production, the breast-feeding phase is important for the meat production chain to provide future animals that will be utilized for other phases of the production system. Additionally, it is characterized by the use of a large number of animals, with 31% of the production herd being represented by the cows (Calegare, 2004). It is estimated that approximately 70% of the energy required for meat production is utilized for functions involved with cow maintenance (Ferrell and Jenkins, 1985). Thus, nearly 50% of the energy required to raise an animal until slaughter is utilized for cow maintenance.

In this context, Brazilian livestock has been pressured to develop an efficient, competitive, and continuous meat production program based on the areas currently used for livestock, which are mandatorily based on the reduction of the production cycle. Thereby, the production systems have intensified to reduce the age of animal at slaughter, increasing the amount and quality of products offered. In this way, knowledge of the potential dry matter intake (DMI) of cows and calves is essential for adequate planning and technology used to achieve production targets established in the system.

During the breast-feeding phase, the correct measurement of milk yield (MY) is indispensable because this parameter represents the amount of nutrients that cows are secreting into the milk. Furthermore, this estimate will be considered to calculate the amount of nutrients that the calf is consuming from the milk, which will be considered to meet the nutrient requirements of these animals, being a factor that directly interferes with the performance of calves. MY can be measured directly and indirectly; the most common methods are differences in calf weights before and after suckling (Williams et al., 1979), manual milking (Totusek et al., 1973; Ferreira et al., 2020) and machine milking procedures after injection of oxytocin (Lopes et al., 2014: Almeida et al., 2018; Ferreira et al., 2021).

Regardless of the method, estimating MY of beef cows is laborious as it demands extensive and intensive calf separation management. These circumstances explain not only the scarcity of studies but also the low number of data points for fitting an equation describing milk production for grazing beef cows.

The energy requirements of the animal correspond to the sum of the needs for maintenance and production, which is divided into energy required for growth, lactation, and pregnancy (Webster, 1979). However, few studies (Fonseca, 2012 a; b) have been conducted in Brazil to estimate the nutrient requirements of animals during the breast-feeding phase, or those of lactating cows and suckling calves.

Thereby, from the knowledge of MY and nutrients requirements of calves, the amount of energy and protein secreted by the milk can be determined, which allows estimating the moment that the milk does not provide enough nutrients and the exact moment for calf supplementation.

The metabolizable energy intake (MEI) that does not incur energy changes in the body will influence the dietary energy required for maintenance, making this parameter considered a characteristic with moderate to high heritability (Carstens et al., 1988). Thereby, energy efficiency, from 60 to 70% of the total energy required for maintenance of the animals (Bottje e Carstens, 2009), has been attributed to protein turnover, ion pumps (Na^+ e K^+) and the uncoupling of oxidative phosphorylation in the mitochondria. Thus, the selection of animals that have lower nutrient requirements could be adopted, with the aim of obtaining more efficient animals.

In this chapter, the discussion about equations developed to estimate DMI and milk production and composition of lactating Nellore cows will be presented, as well as the DMI of suckling Nellore calves. Also, the requirements of energy, protein, and minerals will be presented for lactating Nellore cows and their calves.

DRY MATTER INTAKE OF LACTATING BEEF COWS

In the edition of BR-CORTE (2016), we used the Wilmink model (1987) plus the variable average daily gain (ADG), based on the study by Costa e Silva (2015), who evaluated five models available to estimate the DMI of Nellore cows during seven months of lactation. In this study, the cows received a diet with a high amount of corn silage, in order to simulate a pasture diet, obtaining the following model:

$$DMI\ (g/kg\ BW) = 27.259 - 13.861 \times \exp^{(-0.836 \times WL)} - 0.317 \times WL + 0.606 \times ADG$$

where: DMI = dry matter intake, WL = week of lactation, ADG = average daily gain (kg/d)

Although it showed better estimate of DMI than the BR-CORTE (2010) issue, which considered a constant value of 2.39% of BW for lactating Nellore cows during the first six months of lactation, the suggested equation did not correctly estimate DMI from an independent database with 372 observations (Table 12.2), probably due to the fact that the equation was generated using data from Nellore cows consuming corn silage (Costa e Silva, 2015).

However, considering that grazing cows are subject to variations in the availability and nutritional value of forage, a new equation was developed from data of 3 experiments conducted with lactating Nellore cows under pasture (Table 12.1), containing 372 observations.

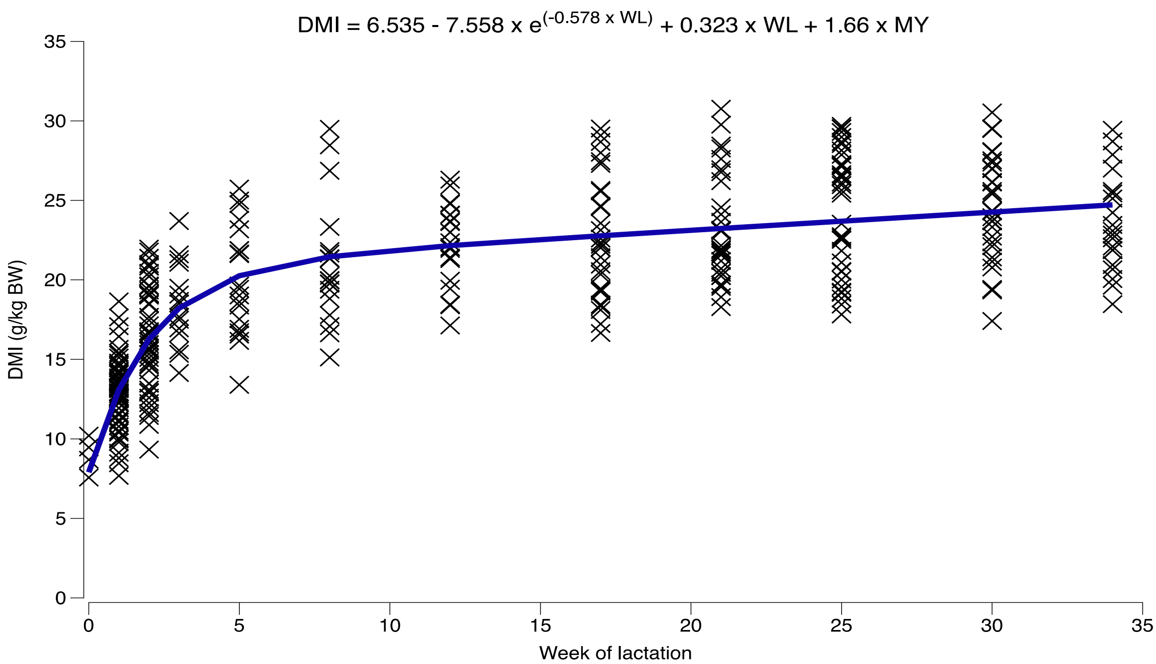

Figure 12.1 - Dry matter intake (g/kg BW) of Nellore cows during lactation period.

Thus, the new equation obtained was:

$$DMI\ (g/kg\ BW) = 6.535 - 7.558 \times \exp^{(-0.578 \times WL)} + 0.323 \times WL + 1.66 \times MY,$$

where DMI = Dry mater intake, WL = Week of lactation, MY = Milk yield (kg/d).

Considering the values predicted by the new suggested equation and the recommendation of BR-CORTE (2016), it can be seen that the equation recommended by BR-CORTE (2016) overestimates the DMI by 6.1 g/kg BW (13.4 *vs*. 7.3 g/kg BW) on the day of calving (Week 0) and underestimates by 6.4 g/kg BW (17.8 *vs*. 24.2 g/kg BW) at week 30.

An independent database containing 92 observations (Table 12.1), was used to validate the suggested equation, by Wilmink (1987).

From the evaluations described in Table 12.2, it is observed that the intercept and the slope of the equation were not different from 0 and 1, respectively. Furthermore, the average prediction error was close to zero, being associated with random error (Table 12.2).

Thus, in the current edition, BR-CORTE recommends that the DMI of Nellore cows be estimated from the following equation:

$$\text{DMI (g/kg BW)} = 6.535 - 7.558 \times \exp^{(-0.578 \times WL)} + 0.323 \times WL + 1.66 \times MY$$

Table 12.1 - Descriptive statistics from the independent database utilized to evaluate dry matter intake (DMI) and milk yield prediction equations of beef cows

Study	Item	n	Means	DP	Maximum	Minimum
Data for development of the equation						
Matos (2023)	Week lactation	217	22.1	7.8	34	8
	Milk yield[1]	217	5.8	0.8	7.2	4.6
	DMI	217	23.3	3.6	30.8	15.1
	Body weight	217	527	65	680	416
	Average daily gain	217	0.11	0.13	0.35	-0.17
David (2022)	Lactation week	37	4.4	1.4	6	3
	Milk yield[1]	37	7.4	0.1	7.5	7.4
	DMI	37	20	2.6	25.7	13.4
	Body weight	37	518	74.1	639	407
	Average daily gain	37	-0.11	0.35	-0.07	-0.17
Ferreira (2022)	Week lactation	118	1.7	1	3	0
	Milk yield[1]	118	6.4	1.4	7.6	-
	DMI	118	14	3.1	23.7	7.6
	Body weight	118	495	9.7	528	455
Data for equation validation						
Lopes (2012)	Week lactation	-	26.5	5.45	37	12
	Milk yield[1]	143	6.97	1.58	9.99	4.24
	DMI	32	11.8	2.35	17	7.95
	Body weight	32	481	50.6	558	359
	Average daily gain	32	-0.34	0.35	0.22	-1.38
Cardenas (2012)	Week lactation	-	28.1	6.38	40	12
	Milk yield[1]	170	7	1.36	9.87	4.21
	DMI	60	12.9	1.45	16.7	9.94
	Body weight	60	450	51.6	567	362
	Average daily gain	60	0.2	0.09	0.4	-0.04

Estimated milk yield, using data from the equation described in Figure 12.2.

MILK YIELD AND COMPOSITION OF BEEF COWS

As previously described, the correct measurement of MY from beef cows is important for calculating nutritional requirements for both cows and calves. In this sense, it is necessary to understand the milk collections methodologies for these estimates.

