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Energy requirements for beef cattle

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INTRODUCTION

The accurate estimation of energy requirements for growing and finishing cattle is one of the key points of a feeding system. Thus, the energy obtained from nutrients (carbohydrates, proteins, and lipids) is important not only for the basal activities maintenance of the organism, but also for improving animals' performance (Caton and Dhuyvetter, 1997). Thus, energy waste is closely related to higher emission of greenhouse gases, which can lead to environmental problems (Tamminga, 1996). Hence, current models developed around the world have been constantly updated to provide more accurate equations and, thus, to assist nutritionists in diets formulation (BR-CORTE, 2016; NASEM, 2016; INRA, 2018). Therefore, the correct estimation of energy requirements is essential for the adequate supply of metabolizable energy required by an animal, which is desirable from both productive and sustainable points of view.

The energy requirements for growing and finishing cattle are estimated in BR-CORTE by the system presented to the scientific community by Lofgreen and Garrett (1968). This system was later known as the California Net Energy System (CNES) and established the basis for energy requirement recommendations of the subsequent editions of the North American System (NRC, 1984, 1996, 2000 and NASEM, 2016). A summary of what was established by the CNES System can be understood from the equation below:

$$MEt = MEm + MEg = (NEm / km) + (NEg / kg) \quad \text{Eq. 8.1}$$

where MEt = total metabolizable energy required, MEm = metabolizable energy requirements for maintenance, MEg = metabolizable energy requirements for gain, NEm = net energy requirements for maintenance, *km* = efficiency of use of the metabolizable energy for maintenance, NEg = net energy requirements for gain and *kg* = efficiency of use of MEg.

It should be noted that the basis of the definitions proposed by CNES and presented in equation 8.1 was established by previous researchers, who quantitatively studied the most varied aspects of energy use by animals (Atwater and Bryant, 1900; Armsby, 1917; Kleiber, 1961; Blaxter, 1962; Brody, 1945; Blaxter et al., 1966; Blaxter, 1969).

Since energy requirements evaluation is made based on what was established in equation 8.1, it is necessary to know the fractions presented in order to make the estimates. The BR-CORTE System uses a database of comparative slaughter experiments (Garrett et al., 1959). These experiments measure metabolizable energy intake (MEI) and the energy retained in the form of tissues in the animal body (NEg). The net energy spent on maintenance (NEm) and the inefficiency of energy use for maintenance (1 – *km*) and gain (1 – *kg*) represent the energy consumed that was transformed into heat (heat production) and are estimated by difference, based on the principles of energy conservation established in the first thermodynamic law (Clausius, 1850). Representative equations of these relationships are shown below:

$$MEI = RE + HP \quad \text{Eq. 8.2}$$

$$MEI = MEt \quad \text{Eq. 8.3}$$

$$RE = NEg \quad \text{Eq. 8.4}$$

$$HP = NEm + ((1 - km) \times MEm) + ((1 - kg) \times MEg) \quad \text{Eq. 8.5}$$

where MEI = metabolizable energy intake, RE = retained energy, HP = heat production, MEt = total metabolizable energy requirements, NEm = net energy requirements for maintenance, *km* = efficiency of use of metabolizable energy for maintenance, MEm = metabolizable energy requirements for maintenance, *kg* = efficiency of metabolizable energy use for gain and MEg = metabolizable energy requirement for gain.

Since the value of heat production (HP) is obtained by the difference between metabolizable energy intake and retained energy, and three of the variables presented in equation 8.5 are derived from HP, mathematical models are used to estimate NEm, *km* and *kg* values, and they will be presented in the following text.

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

BR-CORTE HISTORY

In the BR-CORTE System, these requirements have been estimated from a database that has grown over its different editions, not only in the number of animals, but also in the variation in weights and genetic groups used. The first edition (BR-CORTE, 2006) used individual data from 180 Zebu (nine studies) reared in feedlot. In the second edition (BR-CORTE, 2010), requirements for Zebu and crossbred cattle were estimated from individual data of 626 animals (25 studies) raised in feedlot or pasture. In the third edition, estimates are presented for nutritional requirements for Zebu, crossbred dairy and beef cattle, and cattle in pasture and feedlot from individual data of 1369 animals and 38 different studies (BR-CORTE, 2016).

In this new edition, we used data from 21 studies (636 individual data) to develop new models for predicting RE from carcass gain (CG) of beef cattle with different gender (Bulls, steers, and heifers) and genotypes (Zebu, crossbred beef and dairy cattle).

DATABASE OF BR-CORTE (2016)

BR-CORTE (2016) was updated based on a database consisting of 38 studies carried out under Brazilian conditions (Table 8.1). The database had a greater predominance of animals raised in feddlot (N = 1369). Furthermore, the Zebu genetic group was the largest group represented in the database, with 744 animals (Table 8.1). The crossbred beef group of animals was formed by 142 Angus × Nellore, 62 Limousin × Nellore, 12 Marchigiana × Nellore, 73 Simmental × Nellore, 11 Brown Swiss × Nellore, 23 Brangus and 16 twice crossbred animals, with a greater European blood fraction coming from the Angus breed (Table 8.2). The crossbred dairy group of animals was formed by 16 Holstein × Gyr, 15 Holstein × Guzerat, 155 Nellore × Holstein, 21 Holstein and 79 crossbred dairy animals (Table 8.3). The database of animals reared in pasture was formed by 127 animals, all Nellore (Table 8.4).

Table 8.1 - Descriptive statistics of the data used to obtain the nutritional energy requirements of Zebu animals in feedlot

Items	N	Mean	Maximum	Minimum	SD
Bulls					
iSBW, kg	454	283	438	110	65.6
fSBW, kg	454	383	592	122	91.2
iEBW, kg	454	249	358	95.2	58.6
fEBW, kg	454	337	549	109	85.0
$EBW^{0.75}$, kg	454	70.9	98.2	32.1	12.5
ADG, kg/d	454	1.00	2.65	-0.14	0.45
EBG, kg/d	454	0.95	2.30	-0.13	0.43
RE, kcal/$EBW^{0.75}$	454	50.9	170	-97.4	36.7
MEI, kcal/$EBW^{0.75}$	454	220	467	0.49	78.2
HP, kcal/$EBW^{0.75}$	454	196	309	87.7	52.3
Steers					
iSBW, kg	166	291	399	164	46.7
fSBW, kg	166	364	520	195	68.4
iEBW, kg	166	255	352	150	41.7
fEBW, kg	166	322	469	148	67.0
$EBW^{0.75}$, kg	166	70.0	91.2	42.7	9.23
ADG, kg/d	166	0.71	1.53	-0.22	0.42
EBG, kg/d	166	0.70	1.63	-0.21	0.38
RE, kcal/$EBW^{0.75}$	166	30.8	103	0.63	23.1
MEI, kcal/$EBW^{0.75}$	166	212	310	114	53.8
HP, kcal/$EBW^{0.75}$	166	181	232	104	40.0
Heifers					
iSBW, kg	124	225	347	127	53.4
fSBW, kg	124	271	437	121	72.4
iEBW, kg	124	197	403	104	48.8
fEBW, kg	124	243	397	108	67.7
$EBW^{0.75}$, kg	124	57.2	89.5	33.0	10.7
ADG, kg/d	124	0.57	1.27	-0.12	0.39
EBG, kg/d	124	0.58	1.25	-0.13	0.37
RE, kcal/$EBW^{0.75}$	124	60.3	272	-6.02	52.3
MEI, kcal/$EBW^{0.75}$	124	217.5	338	110	80.5
HP, kcal/$EBW^{0.75}$	124	157	229	92.3	51.36

N = number of animals; SD = standard deviation; iSBW = initial shrunk body weight; fSBW = final shrunk body weight; iEBW = initial empty body weight; fEBW = final empty body weight; $EBW^{0.75}$ = mean metabolic empty body weight; ADG = average daily gain; EBG = empty body gain; RE = retained energy; MEI = metabolizable energy intake; HP = heat production.

Table 8.2 - Descriptive statistics of the data used to obtain the nutritional energy requirements of crossbred beef animals in feedlot

Items	N	Mean	Maximum	Minimum	SD
Bulls					
iSBW, kg	215	302	435	198	51.8
fSBW, kg	215	445	589	230	86.9
iEBW, kg	215	256	366	173	40.2
fEBW, kg	215	388	541	199	81.1
$EBW^{0.75}$, kg	215	75.9	98.3	50.4	11.3
ADG, kg/d	215	1.15	2.11	-0.07	0.43
EBG, kg/d	215	1.11	2.04	-0.05	0.42
RE, kcal/$EBW^{0.75}$	215	58.7	180	-6.72	34.8
MEI, kcal/$EBW^{0.75}$	215	244	489	97.4	76.0
HP, kcal/$EBW^{0.75}$	215	185	489	22.2	80.2
Steers					
iSBW, kg	75	312	434	189	68.9
fSBW, kg	75	414	581	224	93.2
iEBW, kg	75	274	385	166	65.3
fEBW, kg	75	371	518	201	90.3
$EBW^{0.75}$, kg	75	76.0	97.9	49.9	11.7
ADG, kg/d	75	1.10	2.35	-0.36	0.67
EBG, kg/d	75	1.11	2.11	-0.09	0.61
RE, kcal/$EBW^{0.75}$	75	79.9	114	9.49	32.0
MEI, kcal/$EBW^{0.75}$	75	265	505	90.3	105
HP, kcal/$EBW^{0.75}$	75	185	359	101	69.6
Heifers					
iSBW, kg	49	271	331	194	33.5
fSBW, kg	49	345	494	187	88.5
iEBW, kg	49	241	311	150	36.8
fEBW, kg	49	304	443	176	79.8
$EBW^{0.75}$, kg	49	67.1	85.6	45.5	9.14
ADG, kg/d	49	0.86	1.75	-0.31	0.66
EBG, kg/d	49	0.80	1.73	-0.18	0.58
RE, kcal/$EBW^{0.75}$	49	55.2	104	-7.60	33.4
MEI, kcal/$EBW^{0.75}$	49	238	355	112	82.8
HP, kcal/$EBW^{0.75}$	49	182	268	103	53.3

N = number of animals; SD = standard deviation; iSBW = initial shrunk body weight; fSBW = final shrunk body weight; iEBW = initial empty body weight; fEBW = final empty body weight; $EBW^{0.75}$ = mean metabolic empty body weight; ADG = average daily gain; EBG = empty body gain; RE = retained energy; MEI = metabolizable energy intake; HP = heat production.

