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Energy requirement for maintenance and growth of Nellore bulls and steers fed high-forage diets¹

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ABSTRACT: Data from three comparative slaughter experiments with individually fed Nellore bulls (n = 31) and steers (n = 66) were utilized to determine their NE_m and NE_g requirements when fed high-forage diets. The experimental design provided ranges in ME intake, BW, and ADG for the development of regression equations to predict NE_m and NE_g requirements. The Nellore bulls (Trial 1) were divided into two intake levels (ad libitum and 65% of the ad libitum). The steers (Trials 2 and 3) were allocated to three intake levels (ad libitum and 55 and 70% of the ad libitum). In both trials, there were three slaughter groups within each intake level. The three end points for the bulls were different days on treatment (100, 150, and 190 d and 130, 180, and 200 d, respectively, for older and younger animal subgroups). The steers were slaughtered when animals of the ad libitum treatment reached 400, 440, and 480 kg shrunk BW (SBW) on average for the first, second, and third group, respectively. For all body composition determinations, whole empty body components were

weighed, ground, and subsampled for chemical analysis. In each of the trials, initial body composition was determined with equations developed from a baseline slaughter group, using SBW and empty BW (EBW), fat (EBF), and protein (EBP) as variables. The NE_m was similar for bulls and steers; NE_m averaged 77.2 kcal/kg^{0.75} EBW. However, the efficiency of conversion of ME to net energy for maintenance was greater for steers than for bulls (68.8 and 65.6%, respectively), indicating that bulls had a greater ME requirement for maintenance than steers (5.4%; $P < 0.05$). Our analyses do not support the NRC (2000) conclusion that Nellore, a *Bos indicus* breed, has a lower net energy requirement for maintenance than *Bos taurus* breeds. An equation developed with the pooled data to predict retained energy (RE) was similar to the NRC (2000) equation. A second equation was developed to predict RE adjusted for degree of maturity (u): $RE = (6.45 - 2.58/u) \times EWG \times e^{(0.469 \times u)}$, where u = current EBW/final EBW in which final EBW was 365 kg for steers and younger bulls and 456 kg for older bulls at 22% EBF, respectively.

Key Words: *Bos indicus*, Growth, Maintenance, Nellore, Net Energy Requirement

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Introduction

The NRC (2000) is commonly used around the world to formulate diets and to evaluate feeding programs in diverse conditions. However, equations were developed mostly with *Bos taurus* cattle, with a size scaling procedure used to adjust for differences in mature size. The NE_m requirement was assumed to be 10% lower for *Bos indicus* breeds, which included Africander, Barzona,

Brahman, and Sahiwal, based on several studies as reported by the NRC (2000). Other reports support a lower NE_m requirement for *Bos indicus* (Solis et al., 1988; Hotovy et al., 1991). These results suggest performance of *Bos indicus* is at least as good as that of *Bos taurus* cattle in a nutritionally restricted environment. In contrast, the data of Ledger (1977), Ledger and Sayers (1977), and Leal de Araújo et al. (1998a) indicated that the NE_m requirement of *Bos indicus* was about 5% higher than that of British breeds. The work of Ferrell and Jenkins (1998) also does not support the concept that the NE_m requirement is lower in *Bos indicus* than in *Bos taurus* crossbreds. Frisch and Vercoe (1977) reported that when previous weight gain was low, Brahman crossbreds had a lower NE_m requirement than *Bos taurus* crossbreds, but it was similar when previous weight gain was higher. Similarly, Boran crossbred

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steers, a *Bos indicus* breed, had a lower NE_m requirement when limit-fed than when they were fed a high-concentrate diet; however, the converse was observed for Brahman crossbred steers (Ferrell and Jenkins, 1998).

The Nellore breed predominates in beef production in Brazil, which has the largest commercial cattle population in the world (FAO, 2001). Therefore, accurate equations to predict their energy requirements play an important role in cattle production. The objective of this study was to use actual body composition data from serial slaughter studies with Nellore bulls and steers to determine their energy requirement for maintenance and growth.