In the first studies, milk production in beef cows were based on an indirect estimate, weighing calves before and after suckling. This technique generates great stress in the animals due to excess handling, in addition to greater variation and error in the collection, since any factor at the time of weighing (scale, calves that urinate and defecate at the time of suckling) will cause great variation in MY estimates.

Over the years, hand or machine milking has become the most used methodology for this type of assessment (Ferreira et al., 2021).

Table 12.2 - Mean (kg) and descriptive statistics for the relationship between observed and predicted values of dry matter intake (DMI) of lactating Nellore beef cows

Item	Total DMI of cows		
	OBS[1]	BR-CORTE 2016[2]	BR-CORTE 2023[3]
Mean	19.8	21.5	22.7
SD	5.45	2.69	1.95
Maximum	30.7	25.4	20.2
Minimum	6.07	13.4	16.2
R	-	0.04	0.52
CCC[4]	-	-0.15	0.44
Regression			
Intercept			
Estimate	-	28.48	-1.88
SE	-	2.31	3.32
P-value[5]	-	<0.0001	0.57
Slope			
Estimate	-	-0.40	1.19
SE	-	0.11	0.15
P-value[6]	-	<0.0001	0.57
MSEP[7]	-	45.19	11.48
Mean bias	-	3.07	5.9
Systematic bias	-	2.54	0.13
Random errors	-	27.9	5.45

[1]OBS = observed values; [2]BR-CORTE 2016 = values predicted by the equation generated from model proposed by Wilmink (1987) added to average daily gain (ADG); [3]BR-CORTE 2023 = values predicted by the equation generated from model proposed by Wilmink (1987) added to milk yead(MY); [4]CCC = concordance correlation coefficient; [5]H_0: $\beta_0 = 0$; [6]H_0: $\beta_1 = 1$; [7]MSEP = mean square error of prediction.

However, there are two ways to estimate the MY of beef cows without a consensus in the literature: (1) milking in the morning and correct up to 24 hours (M24), (2) milking in the morning and afternoon (AM_PM). In the M24 methodology, recording the times of separation of the calf from the mother on the day before and at the end of milking on the following day are fundamental (Costa e Silva, 2015).

Thus, this edition was based on the meta-analytical approach of Lopes et al. (2022), who collected information from 16 experiments with Nellore cows grazing between 2014 and 2021, totaling 1,503 observations (Table 12.3). This study brough results about the methodology to estimate MY, as well as new equations to estimate the composition and production of milk of Nellore cows.

Firstly, the authors compared MY estimated by the M24 method (Valente et al., 2013; Lopes et al., 2014), and the AM_PM method (Almeida, et al., 2018; Ferreira et al., 2021; Table 12.3). The M24 method was applied to studies that milked in the morning and in the afternoon, and both methods were compared within the AM_PM method. No difference was observed in MY regardless of the method of milk collection. The average was 6.51 and 6.70 kg (±0.098), respectively. Thus, it is recommended to measure the morning milk and correct it for a 24-hr period to estimate the daily milk yield of Nellore cows as described in the studies by Valente et al. (2013) and Lopes et al. (2014), due to less labor and interference in the behavior of animals.

The last edition of BR-CORTE (2016) was based on the study developed by Costa e Silva (2015), suggesting an equation to estimate the MY of Nellore cows. The author evaluated five models to estimate the MY of Nellore cows during seven months of lactation. In this study, cows were fed a diet with a high amount of corn silage (85%) in order to simulate a pasture diet.

The equation that presented the best estimate was the one adjusted using the model proposed by Cobby and Le du (1978). Thus, the BR-CORTE (2016) adopted the following equation:

$$MY = 8.819 - 0.069 \times WL - 8.819 \times \exp^{(-3.211 \times WL)},$$

Where MY = milk yield and WL = week lactation.

Despite presenting a better estimate than the previous edition, the suggested equation overestimates MY as it was generated using data from feedlot Nellore cows (Ferreira et al.,2021).

Table 12.3 - Statistical description of the dataset used to develop and validate the equations to estimate milk yield of beef cows

Study	Estimation method	n[2]	Milk yield				Week lactation		
			mean	DP	minimum	maximum	mean	minimum	maximum
Multiparous									
Lopes et al. (2014)	Corrected for 24 hours	84	6.4	1.6	1.4	10.5	28	12	40
Lopes et al. (2016)	Corrected for 24 hours	17	7.8	1.6	4.3	10.7	7	4	12
Carvalho (2018)[1]	Corrected for 24 hours	30	5.7	1.6	2.1	9.3	26	21	32
Lage (2019)[1]	Morning and afternoon	70	5.0	1.8	1.5	8.8	29	23	35
de Paula et al. (2022)	Morning and afternoon	65	5.5	1.4	2.4	8.7	25	17	32
Moreira (2022)[1]	Morning and afternoon	71	7.1	1.8	2.5	10.3	25	17	32
Saraiva (2023)[1]	Morning and afternoon	104	6.9	2.1	1.7	11.4	19	6	32
Ferreira et al. (2020)	Morning and afternoon	74	7.8	1.3	4.1	10.4	5	3	7
Ferreira et al. (2021)	Morning and afternoon	99	6.6	1.6	2.6	10.1	12	1	30
Souza (2021)[1]	Corrected for 24 hours	178	4.9	1.6	2.0	9.7	17	4	30
Nascimento (2021)[1]	Corrected for 24 hours	139	5.5	2.0	0.6	10.9	17	4	30
Rodrigues (2021)[1]	Morning and afternoon	134	5.9	1.6	2.5	9.8	10	1	29
Primiparous									
Melo (2018)	Corrected for 24 hours	55	5.0	1.5	2.4	8.6	5	2	9
Ferreira et al. (2021)	Morning and afternoon	164	5.9	1.5	2.5	9.18	12	1	30
Rodrigues (2021)[1]	Morning and afternoon	124	6.0	1.3	2.9	8.8	10	1	29
Vital (2021)	Corrected for 24 hours	95	5.3	1.5	1.6	9.2	5	2	9

[1]unpublished data. [2]cow-day observations. Adapted from Lopes et al. (2022).

Thus, Ferreira et al. (2021) developed new equations considering calving order to estimate MY of Nellore cows under grazing conditions. However, considering that grazing cows are subject to variations in forage availability and nutritional value, a robust equation that included a larger amount of data from different regions and herds for greater reliability was needed.

In the study by Lopes et al. (2022), nine studies were used to generate new equations for multiparous cows and 3 studies were randomly chosen for independent validation of the equation (Table 12.3). Considering that multiparous and primiparous cows differ in milk production potential (Ferreira et al., 2021), other four studies were used to develop an equation to estimate MY of primiparous separately (Table 12.3).

The equation by BR-CORTE (2016) did not correctly estimate the milk yield of the dataset and presented greater bias and prediction error (Table 12.4). Thereby, the equation for estimating MY for multiparous beef cows was readjusted and validated using database from the meta-analysis.

The inclusion of an equation for primiparous cows was suggested. However, due the low number of studies and data regarding milk yield of primiparous cows, it was not possible to use an external database to perform an independent validation for this category. However, the unprecedent equation for this category of cows make it relevant to the scientific literature, suggesting it to be used until more data are available for its validation.

The new suggested equations were also based on the model proposed by Cobby and Le Du (1978), being:

$MY = 7.996 - 0.101 \times WL - 7.996 \times \exp^{(-1.447 \times WL)}$, obtained for multiparous cows (> 3 years) and the equation:

$MY = 6.431 - 0.072 \times WL - 6.431 \times \exp^{(-2.188 \times WL)}$ found for primiparous cows (≤ 3 years).

Table 12.4 - Mean (kg) and statistic description for the relationship between predicted and observed milk yield values

Item	Milk yield		
	OBS[1]	Cobby and Le Du (1978)[2]	BR-CORTE (2016)[3]
Mean	6.39	6.52	7.88
SD	1.84	0.95	0.67
Maximum	10.9	7.59	8.67
Minimum	2.33	4.97	6.75
R	-	0.53	0.57
CCC[4]	-	0.42	0.15
Regression			
Intercept			
Estimate	-	-0.34	-6.08
SE	-	0.664	1.07
P-value[5]	-	0.600	< 0.0001
Slope			
Estimate	-	1.03	2.38
SE	-	0.100	0.13
P-value[6]	-	0.769	< 0.0001
MSEP[7]	-	2.57	4.84
Mean bias	-	0.024	2.32
Systematic bias	-	0.0008	0.15
Random errors	-	2.55	2.36

[1]OBS = independent values; [2]Cobby and Le Du (1978) = predicted values by the equation generated from the model proposed by the proposed by Cobby and Le Du (1978); [3]BR-Corte (2016) = predicted values by the equation suggested by Valadares Filho et al. (2016); [4]CCC = correlation and concordance coefficient; [5]H_0: $\beta_0 = 0$; [6]H_0: $\beta_1 = 1$; [7]MSEP = mean square error of prediction.

According to the new equations developed, it is estimated that the MY at the peak of production is 7.59 kg and 6.22 for multiparous and primiparous cows, respectively, taking 3 to 5 weeks until the peak (Lopes et al., 2022).