Table 8.3 - Descriptive statistics of the data used to obtain the nutritional energy requirements of crossbred dairy animals in feedlot

Items	N	Mean	Maximum	Minimum	SD
Bulls					
iSBW, kg	85	407	495	317	50.5
fSBW, kg	85	451	661	191	110
iEBW, kg	85	341	415	266	40.2
fEBW, kg	85	394	600	167	106
$EBW^{0.75}$, kg	85	83.9	107	56.4	14.4
ADG, kg/d	85	1.68	2.64	0.45	0.60
EBG, kg/d	85	1.52	2.54	0.45	0.65
RE, kcal/$EBW^{0.75}$	85	92.5	167	18.5	36.1
MEI, kcal/$EBW^{0.75}$	85	273	348	154	60.5
HP, kcal/$EBW^{0.75}$	85	181	264	11.9	56.3
Steers					
iSBW, kg	88	279	455	104	90.1
fSBW, kg	88	358	575	159	95.9
iEBW, kg	88	231	363	94.9	66.0
fEBW, kg	88	312	510	146	86.5
$EBW^{0.75}$, kg	88	66.9	95.5	36.4	12.8
ADG, kg/d	88	0.97	2.05	0.15	0.43
EBG, kg/d	88	0.95	2.00	0.14	0.48
RE, kcal/$EBW^{0.75}$	88	47.8	112	-93.0	40.2
MEI, kcal/$EBW^{0.75}$	88	258	372	95.7	83.5
HP, kcal/$EBW^{0.75}$	88	210	343	80.9	67.3
Heifers					
iSBW, kg	113	247	399	150	57.6
fSBW, kg	113	309	399	230	55.7
iEBW, kg	113	161	230	115	31.3
fEBW, kg	113	274	375	192	57.6
$EBW^{0.75}$, kg	113	56.6	72.5	43.6	9.19
ADG, kg/d	113	1.00	1.37	0.29	0.30
EBG, kg/d	113	0.88	1.30	0.30	0.37
RE, kcal/$EBW^{0.75}$	113	72.1	115	36.7	23.5
MEI, kcal/$EBW^{0.75}$	113	416	548	348	59.1
HP, kcal/$EBW^{0.75}$	113	344	475	285	57.9

N = number of animals; SD = standard deviation; iSBW = initial shrunk body weight; fSBW = final shrunk body weight; iEBW = initial empty body weight; fEBW = final empty body weight; $EBW^{0.75}$ = mean metabolic empty body weight; ADG = average daily gain; EBG = empty body gain; RE = retained energy; MEI = metabolizable energy intake; HP = heat production.

Table 8.4 - Descriptive statistics of the data used to obtain the nutritional energy requirements of Zebu animals on pasture

Items	N	Mean	Maximum	Minimum	SD
Bulls					
iSBW, kg	99	278	404	138	50.6
fSBW, kg	99	391	661	138	68.6
iEBW, kg	99	242	363	106	41.4
fEBW, kg	99	343	600	118	58.9
$EBW^{0.75}$, kg	99	70.7	103	34.5	9.28
ADG, kg/d	99	0.42	1.13	-0.54	0.38
EBG, kg/d	99	0.34	0.81	-0.55	0.36
RE, kcal/$EBW^{0.75}$	99	24.3	105	-52.3	29.1
MEI, kcal/$EBW^{0.75}$	99	199	307	83.4	54.5
HP, kcal/$EBW^{0.75}$	99	175	340	12.7	59.7
Steers					
iSBW, kg	28	294	455	104	59.8
fSBW, kg	28	370	581	150	91.7
iEBW, kg	28	253	385	94.9	49.3
fEBW, kg	28	325	518	125	76.9
$EBW^{0.75}$, kg	28	70.2	97.9	33.9	9.66
ADG, kg/d	28	0.57	0.95	-0.15	0.33
EBG, kg/d	28	0.47	0.90	-0.10	0.29
RE, kcal/$EBW^{0.75}$	28	16.3	36.9	-12.4	15.5
MEI, kcal/$EBW^{0.75}$	28	210	306	120	54.7
HP, kcal/$EBW^{0.75}$	28	193	278	129	41.3

N = number of animals; SD = standard deviation; iSBW = initial shrunk body weight; fSBW = final shrunk body weight; iEBW = initial empty body weight; fEBW = final empty body weight; $EBW^{0.75}$ = mean metabolic empty body weight; ADG = average daily gain; EBG = empty body gain; RE = retained energy; MEI = metabolizable energy intake; HP = heat production.

ENERGY REQUIREMENTS FOR MAINTENANCE

Net Energy Requirements for Maintenance

NEm can be understood as the animal's total heat production in a state of absolute fasting. It is correlated with meeting basic functions, such as maintaining homeothermy, circulation, respiration, enzymatic system maintenance and tissue synthesis, and meeting voluntary activities such as rumination and walking (Garrett et al., 1959).

Primarily, the maintenance energy requirements were calculated by long-term feeding experiments, where constant intake levels were maintained until the animals reached a balanced body weight for a period of time (Taylor and Young, 1968). Subsequently, the energy requirement was calculated as a regression between energy intake and animal weight gain, and the point where the weight gain equaled to zero, found by extrapolation, was considered as the animal's maintenance energy requirement (Jenkins and Ferrell, 1983). However, this technique estimated the metabolizable energy requirement for maintenance (MEm), whereas NEm, and the gain requirements should be estimated by other methods.

NEm can be obtained by using respirometric techniques, where an animal in a state of absolute fasting is maintained inside a chamber and its CO_2 and methane gas production and oxygen consumption are measured (Ferrell and Oltjen, 2008). Considering the principle that all heat produced is derived from metabolic oxidation of organic compounds, and that oxygen consumption is necessary to produce CO_2, it is possible to estimate NEm (ARC, 1965).

NEm can also be estimated indirectly using the comparative slaughter method as done in the studies adopted to estimate NEm presented in the BR-CORTE. To use this method, animals must be fed with different levels of metabolizable energy, which will result in variation in the energy retained in the body and in heat production (Lofgreen and Garrett, 1968). NEm has been calculated (both in respirometric chambers and by comparative slaughter) using an exponential non-linear HP regression as a function of MEI. At this point, NEm is known as the intercept (β_0) of the model (Ferrell and Jenkins, 1998; Figure 8.1).

$$HP = \beta_0 \times e^{\beta 1 \times MEI} \quad \text{Eq. 8.6}$$

where HP = heat production (Mcal/EBW$^{0.75}$/d), MEI = metabolizable energy intake (Mcal/EBW$^{0.75}$/d) and β_0 and β_1 = parameters of the model.

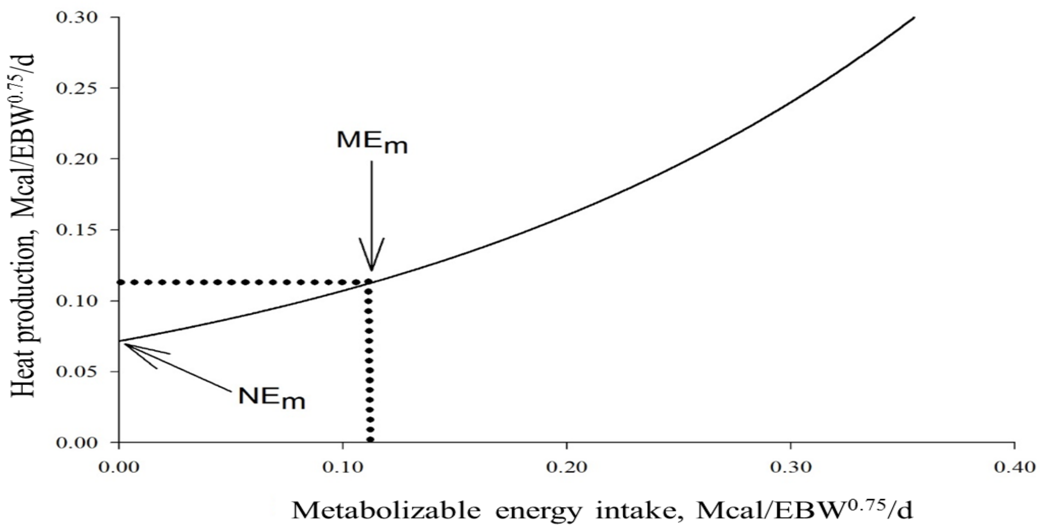

Figure 8.1 - Representation of the relationship between heat production and metabolizable energy intake.

NEm requirements were estimated based on the model above and tested effects of sex, genetic group, and system on the parameters of the model. As the database for pasture-reared animals was not modified in relation to the previous edition, the same recommendations of the previous edition were maintained (Valadares Filho et al., 2010).

a) Animals in feedlot

When the model of equation 8.6 was fitted to the data from feedlot animals, there was no effect of sex on the parameters of the model ($P > 0.05$). Similarly, there was no effect of genetic group on the β_0 parameter of the model ($P = 0.332$), which indicates that there were no differences in the NEm estimate. On the other hand, a genetic group effect was observed on the β_1 parameter of the model described above ($P < 0.001$), which indicates that the genetic group influences the efficiency of use of metabolizable energy for maintenance.