Materials and Methods

Animal and Management Description

This study utilized data from three experiments with growing and finishing Nellore cattle, one with bulls ($n = 31$) and two with steers ($n = 66$), conducted at the Animal Research Center in Nova Odessa (São Paulo, Brazil). Humane animal care and handling procedures were followed. During the trial, animals were fed three times a day (0700, 1100, and 1600) in individual pens with free access to water. The experimental design provided ranges in ME intake, BW, and ADG for the development of regression equations to predict NE_m and NE_g requirements.

Trial 1. Two groups (1a and 1b) of Nellore bulls were used in this trial. They differed in initial shrunk BW (**SBW**) and age. Group 1a was composed of 15 bulls 21 to 24 mo of age (average initial SBW of 311 ± 7.4 kg), and group 1b included 16 bulls 9 to 12 mo of age (average initial SBW of 200 ± 3.7 kg). The baseline group was composed of seven randomly selected bulls (four from group 1a and three from group 1b) and the remaining bulls were randomly allocated to treatments within group. After weaning at 7 to 8 mo of age (weaning weight of 175 kg at 8 mo), all bulls were grazed on guinea grass (*Panicum maximum* Jacq.) until the beginning of the experiment. Two levels of intake (ad libitum and 65% of the ad libitum) were fed, and bulls were slaughtered in pairs within each level of intake and age group during the feeding period, as shown in Table 1. The three slaughter points were approximately at 100, 150, and 190 d on feed for group 1a and 130, 180, and 200 d on feed for group 1b. The diet DM was formulated to contain 12.5 to 13% of CP and consisted of 60% sorghum silage and 40% concentrates (Table 2).

Trial 2. Thirty-five Nellore steers 21 to 24 mo of age (average initial SBW of 327 ± 6.3 kg) were used in this experiment. The baseline group contained eight randomly selected steers, and the remaining steers were allocated to three levels of intake (ad libitum and 55 and 70% of the ad libitum) and three slaughter points as shown in Table 1. Prior to the beginning of the experiment, steers were kept in a feedlot during the dry sea-

son (8 to 13 mo of age and weaning weight of 170 kg at 7 mo) and on pastures of guinea grass (*Panicum maximum* Jacq.) during the wet season. The slaughter points were when steers in the ad libitum treatment reached 400, 440, and 480 kg of SBW on average for the first, second, and third group, respectively, within each intake level. The diet DM was formulated to contain 12.5% CP and consisted of 60% corn silage and 40% concentrates (Table 2). Additional information about this trial can be found in Leme et al. (1994).

Trial 3. Thirty-one steers similar to those of trial 2 were used in this experiment. The average initial SBW was 300 kg. Five randomly selected steers were used in the baseline group, and the remaining steers were distributed according to the design shown in Table 1. A diet similar to that of Trial 2, but with 50% sorghum rather than corn silage, was used (Table 2). Additional information about this trial can be found in Alleoni et al. (1997).

Diet Digestibility Determination

Trial 1. A digestion trial was conducted with six animals (18 to 20 mo) at two levels of intake above the maintenance requirement to determine diet DE. These animals were representative of those used in the comparative slaughter trials and were housed in individual stalls. Feeds (silage and concentrate), orts, feces, and urine were collected during 7 d after 14 d of adaptation. Feeds and orts were sampled daily and stored in a freezer. Feces and urine were weighed daily, and after complete mixing, a 10% and 5% sample of feces and urine, respectively, was collected and stored in a freezer. At the end of the digestibility trial, a subsample of a 7-d composite for each material (silage, concentrate, orts, feces, and urine) was used in the chemical analysis. Composites of feeds, orts, and feces were dried at 60 to 65°C and ground to pass 1-mm screen. Composites of urine were passed through glass wool to remove large particles and a subsample was taken for N determination. Gross energy was determined for silage, concentrate, feces, and orts using a Parr bomb calorimeter (Parr Instrument Co., Moline, IL). Digestible energy was computed from the GE of feeds, orts, and feces. The DE values were regressed on DMI (% of SBW) (r^2 of 0.61) of the animals in the digestibility trial (Table 2) to be used in the comparative slaughter trials to estimate DE content and intake. The DE of the digestible organic matter (**DOM**) was calculated to be 4.327 kcal/g DOM.