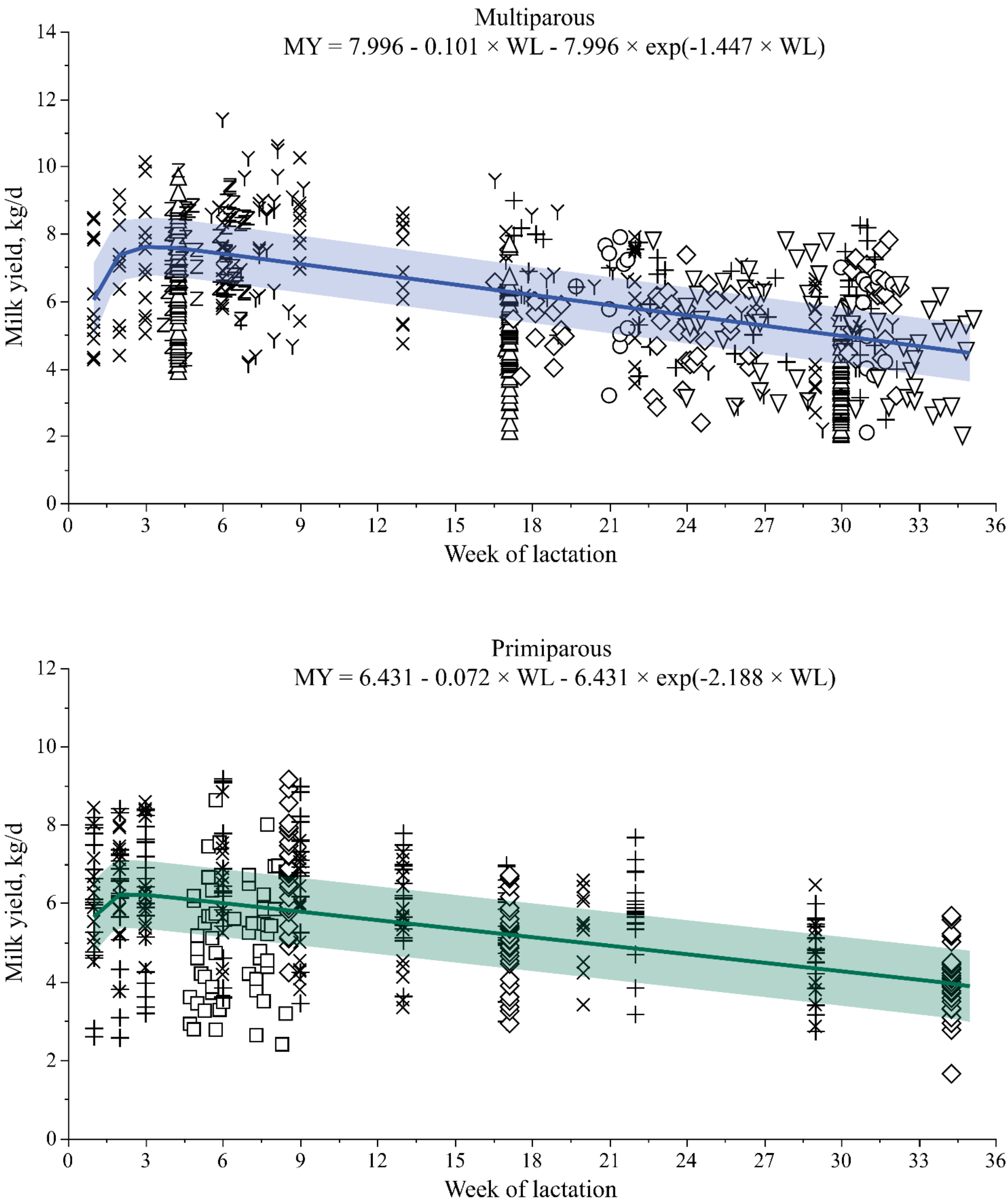

Figure 12.2 - Milk yield versus week of lactation plots for predictions (solid line) and observations (individual cow data, point markers differ in study) for multiparous and multiparous cows under grazing conditions.

The same studies used in the meta-analysis (Lopes et al., 2022) were the basis for estimating milk composition throughout lactation. Thereby, an average was generated for each milk component, as well as linear equations to estimate milk composition according to the lactation week (Table 12.5).

The updated values were close to those recommended by the edition of BR-CORTE (2016), except for fat (5.60 *vs.* 4.76%) and total solids (15.00 *vs.*13.92%).

The greatest fat percentage found in the previous edition may be explained by data coming from cows kept in feedlot system and fed corn silage (Costa e Silva, 2015). The higher energy intake in the diet possibly led to an increase in acetate production providing a greater amount of substrate for new fat synthesis in the mammary gland. Thus, the higher percentage of fat also impacted the total solids values.

The mineral composition of milk from Nellore cows presented was based on the study by Costa e Silva et al. (2015a), with the following average concentrations: 1.11% Ca, 0.76% P, 0.20% Na, 0.25% S, 0.23 ppm Co, 3.20 ppm Cr, 29.9 ppm Fe, 1.40 ppm Mn and 35.4 ppm Zn (Table 12.6).

Table 12.5 - Mean (%) and estimate of milk composition according to the lactation week

Components	mean	Equations
Fat, %	4.76	4.52 + 0.018 x WL[1]
Protein, %	3.56	3.37 + 0.010 x WL
Lactose, %	4.56	4.81 − 0.010 x WL
Total solids, %	13.92	13.6 + 0.021 x WL

[1]WL = Week lactation. Adapted from Lopes et al. (2022).

Table 12.6 - Mineral composition of milk from Nellore cows during lactation

Components	Days of lactation							SEM	P value
	28	56	84	112	140	168	196		
Ca (g/kg)	1.13	1.10	1.10	1.10	1.12	1.11	1.10	0.03	0.46
P (g/kg)	0.81^{a}	0.74^{b}	0.73^{b}	0.76^{ab}	0.77^{ab}	0.77^{ab}	0.76^{ab}	0.02	0.01
Mg (g/kg)	0.06^{c}	0.07^{c}	0.07^{c}	0.07^{bc}	0.08^{ab}	0.08^{a}	0.08^{a}	0.01	<0.001
K (g/kg)	0.71^{ab}	0.70^{ab}	0.71^{ab}	0.73^{a}	0.73^{ab}	0.69^{ab}	0.65^{b}	0.03	0.04
Na (g/kg)	0.22^{a}	0.20^{b}	0.19^{b}	0.19^{b}	0.19^{b}	0.19^{b}	0.20^{ab}	0.01	<0.001
S (g/kg)	0.26	0.24	0.25	0.25	0.26	0.26	0.26	0.01	0.08
Co (ppm)	0.23^{ab}	0.26^{a}	0.20^{b}	0.22^{ab}	0.25^{ab}	0.22^{ab}	0.23^{ab}	0.02	0.03
Cr (ppm)	3.19	3.33	3.24	3.03	3.28	3.27	3.05	0.02	0.12
Cu (ppm)	3.01^{a}	2.28^{b}	1.98^{b}	1.78^{b}	1.73^{b}	1.55^{b}	1.54^{b}	0.20	<0.001
Fe (ppm)	27.9	29.9	27.4	29.3	30.1	32.5	32.0	3.1	0.58
Mn (ppm)	1.47	1.26	1.24	1.36	1.47	1.53	1.47	0.2	0.21
Zn (ppm)	41.1^{a}	35.5^{b}	34.1^{b}	33.9^{b}	34.6^{b}	34.7^{b}	33.8^{b}	1.8	<0.001

Adapted from Costa e Silva et al. (2015a).

DRY MATTER INTAKE OF SUCKLING BEEF CALVES

The BR-CORTE (2010) recommended the constant value of 2.35% BW for total DMI of suckling Nellore calves during the first six months of age, being this recommendation was from the study conducted by Fonseca (2009).

However, Costa e Silva (2015) evaluated five models available in the literature to estimate the DMI of roughage and concentrate for Nellore calves during the breast-feeding phase. Also, by knowing the milk intake from MY of cows and multiplying it by its DM content, we can obtain DMI of milk.

Thereby, from the sum of DMI of milk and solid feedstuff, we can access the total DMI of calves during the breast-feeding period. Thus, in this edition, the following equation proposed by Costa e Silva (2015) was adopted to estimate DMI of roughage and concentrate for suckling beef calves:

$$DMIrc = 0.353 - 0.532 \times DMImilk + 0.01065 \times BW + 0.3497 \times ADG,$$

where DMIrc = Dry matter intake of roughage and concentrate (kg/d), DMImilk = Dry matter intake of milk (kg/d), BW = Body weight (kg), ADG = average daily gain (kg/d).

Additionally, from an independent database that contained 232 observations from five studies conducted on pasture (Table 12.7), this equation was evaluated, resulting in the correct estimate of DMI of roughage and concentrate of suckling beef calves (Table 12.8); being this equation suggested by the BR-CORTE.

Table 12.7 - Descriptive statistics of the independent database utilized to predict dry matter intake of roughage and concentrate of suckling beef calves

Study	Item	n	Mean	DP	Maximum	Minimum
Lopes (2012)	Age (days)		170	-	-	-
	DMI of concentrate	53	0.63	0.32	0.80	0.00
	DMI of roughage	53	2.02	0.59	3.34	0.79
	Body weight	53	188	31.0	256	123
	Average daily gain	53	0.85	0.12	1.14	0.64
Cardenas (2012)	Age (days)		192	33.2	245	120
	DMI of concentrate	62	0.46	0.2	0.97	0.04
	DMI of roughage	62	1.86	0.47	3.04	0.88
	Body weight	62	217	30.2	285	154
	Average daily gain	62	0.67	0.09	0.92	0.42
Márquez (2013)	Age (days)		150	-	-	-
	DMI of concentrate	28	1.08	0.56	2.63	0.28
	DMI of roughage	28	2.17	1.15	6.31	0.77
	Body weight	28	202	21.6	255	151
	Average daily gain	28	0.94	0.09	1.13	0.74
Lopes (2015)	Age (days)		190	-	-	-
	DMI of concentrate	42	0.84	0.61	1.62	0
	DMI of roughage	42	2.01	0.41	3.21	1.38
	Body weight	42	203	29.0	264	148
	Average daily gain	42	0.84	0.12	1.14	0.56
Martins (2016)	Age (days)		182	-	-	-
	DMI of concentrate	47	0.75	0.63	2.79	0.00
	DMI of roughage	47	2.32	1.05	5.63	1.00
	Body weight	47	212	28.1	296	161
	Average daily gain	47	0.81	0.17	1.08	0.43

Table 12.8 - Mean (kg) and statistics description for the relationship between the predicted and the observed values of dry matter intake of roughage and concentrate of calves

Item	DMI of roughage and concentrate	
	OBS[1]	BR-CORTE (2016)[2]
Mean	2.51	2.34
SD	0.64	0.34
Maximum	3.99	3.37
Minimum	0.99	1.35
R	-	0.44
CCC[3]	-	0.33
Regression		
Slope		
Estimate	-	0.55
SE	-	0.29
P-value[4]	-	0.05
Slope		
Estimate	-	0.85
SE	-	0.12
P-value[5]	-	0.24
MSEP[6]	-	0.40
Mean bias	-	0.04
Systematic bias	-	0.002
Random errors	-	0.35

[1]OBS = observed values; [2]BR-Corte (2016) = predicted values by the equation suggested by Valadares Filho et al. (2016); [3]CCC = concordance correlation coefficient; [4]H_0: $\beta_0 = 0$; [5]H_0: $\beta_1 = 1$; [6]MSEP = mean square error of predction.