Zebu cattle:

$$HP = 0.0749 \times e^{3.8684 \times MEI} \quad \text{Eq. 8.7}$$

Crossbred beef cattle:

$$HP = 0.0749 \times e^{4.0612 \times MEI} \quad \text{Eq. 8.8}$$

Crossbred dairy cattle:

$$HP = 0.0749 \times e^{4.1487 \times MEI} \quad \text{Eq. 8.9}$$

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

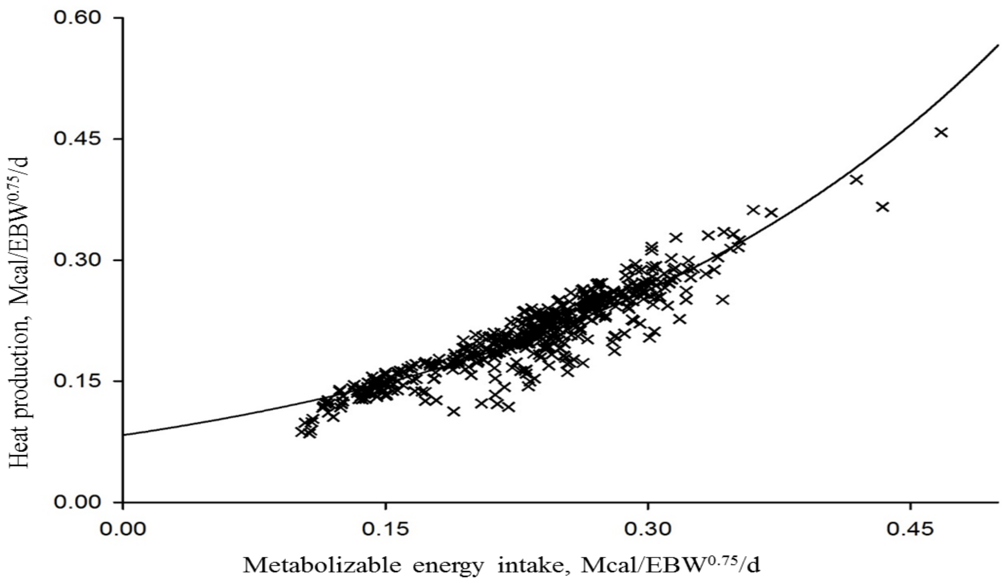

Figure 8.2 - Representation of the relationship between heat production and metabolizable energy intake for Zebu animals reared in feedlot, based on equation 8.7.

Generally, the estimated value of 75 kcal/EBW$^{0.75}$/d for NEm is consistent, because it is similar to the values reported in the literature, as for example, the base metabolic rate of 69 kcal/EBW$^{0.75}$/d, measured in a respirometric chamber (Poczopko, 1971).

The NRC (2000) suggests that there is no difference between steers and heifers for NEm, also described by the ARC (1980) and CSIRO (1990), and recommends a value of 77 kcal/EBW$^{0.75}$/d. The NRC (2000) also suggests that bulls have a NEm requirement 15% greater than the other sexes, but these differences were not observed in our database (Webster et al., 1982; Ferrell and Jenkins, 1985).

The NASEM (2016) changed the recommendation of the previous edition (NRC, 2000) of 77 kcal/EBW$^{0.75}$/d for steers and heifers to 77 kcal/SBW$^{0.75}$/d and also recommended a 15% increase in the NEm for bulls. It was also suggested that Zebu animals, except for Nellore cattle, would have NEm requirements approximately 10% lower than animals with taurine origin, that is, around 69 kcal/SBW$^{0.75}$/d.

However, sex differences were not observed in our database. Chizzotti et al. (2008) also did not observe genetic group effects and estimated a NEm of approximately 75 kcal/EBW$^{0.75}$/d in a study involving data of 389 Nellore or crossbred beef animals (Angus, Red Angus, Simmental, Limousin and Brangus). Generally, the values reported in 2010 and 2016 were similar, which emphasizes the consistency of the BR-CORTE database and the applicability of the estimated values.

b) Animals on pasture

The second edition of the BR-CORTE presented differences in NEm estimate according to the rearing system, and the values were 74.2 and 71.7 kcal/EBW$^{0.75}$/d for animals reared in feedlot and on pasture, respectively. However, with the database of the third edition, there was no effect (P = 0.16) of the rearing system on the β_0 estimate of equation 8.6, and the same NEm value of 75 kcal/EBW$^{0.75}$/d was adopted for both animals reared in feedlot and on pasture. However, a significant difference (P = 0.039) was observed for β_1 estimate suggesting differences regarding MEm.

$$HP = 0.0749 \times e^{4.1986 \times MEI} \quad \text{Eq. 8.10}$$

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

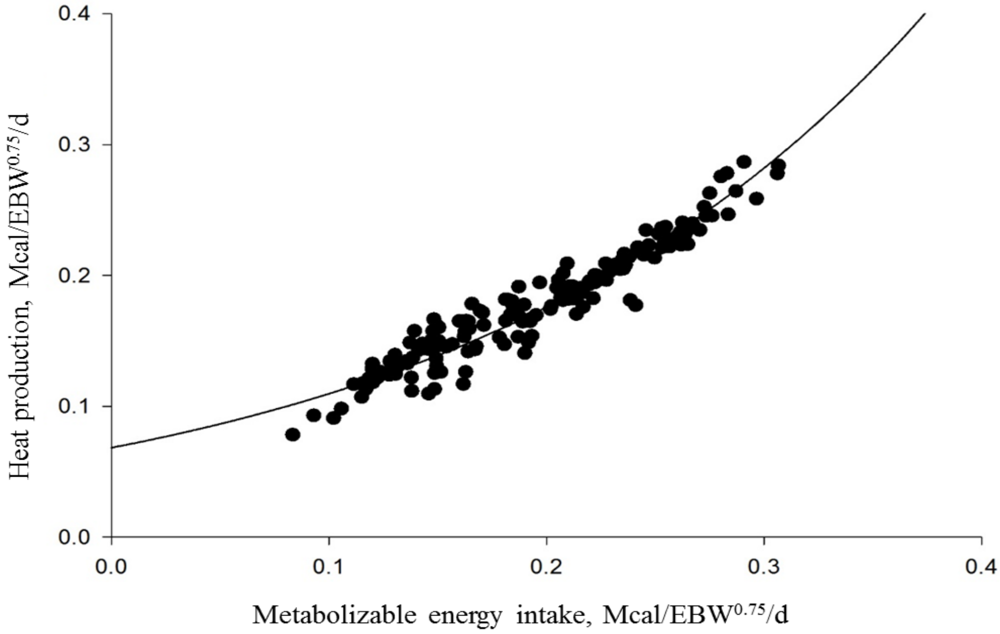

Figure 8.3 - Representation of the relationship between heat production and metabolizable energy intake for Zebu animals reared on pasture, based on the equation 8.10.

Theoretically, NEm is influenced by characteristics that affect the basal metabolism and is independent of diet, which justifies equivalent values for animals reared in different systems (Garrett et al., 1959).

Metabolizable energy requirements for maintenance

The use of the value found for NEm is limited and has no practical application in diet formulation because producing animals are not found in a fasting state. Therefore, the maintenance requirement must be calculated in a more applicable form. In this context, there is the MEm concept, which can be understood as the point at which all of the metabolizable energy intake is used for heat production, that is, no energy is retained in the body (Lofgreen and Garrett, 1968).

To obtain the MEm, the efficiency of use of metabolizable energy for maintenance (*km*) needs to be known. This efficiency can be obtained by applying an iterative process to the exponential model of heat production as a function of the metabolizable energy intake. The point where heat production and metabolizable energy intake are equal, is the value considered to be MEm (Mcal/EBW $^{0.75}$/d). The *km* is estimated from the MEm and NEm ratio (Figure 8.1).

This technique of estimating the *km*, although classic and already used in the first edition of the BR-CORTE (BR-CORTE, 2006), was refuted in the second edition (BR-CORTE, 2010) because it did not take into consideration the action of a series of factors that can affect the *km*. These factors include sex, genetic group, age, environment and the metabolizable energy concentration in the diet (AFRC, 1993; NRC, 2000; CSIRO, 2007). In addition, there is strong evidence that the *km* is also affected by characteristics linked to animal performance, such as weight gain rate and composition (Williams and Jenkins, 2003; Marcondes et al., 2010).

a) Animals on feedlot

Marcondes et al. (2013) used a meta-analysis to study the effect of several variables on the *km*, and found that the efficiency of use of metabolizable energy for gain (*kg*) and empty body gain (EBG) influenced *km* (Eq.8.11), which confirms that the maintenance requirements are affected by animal performance.

$$km = [\beta_0 + (\beta_1 \times kg) + (\beta_2 \times EBG)] \times \theta \qquad \text{Eq. 8.11}$$

where: *km* = efficiency of use of metabolizable energy for maintenance, *kg* = efficiency of use of metabolizable energy for gain, EBG = empty body gain, β_0, β_1 and β_2 = parameters of the equation and θ = fit factor for the rearing system.

In addition, Marcondes et al. (2013) showed a genetic group effect on the estimate of the EBG parameter, which reaffirmed the results found in parameter β_1 of equations 8.7, 8.8, and 8.9.