Trials 2 and 3. The digestion trial was conducted with three and two levels of intake for Trials 2 and 3, respectively, and had nine and six animals similar to those used in the comparative slaughter trials 2 and 3, respectively (Table 2). Similar to Trial 1, three animals (replicates) were used for each level of intake. The DE values were computed from the measurements of the DOM using the 4.327 kcal/g DOM relationship previously determined in Trial 1. Subsequently, linear re-

Table 1. Design and number of animals used in the initial slaughter (base line, BL) and in three slaughter periods (I, II, and III) of three trials (1, 2, and 3) with ad libitum and restricted feed intake at three levels

Trial ^b	Treatments and slaughter period ^a														Total
	BL	Restricted intake (% of the ad libitum)									Ad libitum (AL)				
		55% (REI2)			65% (REI1)			70% (REI1)			I	II	III		
		I	II	III	I	II	III	I	II	III					
1a	3	—	—	—	2	2	2	—	—	—	2	2	2	15	
1b	4	—	—	—	2	2	2	—	—	—	2	2	2	16	
2	8	3	3	3	—	—	—	3	3	3	3	3	3	35	
3	5	—	—	5	—	—	—	—	4	4	4	4	5	31	

^aThe slaughter points in Trial 1 were established by days on feed (100, 150, and 190 d for Trial 1a and 130, 180, and 200 d for Trial 1b); in Trials 2 and 3, the slaughter points were determined by when animals in each of the three slaughter groups fed the ad libitum treatment reached 400, 440, and 480 kg of BW, respectively. REI = restricted intake at two levels for steers and one level for bulls.

^bTrial 1a and 1b were Nellore bulls with 21 to 24 and 9 to 12 mo of age at the beginning of the trial, respectively, and Trials 2 and 3 were Nellore steers 21 to 24 mo of age at the beginning of the trials.

gressions between DE and DMI (%SBW) were derived (Table 2) to be used in the comparative slaughter trials to estimate DE content and intake.

Slaughter and Body Composition Techniques

Before slaughter, BW was taken 18 h after feed and water were withdrawn. At slaughter, steers were stunned with a captive bolt gun and killed by exsanguination using conventional humane procedures. Blood was weighed and sampled. The body was separated into individual components, which were then weighed separately. Included were internal organs (liver, heart, lungs and trachea, kidneys, and spleen), cleaned digestive tract (rumen, reticulum, omasum, abomasum, and small and large intestines), hide, head and tongue, feet, tail, and carcass. The digestive tract was cleaned by emptying and flushing with water, and then the intes-

nation using conventional humane procedures. Blood was weighed and sampled. The body was separated into individual components, which were then weighed separately. Included were internal organs (liver, heart, lungs and trachea, kidneys, and spleen), cleaned digestive tract (rumen, reticulum, omasum, abomasum, and small and large intestines), hide, head and tongue, feet, tail, and carcass. The digestive tract was cleaned by emptying and flushing with water, and then the intes-

Table 2. Ingredients (DM basis) and chemical composition (% of DM) of the diet for each trial and the equations developed to estimate DE from DMI

Item	Trial		
	1	2	3
Animals ^a	6	9	6
SBW, kg ^b	344 ± 11.9	354 ± 7.8	347 ± 7.6
Diet ingredients ^c			
Corn silage	—	59.0	—
Sorghum silage	58.5	—	48.4
Cracked corn grain	27.2	26.9	24.6
Cracked sorghum grain	—	—	6.7
Cottonseed meal	13.3	13.2	17.9
Urea	0.7	0.7	0.9
Ammonium sulfate	—	—	0.1
Limestone	0.3	0.3	0.6
Mineral supplement	—	—	0.7
Diet composition ^d			
CP, %DM	12.5 ± 0.05	12.3 ± 0.08	14.5 ± 0.05
EE, %DM	4.17 ± 0.05	3.39 ± 0.02	5.30 ± 0.09
Ash, %DM	5.13 ± 0.21	6.29 ± 0.01	5.20 ± 0.03
NDF, %DM	47.4 ± 1.83	51.2 ± 0.31	51.1 ± 0.45
DE, Mcal/kg DM	3.360 – 0.313 × DMI	3.430 – 0.319 × DMI	3.477 – 0.377 × DMI

^aNumber of animals used in the digestibility trials.