SUPLEMENTATION OF CALVES DURING BREAST-FEEDING PERIOD

Considering the lactation curve of Nellore cows, the average milk composition, and according to the nutrient requirements obtained for calves through breast-feeding phase, we will be able to estimate the moment that milk is not sufficient to provide the nutrient demanded for calf growth. Also, considering energy and protein as the most limiting nutrients, we showed that after the 12th week or so, at around 80 days of age, the milk does not provide all energy necessary for the calf which has an ADG close to 1 kg/d. However, protein becomes limiting only after the 14th week, approximately at 100 days of age. Therefore, in order for Nellore calves to maintain body weight gain close to 0.9 kg/d until weaning, we recommend the use of multiple supplements through creep feeding after the third month of age, or else using cows with greater potential for milk yield (Table 12.9).

Nevertheless, even increased milk yield due to the greater genetic capacity of cows allows for greater body weight gain at weaning, and the level of nutrients in most pasture systems is limited to supporting high levels of milk yield (Paulino et al., 2012). Additionally, in the 3th and 4th months of age, there are considerable changes in the gastrointestinal tract of the calf, and this is the period when this animal effectively becomes a ruminant (Porto et al., 2009), being more dependent on pasture. However, these processes occur during the wet-dry transition period in most Brazilian productions systems, which causes a decrease in quality and quantity of forage available for grazing. Consequently, the difference between the nutrient requirements of the calf and the amount of nutrients supplied by milk and forage tends to increase, provoking an unfavorable situation in calves concerning nutrient balance. Thus, for the intensive production systems of cattle, which require greater nutrient supply, the supplementation of suckling calves under creep feeding system is recommended. Creep feeding refers to the supply of additional feed for calves during the breast-feeding phase in restricted location (Paulino et al., 2012).

Studies regarding creep feeding in tropical conditions have consistently shown an increase in BW at weaning (Table 12.10), showing the importance of creep feeding to reduce the age at slaughter and the beginning of reproduction activity in animals raised on grazing conditions (Paulino et al., 2010). However, the additional body weight gain with the use of creep feeding is variable. Factors, such as the amount and quality of forage, milk yield of cows, grow potential of calves, breed, sex, age of calves at weaning, and even type of supplement and time of use of creep feeding influence animal performance.

Table 12.9 - Milk yield of Nellore cows, availability of metabolizable energy (ME) and protein (MP) in milk, total requirements of ME and MP of suckling Nellore calves, and the need of milk to meet ME requirements of calves according to the week of lactation and the body weight of the animals

WL[1]	BW[2]	MY[3]	ME milk[4]	MP milk[5]	MEt[6]	MPt[7]	NM[8]
1	36.3	6.01	6.85	303.56	3.47	227.08	3.04
2	42.6	7.35	8.37	371.08	3.92	236.91	3.44
3	48.9	7.59	8.64	383.07	4.34	246.39	3.81
4	55.2	7.57	8.62	381.99	4.76	255.59	4.18
5	61.5	7.49	8.52	377.84	5.16	264.56	4.53
6	67.8	7.39	8.41	372.96	5.55	273.34	4.87
7	74.1	7.29	8.30	367.92	5.93	281.96	5.20
8	80.4	7.19	8.19	362.83	6.31	290.44	5.53
9	86.7	7.09	8.07	357.73	6.68	298.81	5.86
10	93.0	6.99	7.96	352.64	7.04	307.07	6.17
11	99.3	6.88	7.84	347.54	7.39	315.25	6.48
12	105.6	6.78	7.73	342.44	7.74	323.36	6.78
13	111.9	6.68	7.61	337.34	8.35	331.40	7.32
14	118.2	6.58	7.50	332.24	8.70	339.39	7.63
15	124.5	6.48	7.38	327.15	9.05	347.33	7.90
20	156	5.98	6.81	301.65	10.71	386.59	9.40

[1]WL = week lactation; [2]BW = body weight of calf, kg: considering body weight at birth of 30 kg and ADG of 0.9 kg/d; [3]MY = milk yield; [4]ME milk: amount of metabolizable energy available to calf from milk (Mcal/d); [5]MP milk: amount of metabolizable protein available to calf from milk (g/d); [6]MEt = total requirements (maintenance + growth) of metabolizable energy of calf; [7]MPt: total requirements (maintenance + growth) metabolizable protein of calf; [8]NM: need of milk (kg/d) to meet total requirements of ME and calf. Adaptada do BR-CORTE (2016).

Therefore, when the limit imposed by genetics is obeyed, and the capacity of pasture and/or milk to supply the nutrient demand of the calves is lower, the response relative to the use of creep feeding will be greater, reflecting positively on the efficiency and profitability of this technique.

Lopes et al. (2017) evaluated nutritional plans (0,3,6 or 9 g/kg BW) of supplement with 25% CP for suckling beef calves from 4 to 8 months of age. It was observed that animals that received 6 g of supplement /kg BW had higher ADG (0.92 kg/d) and BW at weaning (275 kg). Following these animals in feedlot (Prados et al., (2017) with the animals being slaughtered at 15-16 months, it was observed that the difference in weight at slaughter can be attributed to the additional weight gain with creep feeding.

In a meta-analytical approach, Carvalho et al. (2018) gathered data from 18 studies with creep feeding (between 2007 and 2017). The authors found maximum responses with the use of supplements in the amounts of

7.6 g/kg BW for males and 5.5 g/kg BW for females, with a CP content in the supplement of 22.5%. The maximum additional ADG was 0.2 and 0.1 kg/d for males and females, respectively. Considering these gains and a supplementation period of 150 days, the additional gain obtained with creep feeding would be 30 kg for males and 15 kg for females, corroborating the results of Lopes et al. (2017).

Table 12.10 - Summary of data from studies on creep feeding

Study[a]	Experimental period (d)	Calf sex	Supplement intake (g/d)[b]	CP content in the supplement (g/kg)	ADG[c]	
					NS	SUP
De Paula et al. (2012)	112	Male	583	300	662	728
Valente et al. (2013)	112	Male	530	150-550	608	804
Barros et al. (2014)	112	Female	500	250	687	769
Lopes et al. (2014)	140	Male	900	80-410	727	880
Cardenas et al. (2015)	140	Female	500	80-400	619	677
Barros et al. (2015)	140	Male	850	250	731	843
Marquez et al. (2014)	150	Female	450	250	628	677
Lopes et al. (2017)	140	Male	1200	250	720	873
Almeida (2017)	140	Female	800	250	642	732
Martins et al. (2017)	140	Male	1600	250	500	900

[a/] Data processed; to access individual data, consult references
[b/] Mean intake of supplement from supplemented animals
[c/] ADG = average daily gain (g/d), NS = calves that received only mineral supplementation; or SUP = calves that received multiple supplements.

In relation to breastfeeding behavior, research results have not shown a reduction in milk intake due to the adoption of creep feeding. Valente et al. (2013) evaluated the behavior of beef calves with free access to creep feeding, receiving 5 g/kg BW of supplements and did not observe differences in suckling time between supplemented and non-supplemented calves. Similar results were found by Lopes et al. (2017) and Martins et al. (2017). In these studies, a decrease in grazing time was observed with the supplementation, indicating that there was a substitution in the forage DMI by the supplement, corroborating the absence of change in milk intake. Other studies (Barros et al., 2014; Lopes et al., 2014; Cardenas et al., 2015; Lopes et al., 2017) evaluated the effects of the adoption of creep feeding on intake and did not observe a change in milk intake. However, forage intake was lower in supplemented animals. Therefore, it seems unlikely that calves will replace milk for the supplement. This fact shows that order of preference of the calves is 1st milk, 2nd concentrate, and 3rd forage.

ENERGY REQUIREMENTS FOR LACTATING BEEF COWS

The calculations utilized for nutrient requirements of lactating Nellore cows and their calves followed the same recommendations suggested in the previous chapters. Due to the lack of experiments using lactating beef cows and their calves since the BR-CORTE 2010, the nutrient requirements of these animals were based on the experiment conducted by Fonseca (2009).

The relationship between empty body weight (EBW) and shrunk body weight (SBW) of lactating cows followed the recommendation from chapter 1:

$$EBW = 0.8507 \times SBW^{1.0002},$$

With the relationship between empty body gain (EBG) and ADG being 0.963. Accordingly explained in the chapter of energy requirements for beef cattle, heat production was indirectly obtained by the difference between metabolizable energy intake (MEI) and retained energy (RE), which were determined by comparative slaughter techniques and energy secreted in the milk. Thereby, the net energy required for maintenance (NEm) of beef cows was obtained by the following equation:

$$HP = 97.8 \times \exp^{(0.0024 \times MEI)},\ S_{XY} = 0.5578,$$

Where HP = heat production (kcal/EBW$^{0.75}$/d) e MEI = metabolizable energy intake (kcal/EBW$^{0.75}$/d). Thus, from the previous equation, when MEI is equivalent to heat production in fasting, we can obtain the value of 97.8 kcal/EBW$^{0.75}$/d, that is the net energy required for the maintenance of lactating Nellore cows.

The NRC (1996) established the NEm for beef cattle as 77 kcal/EBW$^{0.75}$/d, obtained from the data of Lofgreen e Garret (1968). Also, this system recommended reduction of 10% for zebu cattle and increase of 20% for lactating beef cows. Therefore, adopting these recommendations, the net energy required for the maintenance of lactating Nellore cows, according to NRC (1996), would be 83.2 kcal/EBW$^{0.75}$/d. Buskirk et al. (1992) estimated the NEm to be 72.5 kcal/SBW$^{0.75}$/d for Angus cows.