Reassessing the model proposed by Marcondes et al. (2013), based on the BR-CORTE updated database, a difference was confirmed between genetic groups for the parameter associated with EBG (β_2), but the original values reported by the authors were maintained for Zebu and crossbred beef cattle. The data for Zebu and crossbred beef cattle had high accuracy (85.04%) (Lin and Torbeck, 1998; Tedeschi, 2004) in the model proposed by Marcondes et al. (2013). Thus, it was decided to maintain the *km* equation for Zebu and crossbred beef cattle, and the model was re-parametrized for crossbred dairy cattle, to minimize the mean squared error in the *km* estimates for these animals:

$$km = [0.513 + (0.173 \times kg) + (\beta_2 \times EBG)] \times \theta \quad \text{Eq. 8.12}$$

where: *km* = efficiency of use of metabolizable energy for maintenance, *kg* = efficiency of use of metabolizable energy for gain, EBG = empty body gain (kg/d), β_2 = 0.100 for Zebu, 0.073 for crossbred beef cattle and 0.010 for crossbred dairy cattle and θ = fit factor for the rearing system that takes the value of 1 for animals reared on feedlot.

The model is in agreement with the conclusions by Garrett (1980b), who suggested that the *km* would be affected by body composition and nutritional plan, since the *kg* is affected by the gain composition and the EBG is affected by the nutritional plan. According to Garrett (1980b) variations in protein turnover could be responsible for part of the variation in the *km*, and thus there would be differences in protein turnover in the genetic groups assessed.

Most of the nutritional requirement systems estimate *km* based on the diet characteristics. The AFRC (1993) and CSIRO (2007) consider the metabolizable energy concentration and gross energy ratio in the diet (qm) (equations 8.13 and 8.14, respectively). The *km* established by the NRC (2000) and NASEM (2016) is based on the study by Garrett (1980a) and considers the metabolizable energy concentration in the diet [ME] as the variable that affects the estimate of the net energy concentration for maintenance [NEm] (Eq. 8.15), and the *km* is obtained by dividing [NEm] by [ME]. On the other hand, Fox et al. (2004) recommended a fixed value of 0.64.

$$km = (0.35 \times q_m) + 0.503 \quad \text{Eq. 8.13}$$

$$km = (0.02 \times q_m) + 0.500 \quad \text{Eq. 8.14}$$

$$NEm = -1.12 + 1.37 \times ME - 0.138 \times ME^2 + 0.0105 \times ME^3 \quad \text{Eq. 8.15}$$

where: *km* = efficiency of use of metabolizable energy for maintenance, qm = metabolizable energy and gross energy ratio in the diet (expressed in % in Eq. 8.13, and in MJ/kg DM in Eq. 8.14) and ME = concentration of metabolizable energy in the diet (Mcal/kg DM).

As reported previously, the NRC (2000) and NASEM (2016) suggested that *Bos taurus indicus* cattle, except the Nellore, would have an NEm 10% lower than taurine animals. However, as was presented previously, no difference was shown for NEm in our database, considering crossbred and Zebu cattle of different sexes. However, the *km* calculation model indicates that this difference may not be related to the NEm, but instead to its use efficiency, and *Bos taurus indicus* animals would be more efficient than crossbred beef cattle, which would be more efficient than crossbred dairy cattle.

b) *Animals on pasture*

Regarding the rearing system, Marcondes et al. (2013) did not compare feedlot and pasture conditions in the development of the *km* models. However, applying the iterative method to the equations generated with the database of Zebu animals reared on feedlot (Eq.8.7) and animals reared on pasture (Eq.8.10) showed that the rearing system influences the MEm estimate. The MEm value obtained for animals on pasture was 128 kcal/EBW$^{0.75}$/d, while for Zebu animals on feedlot it was 118 kcal/EBW$^{0.75}$/d. So presents an 8.5% increase in the final MEm estimate for animals on pasture, that is, animals on pasture present a *km* 8.5% lower than animals reared on feedlot.

$$km = (0.513 + 0.173 \times kg + 100 \times EBG) \times \theta$$

Eq. 8.16

where: *km* = efficiency of use of metabolizable energy for maintenance, *kg* = efficiency of use of energy for gain, EBG = empty body gain (kg/d) and θ = fit factor for the rearing system that presumes a value of 0.92 for pasture reared animals.

The smaller *km* of animals on pasture may be connected to their bigger energy expenditure for movement and forage gathering that may reduce the efficiency of the diet's energy use. Another aspect is the diet quality, since pastures usually have a lower metabolizable energy concentration than feedlot diets, which may lead to a reduction in the *km* (Garrett, 1980b).

Factors that influence the maintenance requirement

a) Voluntary activities

Nutritional requirements have mainly been established for feedlot animals, because the food supplied and metabolizable energy intake can be measured. However, for animals reared on pasture, locomotion is considered greater compared to animals on feedlot. Therefore, the CSIRO (2007) considered that animals on pasture spend more energy on ingestion activity than animals in feedlot and presumed that the energy spent on walking is 0.62 kcal/km horizontal displacement and 6.69 kcal/km vertical displacement. The additional metabolizable energy of ingestion, expressed in MJ, can be calculated by 0.0025 x DMIp x (0.9 – DMDp), where DMIp is the dry matter intake (kg/d) of pasture and DMDp is the dry matter digestibility of pasture. When these corrections are adopted, animals on pasture would present 10 to 20% greater maintenance requirements compared to animals on feedlot, depending on topography, stocking rate, pasture availability and quality.

In the third edition (BR-CORTE, 2016), only six of the 38 studies included in the database were maintained on pasture. This group of animals was assessed separately for nutritional requirements and, as observed previously, there was an 8.5% increase in the MEm requirements of animals on pasture. However, there is still both wide variability and scarcity of data for animals on pasture, which shows that there is still a lot to be studied in this system. Comparative slaughter experiments to estimate nutritional requirements are difficult to carry out on pasture, because both supplement and pasture intake and fecal excretion are usually estimated using markers.

Many studies have been performed to perfect the intake and excretion estimation methods for animals on pasture (Ferreira et al., 2009). However, more experiments are needed to increase the number of repetitions and provide varied conditions so that the statistical procedures can more precisely identify the effect of pasture on maintenance requirements.

b) Environmental effects

The main factors involved in determining the thermoneutral zone are: the environment (air temperature, air humidity, solar radiation and atmospheric pressure) the animal´s skin structure (thickness, heat insulation, wind penetration, ventilation, emissivity, absorptivity and reflectivity) and body characteristics (body shape, size, surface area, area exposed to solar radiation, epidermis emissivity and absorptivity) (Silva, 2000). The thermoneutral zone range, delimited by critical lower and higher temperatures, is defined as the temperature range where there is no additional energy expenditure to maintain body temperature.

Thus, dry matter intake is lower under heat stress, but while the highest critical temperature is surpassed during short periods of the day, intake recovers in hours of cooler temperature. Thus, the use of this adjust is recommended only in extreme cases.

Heat stress increases respiratory frequency, heart rate, panting and energy expenditure to maintain body temperature, but also decreases metabolic heat production. This makes it hard to adopt adjustments in the nutritional requirements for this factor.

Therefore, the NRC (2000) recommends adjustments to the energy requirements for maintenance in the order of

0.0007 Mcal/BW$^{0.75}$ for each 1ºC of variation in the environmental temperature compared to the 20ºC standard temperature. Thus, when the environmental temperature is greater than 20ºC there will be a reduction in the maintenance requirement, and an increase in the maintenance requirement is expected when temperatures are lower than 20ºC.

There are few studies in Brazil that assess the effect of environmental variables on animal nutritional requirements. Thus, adjustments will not be recommended for these factors in this publication.

ENERGY REQUIREMENTS FOR GAIN

Equivalent empty body weight

Applying performance measurements, such as the average daily gain, is essential in prediction systems for nutritional requirements. However, it is as important as get an idea of the average daily gain, it is understanding the composition that the gain presents (Marcondes et al., 2016). One of the ways to infer an animal's gain composition is from the body weight of the animal at maturity, because when the animal is closest to this weight, there will be a greater tendency to deposit fat compared to protein contents in the empty body weight.

First, the weight at maturity was correlated to the stable weight of an adult cow of a determined breed. However, applying this value to growing animals may not give satisfactory results, because some genetic groups attain an adult weight that is much heavier than the weight normally considered for cattle slaughter, and many animals also stabilize their body composition before maturity (Reid et al., 1955). Following this reasoning, several ways were proposed to estimate the weight at animal maturity, endeavoring to correlate it with growth curves (Brown et al., 1976; Menchaca et al., 1996).

According to Reid et al. (1955) and Marcondes et al. (2016), weight at maturity would be reached when the crude protein concentration in the fat-free dry matter of the animals became constant, that is, all tissue deposition would be in the form of fat. For Tedeschi et al. (2002), body weight at maturity of Nellore animals would be reached when these animals attained 22% body fat in the empty body weight. For the NRC (2000), the body fat content that would define the reference weight would be 25% for animals with only traces of marbling.