^bMean ± SE of shrunk BW (SBW) of the animals in the digestibility trials.

^cMineral supplements were offered ad libitum for experiments 1 and 2, and 25,000 UI/kg of vitamin A was used in experiment 3.

^dValues are means ± SE of the feed consumed per animal in each trial. EE = ether extract. DMI are % of shrunk BW.

tines were physically stripped. The carcass was split into two identical longitudinal halves. After a 24-h chill, the right half of the carcass was manually separated into bone and soft tissue, which was reduced to smaller pieces and ground through a mixer/grinder. A similar procedure was followed for the noncarcass tissues, bone, and hide. After fine grinding and individual homogenization, four composited samples (80 g each) were proportionally collected and freeze-dried (80 h) along with blood samples for dry matter determination. Then these samples were mixed together and ground again with dry ice and analyzed for fat (by loss in weight of the dry sample upon extraction with diethyl ether in Soxhlet extraction apparatuses for 10 h; AOAC, 1990), protein (nitrogen analysis via macro Kjeldahl using 1.5 g of sample; AOAC, 1990), and ash (complete combustion in a muffle furnace at 600°C for 16 h; AOAC, 1990).

Empty BW (**EBW**) was computed as the sum of the right and left halves of the warm carcass, hide, head, feet, tail, blood, and cleaned gastrointestinal and internal organs. Because the sum of fat, protein, water, and ash content of the empty body did not add up to the observed EBW (ranged from 99 to 105% of the EBW), the components were proportionally scaled to match the observed EBW.

Data Calculation and Analyses

Prediction of Diet ME. The dietary DE was estimated using regression equations developed from the digestion trial data shown in Table 2, and DE was converted to DE at maintenance level of intake (**DE_m**) using the ARC (1980) equation 3.1 (p 77). We assumed an efficiency of 80% to convert **DE_m** to ME at a maintenance level of intake (**ME_m**; ARC, 1980). To compute dietary ME at production levels, we added the amount of methane (Blaxter and Clapperton, 1965) and urinary losses (Blaxter et al., 1966) and subtracted the fecal energy losses (ARC, 1980; eq. 3.1, p 77) to estimate ME at the level of intake of each animal with an equation developed with the approach described by Blaxter (1969) (Eq. [1]). The DE intake for maintenance was computed as the intercept divided by the slope of the linear regression of retained energy (**RE**, kcal/kg^{0.75} EBW) (Y-variate) on DE intake (kcal/kg^{0.75} EBW) (X-variate) for each trial, then the level of intake above maintenance (L) was calculated by dividing the actual DE intake by the DE intake for maintenance.

$$ME = 0.1234 \times GE \times (1 - L) + DE_m \times (0.637 + 0.163 \times L) \quad [1]$$

where ME is Mcal/d; GE is 4.26 Mcal/d; L is the ratio of actual DE intake to the DE intake for maintenance, and **DE_m** is digestible energy at maintenance requirement intake, Mcal/d.

Calculation of Initial Body Composition. The procedures used to compute energy retained and maintenance energy requirement were similar to those of Lof-

green and Garrett (1968), except we used a regression equation developed from the baseline animals to determine initial composition of the EBW and SBW rather than using their mean BW and body composition. The equations are shown in Table 3. The initial EBW is computed from SBW using the appropriate equation, and then initial empty body fat (**EBF**) and protein (**EBP**) are estimated from EBW for each animal.

Energy Partition. Empty body gains of body components were calculated as the difference between initial and final weights of the respective body components. The caloric values of retained fat and protein were assumed to be 9.367 and 5.686 Mcal/kg, respectively (Lofgreen, 1965).

Heat production (**HP**, kcal/kg^{0.75} EBW) was calculated as the difference between ME intake (**MEI**, kcal/kg^{0.75} EBW) and RE (kcal/kg^{0.75} EBW). The average of the antilog of the intercept confidence interval (95%) of the linear regression between the log of heat production and MEI was used to estimate the requirement for **NE_m** (kcal/kg^{0.75} EBW) (Lofgreen and Garrett, 1968). The ME required for maintenance was calculated by iteration, assuming that the maintenance requirement is the value at which HP is equal to MEI (kcal/kg^{0.75} EBW).