Utilizing the recommendations of the BR-CORTE (2010), the NEm for Zebu cattle of different sexes was estimated as 74.2 kcal/EBW$^{0.75}$/d. Considering the increase of 20% for lactating cows (NRC, 1996), the value obtained for this animal category should be 89.0 kcal/EBW$^{0.75}$/d, which is below the result obtained by Fonseca (2009), 97.8 kcal/EBW$^{0.75}$/d.

Therefore, due to the lack of information for this animal category, we recommended the use of 97.8 kcal/EBW$^{0.75}$/d as the NE required for the maintenance of lactating Nellore cows.

The metabolizable energy required for the maintenance (MEm) of lactating Nellore Cows was obtained when the MEI was equal to the heat production using the iterative model in the previously proposed equation, which resulted in MEm of 135.4 kcal/EBW$^{0.75}$/d. From these values, the efficiency of the use of metabolizable energy (ME) for maintenance (*km*) was estimated as 72% (97.8/135.4). In a study developed by Freetly et al. (2006) using lactating primiparous beef cows (Hereford × Angus × Redpoll × Pinzgauer), the Mem was estimated as 146 kcal/EBW$^{0.75}$/d and the efficiency of the use of ME for maintenance was 72%. Nevertheless, Calegare et al. (2007) estimated MEm of 141.3 kcal/BW$^{0.75}$/d for lactating Nellore cows, with this value being close to that observed by Fonseca (2009).

The energy loss related to body reserves was obtained from the body composition of cows slaughtered after calving as baseline and those fed at maintenance level during the first 90 days of lactation that lost body weight. Then, the negative retained energy was 2.1 Mcal/d divided by body weight losses of 0.48 kg/d, resulting in a mean value of 4.3 Mcal/BW loss. This value is below those recommended by other nutrient requirement systems that utilized *Bos taurus taurus* cattle as a baseline for the calculations which could explain the differences between them (Table 12.11). The efficiency of the use of energy from body reserves for MY obtained by Freetly et al. (2006) was 78%, while the AFRC (1993) and the CSIRO (2007) considered this efficiency as 84%.

Table 12.11 - Energy loss related to body weight mobilization (Mcal/kg BW loss) according to different nutrient requirement systems

Characteristic	Fonseca (2009)	NRC (1996)	CSIRO (2007)		INRA (1989)	AFRC (1993)
			British breeds	European breeds		
Body reserve mobilization	4.3	5.8	6.4	5.5	6.0	4.5

However, few studies involving the estimate of nutrient requirements of Zebu female cattle were conducted in Brazil (Calegare et al., 2007; Fonseca, 2009; Marcondes et al., 2009; Costa e Silva et al., 2015b). Also, these studies were conducted in feedlot, where the animals were housed in individual pens to allow for a better control of important variables such as metabolizable energy intake, which is utilized for the estimates.

Thereby, we believe that there is an underestimation of the energy required for the maintenance of animals raised in feedlot as it is not considered an extra energy expense that would be observed for animals raised on pasture. In an extensive scenario, the heat production of animals is influenced by several interrelated factors such as forage availability and quality, environment conditions, and animal behavior when raised on pasture, as described in the chapter about energy requirements for beef cattle.

According to studies conducted with animals raised on pasture where heat production was estimated from the heartbeat rate, energy expenditure related to activities of grazing and locomotion, both horizontal and vertical plans in pasture areas, corresponded to 8 and 11.2% of the total energy production, respectively (Brosh, et al., 2010). Thus, research evaluating the increase in requirements for maintenance that grazing activities can cause in the lactating herd can be conducted in Brazil to improve the understanding of variations in the energy efficiency of animals (Kelly et al., 2010).

The net energy required for growth (Neg) of lactating Nellore cows was calculated from equations described by Fonseca (2009)

$$NEg = EBG \times (1.0076 \times EBW^{0.2389}),$$

where NEg = net energy requirement for gain (Mcal/d) e EBW = empty body weight (kg/d). The efficiency of metabolizable energy (ME) utilization for gain (kg) of lactating Nellore cows was 0.44, equivalent to the slope of the line produced from the relationship between RE (kcal/EBW$^{0.75}$/d) and MEI (kcal/ EBW$^{0.75}$/d) described in Figure 12.3. Flatt et al. (1967), working with lactating Holstein cows, found a value of 0.64 for kg. If we consider a retained energy equal to zero in this equation, we can estimate the ME requirements for lactation of 140.1 kcal/ EBW$^{0.75}$, a value close to that obtained by the iterative

The energy required for lactation (NE*l*) was considered as the net energy from milk, which resulted in 0.75 Mcal/kg milk in the study of Fonseca (2009). Considering the efficiency of the use of metabolizable energy for lactation (*kl*) equal to *km* (NASEM, 2016) of 0.72, the requirements of ME for lactation (MEl) are 1.04 Mcal/kg milk.

In addition, NE per kg of milk can be obtained from milk constituents, with each component multiplied by its respective energy value. Thus, using the average milk composition from table 12.5, 3.56% CP, 4.56% lactose e 4.76% fat, the requirements of NE for lactation, using the equation proposed by NRC (2001), are NEl (Mcal/ kg milk) = 0.0929 × % fat + 0.0547 × % protein + 0.0395 × % lactose, which results in 0.82 Mcal/kg milk. Moreover, Mel can be calculated as 1.14 Mcal/kg milk (0.82/0.72), which is higher than that found by Fonseca (2009), possibly due to the greater fat content in milk (Table 12.5). Alternatively, if there is no complete milk composition, or when there is only knowledge of the fat content of milk, the equation from the NRC (2001) can be used: NEl (Mcal/kg milk) = 0.36 + 0.0969 × % fat.

To convert ME to TDN, the equation suggested in this edition was (for more details, see chapter 8): ME 0.9455 × DE – 0.3032, and then to convert from DE to TDN, the factor of 4.4 was utilized. Thereby, the NE_l would result in TDN requirements of 0.35 kg/kg milk when ME_l is 1.14 Mcal/kg milk.

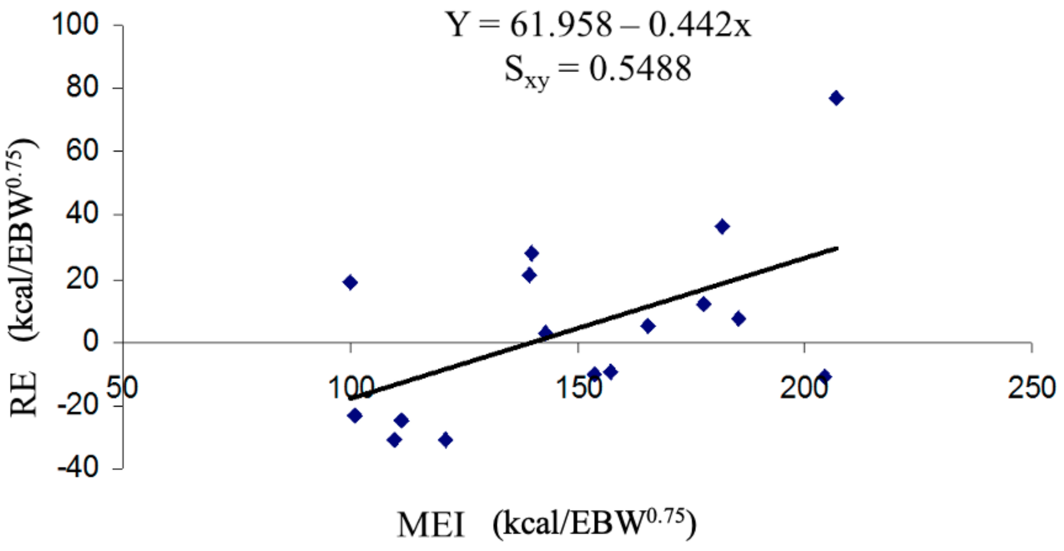

Figure 12.3 - Retained energy as a function of metabolizable energy intake. Adapted from Fonseca et al. (2012).

ENERGY REQUIREMENTS FOR SUCKLING BEEF CALVES

The conversion of SBW to empty body weight (EBW) of suckling beef calves can be obtained by the ratio EBW/SBW, which is equal to 0.962. Also, ADG can be converted to empty body gain (EBG) by the ratio EBG/ADG equal to 0.958 for suckling calves (Fonseca et al., 2012b). Due to the lack of adjustment from the study by Fonseca et al. (2012b), the requirements of ME for the maintenance of suckling calves were not estimated. However, Costa e Silva et al. (2015b) evaluated the requirements of NEm of Nellore calves with body weight varying from 121 to 300 kg and suggested the following equation:

$$HP = 0.294 \times \exp^{(1.0530 \times MEI)}$$

where HP = heat production is given as MJ/EBW$^{0.75}$/d and MEI = metabolizable energy intake (MJ/EBW$^{0.75}$/d).

Thus, from the previous equation, the NEm can be obtained as 294 kJ/EBW$^{0.75}$/d, or 70.3 kcal/EBW$^{0.75}$/d for Nellore calves. For the requirements of ME for maintenance, when MEI is equal to the heat produced at fasting, using the same equation, the value obtained was 118.6 kcal/EBW$^{0.75}$/d. Therefore, dividing NEm by MEm, the efficiency of the use of metabolizable energy for maintenance was 59.3%. The net energy required for growth (NEg) of suckling Nellore calves (Fonseca et al., 2012b) was estimated using the following equation:

$$NEg = 0.0932 \times EBW^{0.75} \times EBG^{0.9157},$$

where NEg = net energy required for growth (Mcal/d), EBW$^{0.75}$ = metabolic empty body weight, and EBG = empty body gain.

To convert the net energy required for growth (NEg) to the metabolizable energy required for growth (MEg), two factors of the efficiency of the use of Meg were utilized, with $kg = 0.69$ for milk intake and $kg = 0.57$ for solid feedstuff intake according to the recommendations by the NRC (2001). Then, in the period from 0 to 90 days of age, the kg of 0.62 was considered (77 × 0.69 + 23 × 0.57) corresponding to the body weight of the animals weighing up to 100 kg; in the period from 90 to 180 days (> 100 kg body weight), the kg of 0.62 was considered (43 × 0.69 + 57 × 0.57), with 77 and 23%, and 43 and 57% being the relationships between milk intake and solid feedstuff consumed by calves in the respective periods (Fonseca, 2009).