From the genetic composition of the animals present in the BR-CORTE database, and based on analysis of the data for body composition of these animals, it was decided to establish the empty body weight at maturity based on the body fat content and the empty body weight exponential ratio in the animals, considering 25% body fat as the point of maturity (Figure 8.4) since the animals in the database mostly have a low degree of marbling (NRC, 2000).

$$BF = \beta_0 \times e^{(\beta_1 \times EBW)} \quad \text{Eq. 8.17}$$

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

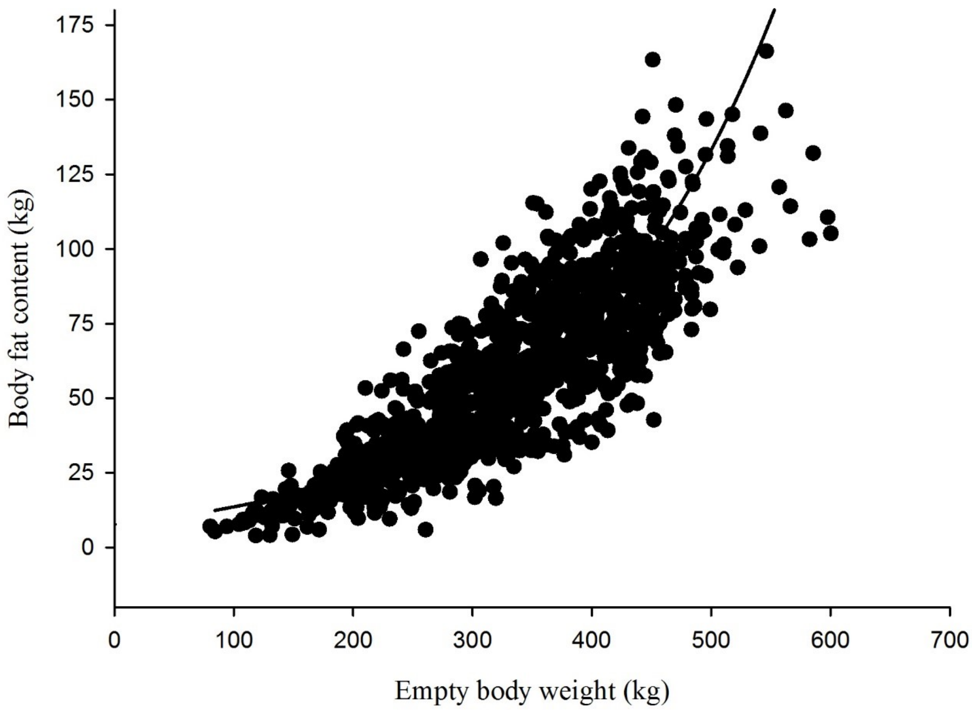

Figure 8.4 - Relationship between empty body weight and body fat, considering all the animals in the BR-CORTE database.

When the model described above was applied to the database, an effect was observed of genetic group and sex on the estimate of the empty body weight at maturity of the animals, and the following values are recommended (Table 8.5).

Table 8.5 - Empty body weight (EBW), fasting body weight (SBW) and body weight (BW) at maturity for different genetic groups/sex classes of beef cattle, estimated from the exponential relationship between body fat content and the animals' empty body weight

Genetic group	Sex	EBW (kg)	SBW (kg)	BW (kg)
Zebu cattle	Bulls	517	585	595
	Steers	433	477	487
	Heifers	402	439	449
Crossbred beef cattle	Bulls	560	631	642
	Steers	482	535	546
	Heifers	417	457	467
Crossbred dairy cattle	Bulls	616	692	708
	Steers	532	588	602
	Heifers	493	535	548

Arnold and Bennett (1991a; b) suggested a 517 kg weight at maturity for bulls and 315 kg for heifers, both for medium body size breeds. Oltjen et al. (1986) estimated a maturity value of 450 kg for steers. As Nellore animals are considered medium-size (NRC, 2000), the data estimated in the present publication is in agreement with the values reported in the literature. Crossbred animals had higher estimated weights at maturity because large size breeds were used in the crosses, which increases progeny weight at maturity.

The NRC (2000) suggests correcting the estimate of the energy requirements for gain by the weight of the animals of different body sizes or weights at maturity, in order to generate an equivalent value for all animals. This is known as the equivalent empty body weight (EQEBW). Thus, the EQEBW can be calculated from the weight at maturity (MEBW) suggested previously for each type of animal and a reference value for empty body weight (SREBW), adopting the following model:

$$EQEBW = (EBW / MEBW) \times SREBW \qquad \text{Eq. 8.18}$$

where EQEBW = equivalent empty body weight (kg), EBW = empty body weight (kg), SREBW = standard reference empty body weight (517 kg) and MEBW = empty body weight at maturity (values presented previously, in kg).

The use of EQEBW allows animals from different genetic groups and/or sexes to be compared at different finishing grades. For this, a reference value needs to be well established to increase the estimate accuracy. In this case, the standard reference empty body weight (SREBW) is the weight where animals would be at the same expected final body fat.

In the BR-CORTE (2010), a value of 440kg was adopted for the SREBW. This value was calculated based on the database of that edition that contained all the animals. For the third edition (BR-CORTE, 2016), the value of the empty body weight at maturity of Zebu bulls (517 kg) was used for the SREBW. This decision was based on the consistency of these animals presented by the database and that they also had most data, and possibly greater reliability in the estimates.

Net energy requirement for gain

Net energy requirement for gain (NEg) can be understood as all the energy that is retained in the empty body weight of the animals in the form of protein or fat (Garrett et al., 1959). Therefore, the composition of the empty body weight gain is the main determinant of the energy requirements for weight gain. In this sense, what determines the composition of the empty body gain is not the absolute body weight, but the weight relative to the weight at maturity of the animal. The closer an animal is to its weight at maturity, the greater the fat deposition compared to protein deposition that tends to increase the requirements for weight gain (Marcondes et al., 2016).

In this context, the model used in the third edition (BR-CORTE, 2016) to estimate NEg is based on the ratio of the energy retained in the body as a function of the EQEBW and the desired empty body weight gain:

$$NEg = \beta_0 \times EQEBW^{0.75} \times EBG^{\beta_1} \qquad \text{Eq. 8.19}$$

where NEg = net energy requirement for weight gain (Mcal/d), EQEBW = equivalent empty body weight (kg), EBG = empty body gain (kg/d) and β_0 and β_1 = parameters of the model.

The analysis of the database in the third edition showed the possibility of the EQEBW absorbing not only intrinsic differences in each genetic group (Figure 8.5B), but also differences between sexes (Figure 8.5A).

In this way, a joint equation was generated using the data from all the animals finished in feedlot (Eq. 8.20) while the requirements for animals on pasture were not altered in relation to the last edition (Eq. 8.21).

$$NEg = 0.061 \times EQEBW^{0.75} \times EBG^{1.035} \qquad \text{Eq. 8.20}$$

$$NEg = 0.052 \times EQEBW^{0.75} \times EBG^{1.062} \qquad \text{Eq. 8.21}$$

where NEg = net energy requirement for weight gain (Mcal/d), EQEBW = equivalent empty body weight (kg) and EBG = empty body gain (kg/d).

For the effect of sex and considering Zebu animals, steers had an NEg 14% greater compared to bulls and 7% lower compared to heifers (Figure 8.5A). For crossbred beef animals, the NEg of steers was 12% higher than bulls and 13% lower than heifers. For crossbred dairy animals, the NEg of steers was 12% higher than for bulls and 6% lower than for heifers.

The BR-CORTE used a similar model to that recommended in the NRC (2000) and NASEM (2016) to estimate NEg, according to the equation: $NEg = 0.0635 \times EQEBW^{0.75} \times EBG^{1.097}$ that is based on the edition of 1984 (NRC, 1984) and was generated for medium-sized animals. Thus, to correct distortions in relation to animal body composition, the NASEM (2016) recommends using the EQSBW. Three different standard reference weights are used to calculate the EQSBW and are based on the level of marbling presented by different genetic groups: 478 kg for animals with some marbling, 462 kg for animals with moderate marbling and 435 for animals with only traces of marbling.

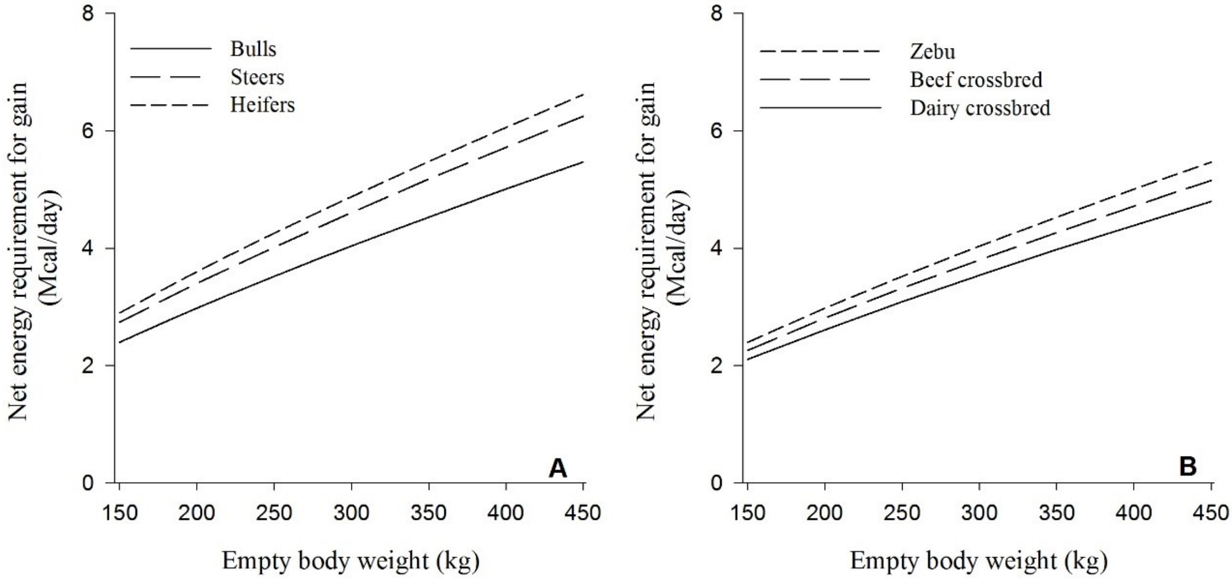

Figure 8.5 - Estimate of net energy requirement for gain for Zebu animals of different sexes (A) and for bulls from different genetic groups (B). For all estimates, the model used was proposed for animals in feedlot, considering the equivalent empty body weight inherent to each category and an empty body weight gain of 1 kg/d.