Linear regressions (Lofgreen and Garrett, 1968) of the log of HP on MEI ($Y = a_1 + b_1 \times X$) were used to calculate energy utilization for maintenance (**k_m**). The intercept and slope were tested for sex effect (steers vs bulls). The slope of the regression of RE on MEI was assumed to be the efficiency of energy utilization for growth (**k_g**). Additionally, an exponential regression ($Y = a_2 \times \exp(b_2 \times X)$) was used to describe the relationship between HP or RE and MEI, and the **NE_m** computed with this exponential regression (**a₂**) was compared with that obtained from the linear regression of the log of HP on MEI (antilog(**a₁**)).

Statistical Analysis

Statistical analyses were performed using SAS (SAS Inst. Inc., Cary, NC). The linear regression analyses of initial body weight were computed with PROC REG for each trial. The analysis of DMI, DE and ME intake was performed by PROC GLM by sex and assuming a factorial design of treatment (intake levels) and trials. The analysis of treatment effect was performed by the MIXED procedure with the REML (restricted maximum likelihood) method by sex and slaughter period. In this analysis, treatments were considered fixed factors and trials as random factors. The least squares means method was used in the multiple comparison analysis. The relationship between body composition, ADG, and EBW was determined with the PROC MIXED and the SOLUTION statement. In this analysis, trials were considered random effects and EBW, treatments, and their interaction were investigated. The PROC REG was used in both simple and multiple linear regressions, and the procedure NLIN was used in the nonlinear parameterization of the variables using the Gauss-

Table 3. Relationship between body weight and body composition of animals in the initial slaughter^a

Trial	Equation	r ²	SEM	n
1a				
EBW, kg	25.1 ± 5.08 + 0.805 ± 0.0165 × SBW	0.99	0.43	3
EBF, kg	3.96 ± 19.6 + 0.111 ± 0.0720 × EBW	0.70	1.52	3
EBP, kg	2.20 ± 25.1 + 0.177 ± 0.0923 × EBW	0.79	1.94	3
1b				
EBW, kg	14.7 ± 2.09 + 0.819 ± 0.0102 × SBW	0.99	0.18	4
EBF, kg	6.29 ± 5.86 + 0.075 ± 0.0321 × EBW	0.73	0.47	4
EBP, kg	-3.48 ± 7.53 + 0.205 ± 0.0413 × EBW	0.92	0.61	4
2				
EBW, kg	1.33 ± 13.7 + 0.879 ± 0.0434 × SBW	0.99	1.45	8
EBF, kg	-13.1 ± 10.6 + 0.18 ± 0.0380 × EBW	0.79	1.12	8
EBP, kg	3.05 ± 7.94 + 0.174 ± 0.0286 × EBW	0.86	0.84	8
3				
EBW, kg	0.199 ± 12.9 + 0.878 ± 0.0427 × SBW	0.99	1.74	5
EBF, kg	-1.14 ± 11.8 + 0.133 ± 0.0445 × EBW	0.75	1.60	5
EBP, kg	-2.58 ± 6.05 + 0.199 ± 0.0227 × EBW	0.96	0.81	5

^aEBW = empty BW, SBW = shrunk BW, EBF = empty body fat, and EBP = empty body protein.

Newton method for convergence. The r^2 of the nonlinear regression was obtained via a linear regression of the predicted values by PROC NLIN on the dependent variate. In order to compare the parameters between classes, we used the qualitative indicator approach (Neter et al., 1996, chap. 11), which consists of adding binary (0 or 1) indicator variables for each class. The comparison of intercept and slope among trials and sexes was done by the PROC GLM procedure using the SOLUTION statement and the sum of squares type 3 (SS3) was evaluated. The interaction and/or the main effect were removed from the statistical model if not significant at $P < 0.05$.

Outliers and systematic bias were identified using the plot of studentized residue against the predicted values (X-variable). Additionally, leverage analysis and Cook's D influence statistic (SAS Inst. Inc., Cary, NC) were used to investigate outliers. Data points with a studentized statistical residue outside the range -2.5 and 2.5 were considered to be outliers and were removed from the dataset. The plot of the studentized residue against predicted values, trials, and independent variables (not shown) was analyzed to test the statistical assumptions (Kuehl, 2000).