DE requirements were calculated as: ME/0.96 (NRC, 2001) for suckling calves) and the TDN requirements were calculated as DE/4.4.

PROTEIN REQUIREMENTS FOR LACTATING BEEF COWS

The requirements of metabolizable protein for maintenance (MPm) were calculated from the equation suggested by the BR-CORTE (2016) (for more details, see chapter 9) for animals raised on pasture:

$$MPm = 3.9 \times SBW^{0.75},$$

where $SBW^{0.75}$ = metabolic shrunk body weight.

The net requirements of protein for growth (NPg) of primiparous Nellore cows were calculated from the equation proposed by Fonseca (2009):

$$NPg\ (g/d) = EBG \times (376.4 \times EBW^{-0.1839}).$$

To convert the NPg for the requirements of metabolizable protein for growth (MPg), the efficiency (*k*) was calculated utilizing the recommendation suggested by the BR-CORTE (2010):

$$k = 47.4\%.$$

The protein required for lactation is based on the amount of protein secreted in the milk. The amount of protein produced in the milk can be estimated from the equation presented to estimate milk yield. The NRC (2001) suggests an equation to calculate the requirements of metabolizable protein for lactation (MP_l):

$$MP_l = CPmilk/0.67 \times 1000,$$

where CPmilk = crude protein in the milk (kg/d), and 0.67 = efficiency of the use of metabolizable protein for lactation.

Considering the average content of CP in milk of 3.56; this CP content was multiplied by the percentage of true protein in milk (AFRC, 1993), which is 95%, resulting in the value of 3.38% or 33.8 g of true protein/ kg milk. Schroeder and Titgemeyer (2008) performed a review regarding the efficiency of the use of MP and said that the efficiencies of the use of digestible protein for body protein growth observed in calves were lower than the fixed value of 67% adopted by the NRC (2001).

Furthermore, this efficiency can be affected by several factors, such as the level of protein and energy intake, BW, age, genotype of animals, and feeding frequency (Schroeder and Titgemeyer, 2008). Due to the lack of consistent values, we considered the efficiency of the use of metabolizable protein for lactation to be 0.67 (NRC, 2001), which resulted in the value of 50.5 g MP/ kg milk, corresponding to the requirements of MP for lactation. This value is greater than 44.8 g de MP/ kg milk presented for milk with 3.15 % CP (AFRC, 1993; NRC, 2001). Therefore, we suggested that requirements of MP for lactating beef cows might be 50.5 g/kg milk.

The microbial crude protein synthesis (MCP) was calculated considering the recommendation presented in chapter 3, where microbial crude protein synthesis (MCP) was calculated as function of the intake of CP and TDN as follows:

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

where CPI = crude protein intake (kg/d) and TDNI = intake of total digestible nutrients (kg/d).

Thus, the requirements of rumen degradable protein (RDP) were calculated from the recommendations of this edition, where microbial protein synthesis equals RDP requirements (for more details, see chapter 9):

$$RDP = MCP,$$

where the requirements of rumen undegradable protein (RUP) were obtained from the following equation:

$$RUP = (\text{Total metabolizable protein} - (MCP \times 0.64))/0.80.$$

So, the requirements of CP would be equal to the sum of RDP and RUP.

PROTEIN REQUIREMENTS FOR SUCKLING BEEF CALVES

The recommendations for the requirements of metabolizable protein for maintenance (MPm) were based on the equation suggested by the BR-CORTE (2016) for animals raised on pasture (for more details, see Chapter 9):

$MPm = 3.9 \times SBW^{0.75}$.

The requirements of protein for the growth of suckling beef calves were calculated from the equation developed by Fonseca (2009):

$$NPg\ (g/d) = EBG \times (139.7 \times EBW^{0.0351}).$$

To convert the NPm for the requirements of metabolizable protein for growth (MPg), the efficiency (*k*) was calculated using the equation described by the BR-CORTE (2010):

$$k = 84.665 - 0.1179 \times EQEBW.$$

The same way as for cows, the microbial crude protein synthesis (MCP) was calculated considering the recommendation presented in Chapter 3, in which microbial synthesis was calculated as a function of CP (CPI) and TDN (TDNI) intakes.

However, when consuming milk, calves present reflex for the formation of an esophageal groove, making milk go directly into the abomasum without suffering the action of microorganisms in the rumen. In this case, considering that protein and energy from milk interfere with MCP would not be the most correct. Thus, for suckling calves, we recommended that the intakes of CP and TDN from milk should be removed from the calculation of MCP, because, otherwise, there will be an overestimation of RDP and an underestimation of RUP. Therefore, to calculate MCP of suckling calves, we recommended the use of the following equation:

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

where total CPI = total crude protein intake in the diet (kg/d), CPImilk = crude protein intake from milk (kg/d), total TDNI = total digestible nutrient intake in the diet (kg/d), and TDNImilk = total digestible intake from milk (kg/d).

For the calculation of CPImilk, the milk yield of cows might be quantified and multiplied by the CP content of the milk. For TDN, initially, the contents of CP, lactose and fat in the milk might be quantified. According to the publication by Maynard et al. (1979), which states that the digestibility of milk constituents is 0.98 (carbohydrates), 0.95 (fat) and NASEM (2016) of 0.95 (protein), we considered the sum of the digestible constituents of the milk to account for the TDN intake of milk as shown in the following equation:

$$TDNmilk = MY \times ((\%\ CP \times 0.95 + \%\ lactose \times 0.98) + (2.25 \times \%\ fat \times 0.95)).$$

Considering the mean milk composition in the study by Costa e Silva et al. (2015a) as 3.56 % CP, 4.56% lactose and 4.76 % fat, the TDN content this milk would be approximately 18% on a natural basis or 129.6% on a milk dry matter basis (18.0/0.139).

However, considering that calves with a BW less than 100 kg presenting low microbial activity in the rumen due to the intake almost exclusively from milk, and data for this animal category beyond this point being scarce for this body weight range, this edition adopted the same recommendation as the BR-CORTE (2010) to estimate microbial protein synthesis (MCP) of 120 g MCP/kg TDN. However, we highlight the need to discount TDN from milk, otherwise, the estimate of MCP would be overestimated.

Additionally, the requirements of rumen degradable protein (RDP) were calculated from the recommendation of this edition, for which microbial protein synthesis is equal to the RDP requirements (for more details, see Chapter 9):

$$RDP = MCP,$$

where the requirements of rumen undegradable protein (RUP) were obtained from the following equation:

$$RUP = (total\ metabolizable\ protein - (MCP \times 0.64))/0.80.$$

To obtain CP requirements, the sum of the requirements of RDP and RUP should be considered.

MINERAL REQUIREMENTS FOR LACTATING BEEF COWS AND THEIR CALVES

Due to the lack of data related to mineral requirements for maintenance and retention coefficient of lactating beef cows and suckling calves, these estimates were calculated according to recommendations presented in Chapter 10 about the mineral requirements for beef cattle. Regarding the net requirements of macrominerals (Ca, P, Mg, Na, and K) for growth, the amounts of each mineral present in the animal body were regressed as a function of EBW from the following model:

$$Mi = a \times EBW^{b},$$

where Mi = the amount of each micromineral (ca, P, Mg, Na, and K; g) present in the animal body and EBW = empty body weight (kg).

From the derivative of the equation above, the net requirements of macrominerals (Ca, P, Mg, Na, and K) for growth of lactating beef cows and suckling calves were calculated from the following model:

$$Y = a \times b \times EBW^{b-1},$$

where Y = net requirements of each mineral for growth (g/d), EBW = empty body weight (kg).

Thus, the equations of the net requirements of each mineral for growth considering each animal category are shown in the Table 12.12. Due to the lack of adjustment to Ca data from lactating cows (Fonseca, 2009), the recommendation of Chapter 10 was used to estimate the net requirements for the growth of this mineral. Furthermore, due to the lack of sulfur and microminerals recommendations for both cattle categories (Fonseca, 2009), the equations described in Chapter 10 were adopted.

Table 12.12 - Net requirements of macrominerals for growth of lactating beef cows and their calves

Item	Equations	
	Cows[1]	Calves
Ca	EBW < 462 kg: EBG × (147 × $EBW^{-0.50}$) EBW ≥ 462 kg: NCag (kg) = 0	EBG × (54.8 × $EBW^{-0.3981}$)
P	EBG × (54.4 × $EBW^{-0.4484}$)	EBG × (8.6 × $EBW^{-0.0371}$)
Mg	EBG × (1.4 × $EBW^{-0.3227}$)	EBG × (0.4 × $EBW^{-0.0173}$)
Na	EBG × (1.4 × $EBW^{-0.0575}$)	EBG × (1.2 × $EBW^{-0.0209}$)
K	EBG × (3.1 × $EBW^{-0.2142}$)	EBG × (1.5 × $EBW^{-0.0636}$)

[1]Recomendation for calcium of chapter 10. Other equations adapted from Fonseca (2009). EBW = empty body weight (kg); EBG = empty body gain (kg/d). Considering cows heavier than 544 kg BW, the net Ca required for growth is equal to zero (for more details, see Chapter 10)

TABLES OF NUTRIENTS REQUIREMENTS FOR LACTATING BEEF COWS AND THEIR CALVES

Dietary nutrients requirements can be calculated from estimates of the requirements of energy, protein, and macrominerals for growth of lactating beef cows and suckling calves. The equations utilized for the calculations of nutrient requirements of lactating beef cows and suckling calves can be seen in Tables 12.13, 12.14 and 12.15, respectively, with the equation utilized to calculate microbial N described in Chapter 3, for maintenance, retention coefficient, and dietary requirements of microminerals described in Chapter 10.