Differences in weight at maturity of the genetic groups reflect different degrees of fat deposition in animals with the same body weight. Thus, for animals with the same absolute weight and the same weight gain rate, higher energetic concentrations are expected in the gain, and consequently greater NEg, for animals from genetic groups with lower weight at maturity compared to animals from genetic groups with later maturity (Marcondes et al., 2016).

Finally, the EBG can be estimated from the net energy available for gain, which would be computed from the difference between the total energy intake by the animal and its net energy requirement for maintenance, using the following model:

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

Eq. 8.22

In this context, a Nellore bull with 350 kg body weight, equivalent to a 300 kg EQEBW, would have a dry matter intake of approximately 8 kg/d, with a net energy requirement for maintenance of 5.40 Mcal/d. Considering a net energy available for gain of 5.12 Mcal/d, then, an EBG of approximately 1.16 kg/d would be expected.

Use of carcass gain to estimate NEg

A study published by Benedeti et. al. (2021) was used as base to develop this topic. As mentioned before, NEg is the amount of energy that is held within the EBW as protein or fat (Garret et al., 1959). Thus, the NASEM (2016) and BR-CORTE (2016) systems consider the EQEBW and EBG as variables to predict NEg. The EQEBW can be used to correct distortions related to the body composition of animals, in order to generate an equivalent value for animals with different weights at maturity (Valadares Filho et al., 2019). On the other hand, the EBG considers all body constituents, including carcass components, leather, blood, viscera, etc. (Giombelli et al., 2016). However, obtaining this measurement is laborious since the gastrointestinal tract needs to be thoroughly washed and weighed with other carcass and non-carcass components. Furthermore, these procedures are not commonly performed in commercial slaughterhouses, preventing the use of commercial cattle data to develop models that predict the energy requirements of beef cattle.

Carcass weight (CW) is a commonly measurement collected at the slaughter of beef cattle and represents only the carcass tissue accumulation. Thus, replacing EBG by carcass gain (CG) could simplify the estimation of RE requirements. Therefore, as a first step, Benedeti et al. (2021) proposed a new model (Eq. 8.23) to estimate the CW of beef cattle with different genders (Bulls, steers, and heifers), genotypes (Zebu, crossbred beef and dairy cattle), and slaughter conditions (experimental and commercial). More details can be found in Chapter 6.

$$CW\ (kg) = -11.0 + P + [(0.609 + G + B) \times SBW]. \quad \text{Eq. 8.23}$$

where CW = carcass weight (kg); P = slaughter condition (if commercial = -10.98, if experimental = 0); G = gender effect (if heifer = - 0.00612, if steer = 0, if bull = 0.008169), B = genotype effect (if Zebu = 0, if crossbred beef cattle = - 0.01595, if crossbred dairy cattle = -0.03301), and SBW = shrunk body weight (kg).

Performance measurements (such as ADG, CG and EBG) are important for predicting energy requirements because they can be related to the energy needed for body mass deposition (Costa e Silva et al., 2016). Thus, the current equations of BR-CORTE (2016) use EBG to estimate the NEg (Eq. 8.19). The EBG, in turn, is calculated using a non-linear equation that considers ADG as an independent variable:

$$EBG,\ kg/d = 0.9630 \times ADG^{1.0151} \quad \text{Eq. 8.24}$$

where EBG = empty body weight gain (kg/d); ADG = average daily gain (kg/d).

An issue that must be considered is that the ADG values may vary according to the weighing methodology. Thus, animals can be weighed after different periods of fasting (Krinchev et al., 2018; Martins et al., 2019) or even not be fasted prior to slaughter (some commercial conditions). Furthermore, in commercial plants, animals can be transported long distances before being weighed and slaughtered, which may affect ADG. Hence, the use of CG can be an alternative to replace ADG in EBG calculations. Thus, after validating Eq. 8.23, two models were developed with the objective of: 1) predicting EBG from CG; 2) predicting NEg from CG (Benedeti et al., 2021).

Data from 21 studies were used to perform this meta-analysis (Table 8.6). Thus, the database with 636 individual observations of heifers, steers, and bulls of different genotypes (Zebu, crossbred beef and dairy cattle). All studies used comparative slaughter as a method to determine animals' body composition and energy retention (Garrett et al., 1959).

For the prediction of CG from EBG, a linear model with intercept had the lowest value for the Akaike information criterion. On the other hand, a nonlinear equation had the best fit for NEg prediction when EBG was replaced by CG. Thus, the new models proposed for the prediction of EBG and NEg were:

$$EBG\ (kg) = 0.044 + 1.47 \times CG. \quad \text{Eq. 8.25}$$

$$NEg\ (Mcal/d) = 0.082 \times EQEBW^{0.75} \times CG^{0.777}. \quad \text{Eq. 8.26}$$

where EBG = empty body weight gain (kg/d), CG = carcass gain (kg/d), NEg = net energy for gain (MJ/d) and EQEBW = equivalent empty body weight (kg). The relationship between NEg and CG of the animals used to develop the new equations is shown in Figure 8.6.

The validations of the two new equations (Eq. 8.25 and 8.26) were performed using data from 5 independent studies (Table 8.7), encompassing data from our research group (Inside) and from literature publications (Outside; Goulart et al., 2008; Bonilha et al., 2013; Bonilha et al., 2014). The inside dataset was composed of 49 observations, encompassing only bulls with two genotypes (Zebu and dairy crossbred). The outside dataset consisted of 8 means calculated from 115 animals, encompassing only bulls with two genotypes (Zebu and crossbred beef cattle).

Table 8.6 - Descriptive statistics of the data used to develop models to predict empty body gain and net energy gain in Zebu animals with different genders and genotypes

Item*	Total data	Gender			Genotype		
		Bulls	Steers	Heifers	Zebu	Crossbred beef cattle	Crossbred dairy cattle
Studies (n)	21	14	8	7	13	6	4
Animals (n)	636	362	151	123	349	190	97
Initial (kg)							
SBW	285	287	319	233	260	302	337
EBW	247	250	275	203	229	262	279
CW	154	158	175	117	142	164	173
Final (kg)							
SBW	400	421	422	312	368	437	441
EBW	362	382	379	279	336	395	389
CW	232	248	240	174	216	256	243
EBG (kg/d)	1.05	1.17	1.05	0.716	0.955	1.10	1.31
CG (kg/d)	0.804	0.83	0.887	0.626	0.821	0.759	0.828
NEg ($kJ \times d^{-1}/EBW^{0.75}$)	340	348	378	272	323	336	412

CG = carcass gain; CW = carcass weight; EBG = empty body weight gain; EBW = empty body weight; NEg = net energy for gain; SBW = shrunk body weight.

Table 8.7 - Descriptive statistics of the data used to validate models developed to predict empty body gain and retained energy in Zebu animals with different genders and genotypes

Item	Data set*	
	Inside	Outside
Studies, n	2	3
Animals, n	49	8**
Gender, %		
Bull	100	100
Genotype, %		
Zebu	55.1	80.0
Crossbred beef cattle	-	20.0
Crossbred dairy cattle	44.9	-
Carcass gain kg/d	0.59	0.677
Equivalent empty body weight, kg	302	343

*Inside = independent data from our research group studies; Outside = independent data from literature publications (Goulart et al., 2008; Bonilha et al., 2013; Bonilha et al., 2014).
**8 means from 115 animals.

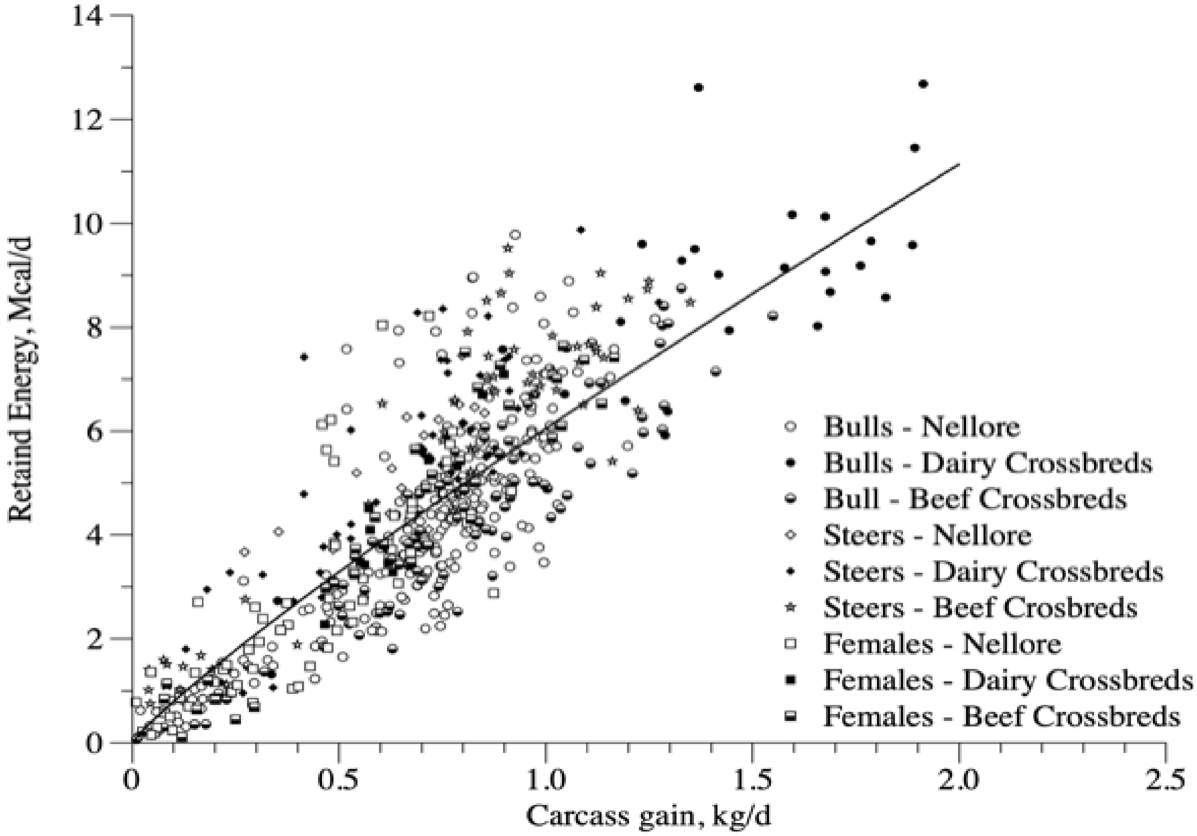

Figure 8.6 - Relationship between retained energy and carcass gain of the animals used to develop the new equations for estimating empty body gain and net energy for gain (adapted from Benedeti et al., 2021).