Because animals were selected for homogeneity for the experiments, and the animals were individually fed, each animal was considered to be an experimental unit. The data were pooled across ages for Trials 1a and 1b when there was no significant effect ($P > 0.10$) of age. Similarly, data from Trials 2 and 3 were combined to evaluate the effect of castration (sex effect) when trial effect (2 and 3) was not significant ($P > 0.10$).

Results and Discussion

Prediction of Diet ME. The efficiencies of dietary DE to ME were 80.8 to 82.1% with a mean of 81.4% in Trial

1, 80.4 to 82.1% with a mean of 81.1% in Trial 2, and 80.9 to 82% with a mean of 81.6% in Trial 3. These values are within the range of reported values for beef cattle (81% by Cammell et al., 1993 and 82% by Lofgreen and Garrett, 1968). However, the use of fixed values may under- or overestimate dietary ME, depending on the level of intake of DM. When intake increases, the loss of energy due to fecal excretion tends to increase due to a faster ruminal turnover, decreasing the ruminal degradation of digestible fiber, which in turn yields less DE (ARC, 1980). Additionally, the fecal loss is greater for low-quality forages than for those of high quality. The loss of methane is variable, depending on the profile of VFA production (Van Soest, 1994); the metabolizability of VFA changes, depending on their profile in the rumen (Moe, 1981). The NRC (2000) assumes that these variables offset each other in accounting for ME and uses a constant of 82% to convert DE to ME.

Performance, Body and Gain Composition. Table 4 shows the mean body composition for the animals in each treatment group as computed from the baseline animals. The initial SBW was similar for all trials, except for the younger bulls (1b). Steers tended to have more fat (%EBW) than bulls, but overall the initial compositions were very similar. Five animals from the REI2 of Trial 2 were removed from our analyses because they lost weight during the trial.

The analysis of DMI ($\text{g/kg}^{0.75}$ SBW), DE intake (DEI, $\text{kcal/kg}^{0.75}$ SBW), and MEI for each of the treatment groups for bulls (Trial 1) indicated that there was no interaction between trial and treatment effects ($P > 0.05$) and there was no trial effect ($P > 0.05$); therefore, we pooled the data across trials (1a and 1b). As expected, DMI (kg/d and $\text{g/kg}^{0.75}/\text{d}$), DEI, and MEI (Mcal/d and $\text{kcal/kg}^{0.75}/\text{d}$) were greater for both bulls and steers in the ad libitum treatment than for those in the

Table 4. Initial body composition of Nellore bulls and steers for each trial^a

Variable	Bulls		Steers	
	1a	1b	2	3
n	3	4	8	5
SBW, kg	306 ± 18.5	204 ± 10.4	313 ± 12.6	300 ± 20.4
EBW, kg	271 ± 14.9	182 ± 8.5	276 ± 11.2	264 ± 17.9
HCW, kg	171 ± 10.4	115 ± 5.4	178 ± 7.5	170 ± 11.6
Fat, %EBW	12.6 ± 0.4	11.0 ± 0.3	13.3 ± 0.4	12.9 ± 0.5
Protein, %EBW	18.5 ± 0.5	18.6 ± 0.3	18.5 ± 0.4	18.8 ± 0.2
Water, %EBW	64.0 ± 0.4	65.9 ± 0.4	63.6 ± 0.3	63.4 ± 0.4
Ash, %EBW	4.83 ± 0.23	4.56 ± 0.01	4.59 ± 0.10	4.91 ± 0.13

^aValues are mean and SE by sex and trial. SBW = shrunk BW, EBW = empty BW, and HCW = hot carcass weight.

restricted treatments ($P < 0.05$). Because the mean DMI of Trial 3 was greater than that of Trial 2, DEI and MEI was greater for Trial 3 than for Trial 2 ($P < 0.05$) and no interaction was observed between treatments and trials ($P > 0.05$). The growth performance, body composition, and energy balance data are shown in Table 5 for bulls and in Table 6 for steers. Bulls and steers in the ad libitum treatment had greater empty weight gain (EWG), ADG, RE, and HP ($P < 0.05$), indicating that HP increased as MEI increased.