Table 12.13 - Summary of the equations to estimate energy and protein requirements for lactating beef cows and their calves

Item	Equations		Unidad
	Cows	Calves	
DMI	$6.535 - 7.558 \times \exp^{(-0.578 \times WL)} + 0.323 \times WL + 1.66 \times MY$	$0.353 - 0.532 \times DMImilk + 0.01065 \times BW + 0.3497 \times ADG$	
MY	Multiparous cows (> 3 years) $MY = 7.996 - 0.101 \times WL - 7.996 \times \exp^{(-1.447 \times WL)}$, Primiparous cows (≤ 3 years) $MY = 6.431 - 0.072 \times WL - 6.431 \times \exp^{(-2.188 \times WL)}$,	-	kg/d
SBW	$0.8915 \times BW^{1.0151}$	-	kg
EBW	$0.8507 \times SBW^{1.0002}$	$0.962 \times SBW$	kg
EBG	$0.963 \times ADG^{1.0151}$	$0.958 \times ADG$	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	0.44	Milk = 0.69 Solids = 0.57	-
MEg	NEg/kg		Mcal/d
NE_l	0.82	-	Mcal/kg milk
k_l	*km*	-	-
ME_l	NE_l/ k_l		Mcal/d
MEt	$MEm + MEg + ME_l$	MEm + MEg	Mcal/d
DE	$(((MEt/DMI) + 0.3032)/0.9455) \times DMI$	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	$84.665 - 0.1179 \times EQEBW$	%
MP_l	50.5	-	g/kg milk
MPt	$MPm + MPg + MP_l$	g/d	MPt
CPImilk	-	$MY \times 0.0356$	g/d
TDNImilk	-	$MY \times 0.18$	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 – TDNImilk 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	$(MPt - (MCP \times 0.64))/0.80$		g/d
CP	RDP + RUP		g/d

Table 12.14 - Summary of the equations to estimate net requirements of macrominerals (Ca, P, Mg, Na, and K) for growth (g/d) of lactating beef cows and their calves

Item	Equations	
	Cows	Cows
Ca	EBW < 462 kg: EBG × (147 × $EBW^{-0.50}$) EBW ≥ 462 kg: NRGCa (kg) = 0	EBG× (54.8 × $EBW^{-0.3981}$)
P	EBG × (54.4 × $EBW^{-0.4484}$)	EBG × (8.6 × $EBW^{-0.0371}$)
Mg	EBG × (1.4 × $EBW^{-0.3227}$)	EBG × (0.4 × $EBW^{-0.0173}$)
Na	EBG × (1.4 × $EBW^{-0.0575}$)	EBG × (1.2 × $EBW^{-0.0209}$)
K	EBG × (3.1 × $EBW^{-0.2142}$)	EBG × (1.5 × $EBW^{-0.0636}$)

[11]EBW = empty body weight (kg); EBG = empty body gain (kg/d). NRGCa = net Ca required for growth is equal to zero (for more details, see Chapter 10)

Table 12.15 - Summary of the equations utilized for the calculation of net requirements of S and microminerals (Cu, Co, Cr, Fe, Mn, Mo, Se e Zn) for beef cattle (Adopted from Chapter 10)

Mineral	Net requirements for maintenance	Retention coefficient	Net requirements for growth (NRG)[1]
	µg/kg body weight	%	mg/d
S	10.4	77.3	NRG_S = EBG × (0.03 × $EBW^{0.8900}$)
Cu	95.6	73.5	NRG_{Cu} = EBG × (1.25 × $EBW^{0.33}$)
Co	13.5	86.8	NRG_{Co} = EBG × (0.045 × $EBW^{-0.023}$)
Cr	22.9	78.4	NRG_{Cr} = EBG × (0.23 × $EBW^{0.61}$)
Fe	2,942	73.4	NRG_{Fe} = EBG × (10.4 × $EBW^{0.24}$)
Mn	184.9	43.9	NRG_{Mn} = EBG × (0.07 × $EBW^{0.80}$)
Mo	3.27	49.7	NRG_{Mo} = EBG × (0.0035 × $EBW^{0.41}$)
Se	3.72	48.7	NRG_{Se} = EBG × (1.07 × $EBW^{-0.07}$)
Zn	334.4	66.8	NRG_{Zn} = EBG × (1.16 × $EBW^{0.86}$)
	mg/kg body weight	%	g/d
S	10.4	77.3	NRG_S = EBG × (0.03 × $EBW^{0.8900}$)

[1]EBG = empty body gain (kg/d); EBW = empty body weight (kg)

Thereby, considering lactating beef cows with 450 kg in the 10[th] week of lactation with average daily gain of 0.2 kg/d, we have:

• $MY = 7.996 – 0.101 × WL – 7.996 × exp^{(-1.447 × WL)} = 7.996 – 0.101 × 10 – 7.996 × exp^{(-1.447 × 10)} = 6.99$ kg/d.
• $DMI = 6.535 – 7.558 × exp^{(-0.578 × 10)} + 0.323 × 10 + 1.66 × 6.99 = 21.34$ g/kg BW
• DMI = 21.34 g/kg BW × 450 kg = 9.6 kg/d
• $SBW = 0.8915 × BW^{1.0151} = 0.8915 × 450^{1.0151} = 439.9$ kg
• $EBW = 0.8507 × SBW^{1.0002} = 0.8507 × 439.9^{1.0002} = 374.7$ kg
• $EBG = 0.963 × ADG^{1.0151} = 0.963 × 0.2^{1.0151} = 0.188$ kg/d

- **Energy requirements**:
• $NEm = 97.8 × EBW^{0.75} = 97.8 × 374.7^{0.75} = 8329.4$ kcal/d = 8.33 Mcal/d
• $NEm = 135.0 × EBW^{0.75} = 135.0 × 374.7^{0.75} = 11497$ kcal/d = 11.50 Mcal/d
• $NEg = 1.0076 × EBW^{0.2389} × EBG = 1.0076 × 374.7^{0.2389} × 0.188 = 0.78$ Mcal/d

• MEg = NEg/*kg* = 0.78/0.44 = 1.77 Mcal/d
• NE_l = 0.82 Mcal/kg milk = 0.82 × 6.99 = 5.73 Mcal/dia
• $ME_l = NE_l/k_l$ = 5.73/0.72 = 7.96 Mcal/dia
• MEt = MEm + MEg + ME_l = 11.50 + 1.77 + 7.96 = 21.23 Mcal/dia
• DE = (((MEt/DMI) + 0.3032)/0.9455) × DMI = (((21.23/9.6) + 0.3032)/0.9455) × 9.6 = 25.53 Mcal/d
• TDN = DE/4.4 = 25.53/4.4 = 5.80 kg/d

- Protein requirements:

• MPm = 3.9 × $SBW^{0.75}$ = 3.9 × $439.9^{0.75}$ = 374.6 g/d
• NPg = 0.3764 × $EBW^{-0.1839}$ × EBG = 0.3764 × $374.7^{-0.1839}$ × 0.188 = 0.0238 kg/d = 23.80 g/d
• MPg = NPg/*k* = 23.80/0.474 = 50.2 g/d
• MP_l = 50.5 g/kg milk = 50.5 × 6.99 = 353 g/d
• MPt = MPm + MPg + MP_l = 374.6 + 50.2 + 353 = 777.8 g/d
• MCP = -53.07 + 304.89 × CPI + 90.8 × TDNI – 3.13 × $TDNI^2$ = -53.07 + 304.89 × 1.11 + 90.8 × 5.80 – 3.13 × $(5.80)^2$ = 706.9 g/d
• RDP = MCP = 706.9 g/d
• RUP = (MPt – (MCP × 0.64))/0.80 = (777.8 – (706.9 × 0.64))/0.80 = 406.7 g/d
• PB = RDP + RUP = 706.9 + 406.7 = 1.11 kg/d

To obtain the concentration required of TDN and CP (% DM in the diet), the requirements of TDN (5.83 kg/d) and CP (1.11 kg/d) might be divided by the DMI of the animal.

• TDN (% DM in the diet) = TDN/DMI = 5.80/9.6 = 60.4%
• CP (% DM in the diet) = CP/DMI = 1.11/9.6 = 11.6%

- **Macromineral requirements**:

• Calcium:
- Net requirements for maintenance = 11.7 × 450/1000 = 5.27 g/d
- Net requirements for gain = EBG × (147 × $EBW^{-0.50}$) = 0.188 × (147 × $374.7^{-0.50}$) = 1.42 g/d
- Net requirements for lactation = 1.1 g/kg milk = 1.1 × 6.99 = 7.68 g/d
- Dietary requirements = (Net requirements for maintenance + gain + lactation) / retention coefficient = (5.27 + 1.42 + 7.68)/0.568 = 25.30 g/d

• Phosphorus:
- Net requirements for maintenance = 13.5 × 450/1000 = 6.08 g/d
- Net requirements for gain = EBG × (54.4 × $EBW^{-0.4484}$) = 0.188 × (54.4 × $374.7^{-0.4484}$) = 0.71 g/d
- Net requirements for lactation = 0.77 g/kg milk = 0.77 × 6.99 = 5.38 g/d
- Dietary requirements = (Net requirements for maintenance + gain + lactation) / retention coefficient = (6.08 + 0.71 + 5.38)/0.678 = 17.95 g/d

Ca:P ratio = 25.30/17.95 = 1.41

• Magnesium:
- Net requirements for maintenance = 5.9 × 450/1000 = 2.66 g/d
- Net requirements for gain = EBG × (1.4 × $EBW^{-0.3227}$) = 0.188 × (1.4 × $374.7^{-0.3227}$) = 0.039 g/d
- Net requirements for lactation = 0.07 g/kg milk = 0.07 × 6.99 = 0.49 g/d
- Dietary requirements = (Net requirements for maintenance + gain + lactation)/retention coefficient = (2.66 + 0.039 + 0.49)/0.355 = 8.97 g/d

• Sodium:

- Net requirements for maintenance = $6.3 \times 450/1000 = 2.84$ g/d
- Net requirements gain = EBG × ($1.4 \times \text{EBW}^{-0.0575}$) = $0.188 \times (1.4 \times 374.7^{-0.0575}) = 0.186$ g/d
- Net requirements for lactation = 0.2 g/kg milk = $0.2 \times 6.99 = 1.39$ g/d
- Dietary requirements = (Net requirements for maintenance + gain + lactation)/retention coefficient = $(2.84 + 0.186 + 1.39)/0.371 = 11.91$ g/d

• Potassium:

- Net requirements for maintenance = $23.5 \times 450/1000 = 10.58$ g/d
- Net requirements for gain = EBG × ($3.1 \times \text{EBW}^{-0.2142}$) = $0.188 \times (3.1 \times 374.7^{-0.2142}) = 0.164$ g/d
- Net requirements for lactation = 0.7 g/kg milk = $0.7 \times 6.99 = 4.89$ g/d
- Dietary requirements = (Net requirements for maintenance + gain + lactation)/retention coefficient = $(10.58 + 0.164 + 4.89)/0.484 = 32.3$ g/d

• Sulfur:

- Net requirements for maintenance = $10.4 \times 450/1000 = 4.68$ g/d
- Net requirements for gain = EBG × ($0.03 \times \text{EBW}^{0.89}$) = $0.188 \times (0.03 \times 374.7^{0.89}) = 1.10$ g/d
- Net requirements for lactation = 0.3 g/kg milk = $0.3 \times 6.99 = 2.10$ g/d
- Dietary requirements = (Net requirements for maintenance + gain + lactation)/retention coefficient = $(4.68 + 1.10 + 2.10)/0.773 = 10.2$ g/d

- **Micromineral requirements**:

• Cobalt:

- Net requirements for maintenance = $13.5 \times 450/1000 = 6.08$ mg/d
- Net requirements for gain = EBG × ($0.045 \times \text{EBW}^{-0.023}$) = $0.188 \times (0.045 \times 374.7^{-0.023}) = 0.007$ mg/d
- Net requirements for lactation = 0.23 mg/kg milk = $0.23 \times 6.99 = 1.608$ mg/d
- Dietary requirements = (Net requirements for maintenance + gain + lactation)/retention coefficient = $(6.08 + 0.007 + 1.608)/0.868 = 8.86$ mg/d

• Copper:

- Net requirements for maintenance = $95.6 \times 450/1000 = 43.02$ mg/d
- Net requirements for gain = EBG × ($1.25 \times \text{EBW}^{0.33}$) = $0.188 \times (1.25 \times 374.7^{0.33}) = 1.66$ g/d
- Net requirements for lactation = 1.99 mg/kg milk = $1.99 \times 6.99 = 13.91$ g/d
- Dietary requirements = (Net requirements for maintenance + gain + lactation)/retention coefficient = $(43.02 + 1.66 + 13.91)/0.735 = 79.7$ mg/d

• Chromium:

- Net requirements for maintenance = $22.9 \times 450/1000 = 10.31$ mg/d
- Net requirements for gain = EBG × ($0.23 \times \text{EBW}^{0.61}$) = $0.188 \times (0.23 \times 374.7^{0.61}) = 1.61$ mg/d
- Net requirements for lactation = 3.2 mg/kg milk = $3.2 \times 6.99 = 22.37$ g/d
- Dietary requirements = (Net requirements for maintenance + gain + lactation)/retention coefficient = $(10.31 + 1.61 + 22.37)/0.784 = 43.7$ g/d

• Iron:

- Net requirements for maintenance = $2942 \times 450/1000 = 1324$ mg/d
- Net requirements for gain = EBG × ($10.4 \times \text{EBW}^{0.24}$) = $0.188 \times (10.4 \times 374.7^{0.24}) = 8.10$ mg/d

- Net requirements for lactation = 29.9 mg/kg milk = 29.9 × 6.99 = 209 mg/d
- Dietary requirements = (Net requirements for maintenance + gain + lactation)/retention coefficient = (1324 + 8.10 + 209)/0.734 = 2099 mg/d

• Manganese:
- Net requirements for maintenance = 184.9 × 450/1000 = 83.21 mg/d
- Net requirements for gain = EBG × (0.07 × $EBW^{0.80}$) = 0.188 × (0.07 × $374.7^{0.80}$) = 1.50 mg/d
- Net requirements for lactation = 1.41 mg/kg milk = 1.41 × 6.99 = 9.85 mg/d
- Dietary requirements = (Net requirements for maintenance + gain + lactation)/retention coefficient = (83.21 + 1.50 + 9.85)/0.439 = 215.44 mg/d

• Zinc:
- Net requirements for maintenance = 334.4 × 450/1000 = 150.5 mg/d
- Net requirements for gain = EBG × (1.16 × $EBW^{0.86}$) = 0.188 × (1.16 × $374.7^{0.86}$) = 35.64 mg/d
- Net requirements for lactation = 35.4 mg/kg milk = 35.4 × 6.99 = 247.44 mg/d
- Dietary requirements = (Net requirements for maintenance + gain + lactation)/retention coefficient = (150.5 + 35.64 + 247.44)/0.668 = 649 mg/d

To exemplify the nutrient requirements of suckling beef calves, a 150 kg calf, at its 19th week of life, with ADG of 0.80 kg/d and consuming a diet consisting of 43% milk and 57% forage + concentrate on DM basis:

• DMImilk = MY × % DM milk = 6.08 × 0.139 = 0.85 kg/d
• DMIrc = 0.353 – 0.532 × 0.85 + 0.01065 × 150 + 0.3497 × 0.80 = 1.78 kg/d
• DMItotal = DMIrc + DMImilk = 1.78 + 0.85 = 2.63 kg/d
• EBW = 0.962 × SBW = 0.962 × 150 = 144 kg
• EBG = 0.958 × ADG = 0.958 × 0.80 = 0.77 kg/d

- **Energy requirements**:
• NEm = 70.3 × $EBW^{0.75}$ = 70.3 × $144^{0.75}$ = 2.93 Mcal/d
• MEm = 118.6 × $EBW^{0.75}$ = 118.6 × $144^{0.75}$ = 4.94 Mcal/d
• NEg = 0.0932 × $EBW^{0.75}$ × $EBG^{0.9157}$ = 0.0932 × $144^{0.75}$ × $0.77^{0.9157}$ = 3.04 Mcal/d
• *kg* = 43 × 0.69 + 57 × 0.57 = 0.62
• MEg = NEg/kg = 3.04/0.62 = 4.9 Mcal/d
• MEt = MEm + MEg = 4.94 + 4.9 = 9.84 Mcal/d
• DE = ME/0.96 = 9.84/0.96 = 10.25 Mcal/d
• TDN = DE/4.4 = 10.25/4.4 = 2.33 kg/d

- **Protein requirements:**
• MPm = 3.9 × $SBW^{0.75}$ = 3.9 × $150^{0.75}$ = 167.2 g/d
• NPg = 0.1397 × $EBW^{0.0351}$ × EBG = 0.1397 × $144^{0.0351}$ × 0.77 = 0.1275 kg/d = 127.5 g/d
• *k* = 84.665 – 0.1179 × EQEBW = 84.665 – 0.1179 × 144 = 67.7%
• MPg = NPg/*k* = 127.5/0.677 = 188.4 g/d
• MPt = MPm + MPg = 167.2 + 188.4 = 355.6 g/d
• CPImilk = MY × 0.0356 = 6.09 × 0.0356 = 0.22 kg
• TDNImilk = MY × 0.18 = 6.09 × 0.18 = 1.10 kg

• $MCP = -53.07 + 304.89 \times (CPI - CPImilk) + 90.79 \times (TDNI - TDNImilk) - 3.13 \times (TDNI - TDNImilk)^2 = -53.07 + 304.9 \times (0.471 - 0.22) + 90.79 \times (2.33 - 1.10) - 3.13 \times (2.33 - 1.10)^2 = 132.03$ g/d
• RDP = MCP = 132.03 g/d
• RUP = (MPt – (MCP × 0.64))/0.80 = (355.6 – (132.03 × 0.64))/0.80 = 338.9 g/d
• CP = RDP + RUP = 132.03 + 338.9 = 471 g/d

As for cows, to obtain the concentration required of TDN and CP (%DM in the diet), the requirements of TDN (2.33 kg/ d) and CP (471 g/d) can be divided by the DMI of the animal.

• TDN (% DM in the diet) = TDN/DMI = 2.33/2.63 = 88.7%
• CP (% DM in the diet) = CP/DMI = 0.471/2.63 = 17.9%

- Mineral requirements:

• Calcium:
- Net requirements for maintenance: 11.7 × 150/1000 = 1.76 g/d
- Net requirements for gain = $EBG \times (54.8 \times EBW^{-0.3981}) = 0.77 \times (54.8 \times 144^{-0.3981}) = 5.83$ g/d
- Dietary requirements = (Net requirements for maintenance + gain)/retention coefficient = (1.76 + 5.83)/0.568 = 13.4 g/d

• Phosphorus:
- Net requirements for maintenance: 13.5 × 150/1000 = 2.03 g/d
- Net requirements for growth = $EBG \times (8.6 \times EBW^{-0.0371}) = 0.77 \times (8.6 \times 144^{-0.0371}) = 5.51$ g/d
- Dietary requirements = (Net requirements for maintenance + growth)/retention coefficient = (2.03 + 5.51)/0.678 = 11.1 g/d

Ca:P ratio= 13.4/11.1 = 1.20

• Magnesium:
- Net requirements for maintenance: 5.9 × 150/1000 = 0.89 g/d
- Net requirements for growth = $EBG \times (0.4 \times EBW^{-0.0173}) = 0.77 \times (0.4 \times 144^{-0.0173}) = 0.28$ g/d
- Dietary requirements = (Net requirements for maintenance + growth)/retention coefficient = (0.89 + 0.28)/0.355 = 3.29 g/d

• Sodium:
- Net requirements for maintenance: 6.3 × 150/1000 = 0.95 g/d
- Net requirements for growth = $EBG \times (1.2 \times EBW^{-0.0209}) = 0.77 \times (1.2 \times 144^{-0.0209}) = 0.83$ g/d
- Dietary requirements = (Net requirements for maintenance + growth)/retention coefficient = (0.95 + 0.83)/0.371 = 4.80 g/d

• Potassium:
- Net requirements for maintenance: 23.5 × 150/1000 = 3.53 g/d
- Net requirements for growth = $EBG \times (1.5 \times EBW^{-0.0636}) = 0.77 \times (1.5 \times 144^{-0.0636}) = 0.84$ g/d
- Dietary requirements = (Net requirements for maintenance + growth)/retention coefficient = (3.53 + 0.84)/0.484 = 9.03 g/d

We emphasize that there are no studies that aim to evaluate dietary requirements of S and microminerals for this animal category, being suggested the use of the same recommendations of Chapter 10.

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