Analyzing Eq. 8.25, we can observe that when EBG is estimated from the CG, high performance animals are expected to have higher carcass deposition, which seems biologically plausible. As an example of calculation, animals with 0.200 and 1.00 kg of CG would have estimated EBG of 0.338 and 1.51 kg, respectively. Thus, the CG represents 59.4% of the EBG for the former animal, while the same ratio for the animal with the highest performance is 66.2%. According to the literature, the CG/EBG ratio of Zebu cattle varies from 60.0 to 65.0% (Costa et al., 2005; Missio et al., 2009). Therefore, validation analyzes showed that the Eq. 8.25 adequately estimated the EBG using both data from our research group (inside) and from other literature publications (outside; Table 8.8). Furthermore, the high R, CCC and low MSEP observed for the new approach indicate good reproducibility and precision of the proposed equation, making it suitable for estimating EBG from CG.

Regarding the proposed model to calculate NEg from CG (Eq. 8.26), the results indicated a non-linear relationship between these two parameters, evidenced by the increase in energy requirements observed for animals with better performance. Thus, the proposed model presented the highest CCC and the lowest MSEP value in the validation analyses, indicating high reproducibility and accuracy. Furthermore, the MSEP partitioning showed a low participation of SB and MaF, which indicates a lower proportion of prediction error associated with the model. Moreover, validation analysis with outside data showed that the equation was adequate to predict NEg, which is supported by its high R and CCC values and low MSEP. These results indicate that the model presented a good reproducibility index, which may be responsible for accuracy and precision simultaneously. Therefore, the proposed equation accurately and precisely estimated NEg for Zebu cattle and, therefore, are recommended for this purpose.

However, although the new equations proposed to estimate NEg using CG have been validated, CW estimates are still very variable, mainly for animals slaughtered in commercial slaughterhouses. Thus, more results will be needed for the proposed models to become more robust. Therefore, the committee decided to recommend the Eq. 8.20 and 8.21, which estimate NEg using EQEBW and EBG.

Table 8.8 - Validation analysis of the relationship between the values (observed and estimated) of empty body gain (EBG) and net energy for gain (NEg) of Zebu cattle with different gender and genotypes

Item*	Eq. 8.25 evaluation (EBG, kg/d)		Eq.8.26 (NEg, MJ/d) evaluation			
			Inside**		Outside**	
	Observed	Predicted	Observed	Predicted	Observed	Predicted
Mean	0.922	0.939	14.3	16.5	16.8	19.8
Standard deviation	0.367	0.332	6.84	6.68	6.96	4.40
Maximum	1.69	1.66	28.3	32.7	25.4	26.6
Minimum	0.093	0.089	0.767	0.935	8.33	12.9
R	-	0.961	-	0.92	-	0.922
CCC	-	0.956	-	0.874	-	0.736
Regression						
Intercept						
Estimate	-	-0.074	-	-1.24	-	-12.0
Standard error	-	0.045	-	1.04	-	5.05
P-value (H_0: a=0)	-	0.109	-	0.240	-	0.055
Slope						
Estimate	-	1.06	-	0.942	-	1.457
Standard error	-	0.045	-	0.058	-	0.251
P-value (H_0: b=1)	-	0.184	-	0.327	-	0.117
MSEP	-	0.011	-	12.0	-	18.9
SB	-	0.0003	-	4.82	-	8.96
MaF	-	0.0004	-	0.147	-	3.55
MoF	-	0.01	-	7.02	-	6.38

*R = coefficient of determination; CCC = correlation and concordance coefficient; MSEP = mean square error of the prediction; SB = squared bias; MaF = magnitude of random fluctuation; MoF = model of random fluctuation.
**Inside = independent data from our research group studies; Outside = independent data from literature publications (Goulart et al., 2008; Bonilha et al., 2013; Bonilha et al., 2014).

Metabolizable energy requirement for gain

Similar to NEm, NEg cannot be applied directly to the diet formulation, and needs to be converted to the form of metabolizable energy requirement for gain (MEg). Thus, to convert the NEg to MEg, it is necessary to know the efficiency of the use of the metabolizable energy for weight gain (*kg*). The *kg* is usually estimated from a linear regression of the energy retained as a function of the intake of metabolizable energy for gain, where it is assumed that inclination of this straight line (β_1) would represent *kg* (Figure 8.7).

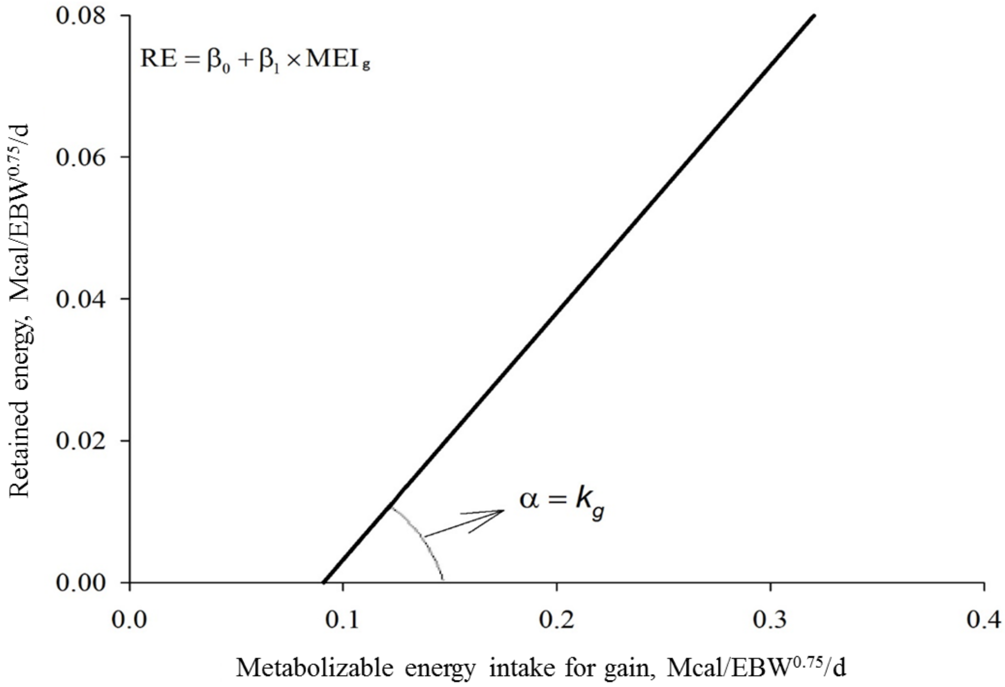

Figure 8.7 - Retained energy and metabolizable energy intake for gain ratio.

However, high variation was observed in the *kg* values between experiments when this value was considered as constant (Figure 8.7), because variations in tissue deposition were ignored. Thus, the efficiency with which energy is retained in the body depends on the proportions of energy retained as protein and fat, emphasizing that energy deposition as fat is more efficient than that of protein (Owens et al., 1995).

As fat is the main form of energy reserve in an animal's body and presents a caloric value of 9.367 kcal/g (Blaxter and Rook, 1953), while protein presents 5.686 kcal/g (Garrett, 1958), the higher the percentage of protein in the gain, the lower will be its energetic concentration. From this principle, Tedeschi et al. (2004) proposed estimating the *kg* based on the percentages of energy retained as protein and on the partial efficiencies of fat and protein deposition:

$$Kg = (kfat \times kp) / [kp + (REp/100) \times (kfat - kp)]$$

Eq. 8.27

where *kg* = efficiency of the use of metabolizable energy for gain (%), *kfat* = efficiency of energy deposition as fat (%), *kp* = efficiency of energy deposition as protein (%) and REp = proportional energy retained as protein (%).

It is well-known that energy deposition as fat is more efficient than as protein; Tedeschi et al. (2004) found values of 20 and 75% for *kfat* and *kp*, respectively. The CSIRO (2007) recommends 45 and 75%, and Chizzotti et al. (2008) obtained 34 and 79% for *kfat* and *kp*, respectively.

Nevertheless, Marcondes et al. (2013) observed overestimation in *kg* values when using the above method and proposed estimating *kg* from the direct ratio with energy retained as protein (REp). For this, the authors obtained *kg* from the RE and metabolizable energy intake for gain (MEIg) for each one of the 25 studies and related the values found to several other variables (Figure 8.8).

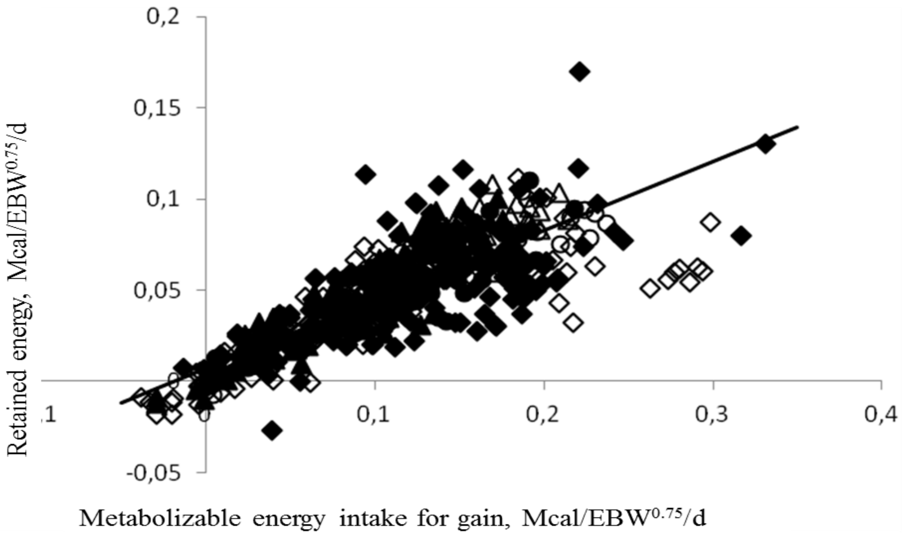

Figure 8.8 - Metabolizable energy intake for gain and retained energy ratio. Symbols represent data from bulls (▲, Δ), steers (◊,♦) and heifers (○, ●). Solid dots represent Zebu animals and empty dots represent crossbred beef cattle (adapted from Marcondes et al., 2010).

The authors observed that the REp was the best variable to explain *kg* and that this variable is important because it correlates the gain efficiency with the gain composition of the animals (Tedeschi et al., 2004; Chizzotti et al., 2008). Thus, the equation obtained by Marcondes et al. (2013) and recommended to estimate *kg* in the current edition is:

$$kg = 0.327 / (0.539 + REp) \quad \text{Eq. 8.28}$$

where *kg* = efficiency of use of the metabolizable energy for gain (%) and REp = proportion of the energy retained as protein.

However, applying this model depends on an accurate REp estimate. Tedeschi et al. (2004) and Chizzotti et al. (2008) proposed exponential models to estimate the REp, and the respective equations were:

$$REp = 0.0554 + 1.6939 \times e^{[-0.5573 \times (RE / EBG)]} \quad \text{Eq. 8.29}$$

$$REp = 10.1 + 166.7 \times e^{[-0.660 \times (RE / EBG)]} \quad \text{Eq. 8.30}$$

However, Marcondes et al. (2013) did not use the same model, because for any of the equations above, there would still be retention as protein even with RE equal to zero. Thus, the authors used a potential model to describe energy retention as protein and obtained the following equation:

$$REp = 1.140 \times (RE / EBG)^{-1.137} \quad \text{Eq. 8.31}$$

where REp = proportion of the energy retained as protein, RE = retained energy or net energy requirement for gain (Mcal/d) and EBG = empty body gain (kg/d).

The NRC (2000) adopted the principle of metabolizable energy concentration in the diet to estimate the net energy concentration for gain and the *kg* estimated by the [NEg] and [ME] ratio. Similarly, the AFRC (1993) considers the metabolizable energy and gross energy ratio to estimate the q_m and later the *kg*.

$$NEg = -1.65 + 1.42 \times ME - 0.174 \times ME^2 + 0.0122 \times ME^3 \quad \text{Eq. 8.32}$$

$$km = (0.78 \times q_m) + 0.006 \quad \text{Eq. 8.33}$$

where [ME] = metabolizable energy concentration in the diet (Mcal/kg DM), *km* = efficiency of the use of the metabolizable energy for maintenance, q_m = metabolizable energy and gross energy ratio in the diet.

Marcondes et al. (2013) did not obtain accurate *kg* predictions when they used only the metabolizable energy concentration in the diet, and they concluded that using variables that include characteristics related to the weight gain composition of the animals is indicated for *kg* estimate.

SUMMARY OF THE MODELS AND CALCULATION EXAMPLES

The following is a summary of the models described in this chapter.

Table 8.9 - Summary of the models to estimate energy requirements for animals on pasture

Item	Models
SBW (kg)	$0.8915 \times BW^{1.0151}$
EBW (kg)	$0.8507 \times SBW^{1.0002}$
EBG (kg/d)	$0.9630 \times ADG^{1.0151}$
EQEBW (kg)	(EBW / MEBW) × 517
NEm (Mcal/d)	$0.075 \times EBW^{0.75}$
NEg (or RE, Mcal/d)	$0.052 \times EQEBW^{0.75} \times EBG^{1.062}$
REp	$1.140 \times (RE / EBG)^{-1.137}$
kg	*kg* = 0.327 / (0.539 + REp)
km	[0.513 + (0.173 × *kg*) + (0.100 × EBG)] × 0.92
MEm (Mcal/d)	NEm / *km*
MEg (Mcal/d)	NEg / *kg*
MEt (Mcal/d)	MEm + MEg
DE (Mcal/d)	[((MEtotal / DMI) + 0.3032) / 0.9455] × DMI
TDN (kg/d)	DE / 4.4

Table 8.10 - Summary of the models to estimate energy requirements for animals in feedlot

Item	Models	
SBW (kg)	Zebu and Crossbred beef cattle: $0.8915 \times BW^{1.0151}$	
	Crossbred dairy cattle: $0.9247 \times BW^{1.0085}$	
EBW (kg)	Bulls	Zebu cattle: $0.8126 \times SBW^{1.0134}$
		Crossbred cattle: $0.7248 \times SBW^{1.0314}$
	Steers	Zebu cattle: $0.6241 \times SBW^{1.0608}$
		Crossbred cattle: $0.6586 \times SBW^{1.0499}$
	Heifers	Zebu cattle: $0.6110 \times SBW^{1.0667}$
		Crossbred cattle: $0.6314 \times SBW^{1.0602}$
EBG (kg/d)	$0.9630 \times ADG^{1.0151}$	
EQEBW (kg)	(EBW / MEBW) × 517	
NEm (Mcal/d)	$0.075 \times EBW^{0.75}$	
NEg (Mcal/d)	$0.061 \times EQEBW^{0.75} \times EBG^{1.035}$	
REp	$1.140 \times (RE / EBG)^{-1.137}$	
kg	*kg* = 0.327 / (0.539 + REp)	
km	Zebu: [0.513 + (0.173 × *kg*) + (0.100 × EBG)] × 1	
	Crossbred beef cattle: [0.513 + (0.173 × *kg*) + (0.073 × EBG)] × 1	
	Crossbred dairy cattle: [0.513 + (0.173 × *kg*) + (0.010 × EBG)] × 1	
MEm (Mcal/d)	NEm / *km*	
MEg (Mcal/d)	NEg / *kg*	
MEt (Mcal/d)	MEm + MEg	
DE (Mcal/d)	{[(MEtotal / DMI) + 0.3032] / 0.9455} × DMI	
TDN (kg/d)	DE / 4.4	

To illustrate the application of the models presented in this Chapter, an estimate of the energy requirements will be made for a Nellore bull with 520 kg body weight with ADG of 1.6 kg/d and in feedlot.

- $SBW = 0.8915 \times BW^{1.0151} \rightarrow 0.8915 \times 520^{1.0151} \rightarrow 509.5$ kg
- $EBW = 0.8126 \times SBW^{1.0134} \rightarrow 0.8126 \times 509.5^{1.0134} \rightarrow 450.1$ kg

- $EBG = 0.9630 \times ADG^{1.0151} \rightarrow 0.9630 \times 1.6^{1.0151} \rightarrow 1.5518$ kg/d
- $EQEBW = (EBW / 517) \times 517 \rightarrow (450.1 / 517) \times 517 \rightarrow 450.1$ kg
- $NEg = 0.061 \times EQEBW^{0.75} \times EBG^{1.035} \rightarrow 0.061 \times 450.1^{0.75} \times 1.5518^{1.035} \rightarrow 9.40$ Mcal/d
- $REp = 1.140 \times (RE / EBG)^{-1.137} \rightarrow 1.140 \times (9.40 / 1.5518)^{-1.137} \rightarrow 0.147$
- $kg = 0.327 / (0.539 + REp) \rightarrow 0.327 / [0.539 + 0.147] \rightarrow 0.48$
- $MEg = NEg / kg \rightarrow 9.40 / 0.48 \rightarrow 19.6$ Mcal/d
- $NEm = 0.075 \times EBW^{0.75} \rightarrow 0.075 \times 450.1^{0.75} \rightarrow 7.33$ Mcal/d
- $km = [(0.513 + 0.173 \times kg + 0.100 \times EBG) \times 1] \rightarrow [(0.513 + 0.173 \times 0.48 + 0.100 \times 1.5518) \times 1] \rightarrow 0.75$
- $MEm = NEm / km \rightarrow 7.33 / 0.75 \rightarrow 9.77$ Mcal/d
- $MEtotal = MEg + MEm \rightarrow 19.6 + 9.77 \rightarrow 29.4$ Mcal/d
- $DE = [((MEtotal / DMI) + 0.3032) / 0.9455] \times DMI \rightarrow [((29.4 / 10.87) + 0.3032) / 0.9455] \times 10.87 \rightarrow 34.7$ Mcal/d
- $TDN = DE / 4.4 \rightarrow 34.7 / 4.4 \rightarrow 7.88$ kg/d

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