The equations to predict fat in gain (**FIG**, kg/d, Eq. [2], $R^2 = 0.997$, RMSE = 0.009, $n = 70$) and protein in gain (**PIG**, kg/d, Eq. [3], $R^2 = 0.914$, RMSE = 0.014, $n = 70$) are shown below. The intercepts (Eq. [2] and [3])

and the coefficient of concentration of RE (**REc**, Mcal/kg) are not different from zero ($P > 0.05$). There was no effect of sex ($P > 0.05$) in the slope coefficients. Figure 1 shows the residual plot of FIG and PIG values with those predicted with Eq. [2] and [3], respectively.

$$\text{FIG}_{(\text{kg/d})} = (0.0122 \pm 0.0102 + c_1) - 0.00131 \pm 0.0205 \times \text{REc} - 0.159 \pm 0.0153 \times \text{EWG} + 0.1203 \pm 0.00304 \times \text{REc} \times \text{EWG} \quad [2]$$

$$\text{PIG}_{(\text{kg/d})} = (-0.00837 \pm 0.00478 + c_2) - 0.183 \pm 0.02 \times \text{FIG}_{\text{kg/d}} + 0.232 \pm 0.011 \times \text{EWG} \quad [3]$$

Table 5. Effect of stage of growth on body composition and energy balance of Nellore bulls^a

Variable	Slaughter period and treatment (Trt)									Regression of variables on EBW and Trt ^b	
	1			2			3			EBW	Trt
	AL	REI	SEM	AL	REI	SEM	AL	REI	SEM		
N	4	4	—	4	4	—	4	4	—	—	—
DOF	120	120	—	168	168	—	195	195	—	—	—
SBW, kg	383 ^c	308 ^d	27.3	402 ^c	323 ^d	20.3	420 ^c	316 ^d	9.7	***	—
EBW, kg	343 ^c	277 ^d	19.9	365 ^c	288 ^d	17.3	386 ^c	284 ^d	10.0	—	—
EWG, g/d	863 ^c	371 ^d	63.6	838 ^c	315 ^d	40.8	1,028 ^c	524 ^d	118.4	***	***
ADG, g/d	977 ^c	395 ^d	80.5	920 ^c	410 ^d	68.3	866 ^c	335 ^d	41.8	***	***
HCW, kg	220 ^c	179 ^d	11.2	236 ^c	184 ^d	12.9	253 ^c	183 ^d	8.2	***	—
Fat, %EBW	15.5	13.5	1.87	17.7 ^c	13.5 ^d	1.65	19.3 ^c	15.4 ^d	1.28	***	—
Protein, %EBW	18.5	18.6	0.560	18.6	19.0	0.399	18.2	18.8	0.385	*	—
Water, %EBW	61.9	63.2	1.49	59.3 ^d	62.9 ^c	1.26	58.3 ^d	61.1 ^c	0.92	***	—
Ash, %EBW	4.51	4.63	0.250	4.38	4.67	0.364	4.29 ^d	4.66 ^c	0.093	—	*
FIG, %EWG	25.1	21.4	8.97	26.7	20.5	7.07	29.5	28.8	3.62	**	—
PIG, %EWG	18.2	19.5	2.62	18.6	20.6	1.61	17.6	19.5	1.21	**	—
DMI, kg/d	6.74 ^c	3.88 ^d	0.378	6.76 ^c	3.97 ^d	0.330	6.76 ^c	3.95 ^d	0.331	***	***
DMI, g/kg ^{0.75} EBW	96.4 ^c	61.4 ^d	2.65	96.0 ^c	62.1 ^d	1.30	93.3 ^c	62.3 ^d	3.25	—	***
MEI, kcal/kg ^{0.75} EBW	213 ^c	145 ^d	5.49	212 ^c	147 ^d	3.03	208 ^c	147 ^d	5.82	**	***
RE, kcal/kg ^{0.75} EBW	43.9 ^c	19.4 ^d	6.79	43.6 ^c	17.8 ^d	3.53	43.3 ^c	18.9 ^d	2.04	**	***
HP, kcal/kg ^{0.75} EBW	169 ^c	126 ^d	5.61	169 ^c	129 ^d	4.44	165 ^c	128 ^d	5.90	—	***

^aREI = restricted intake (65% of the AL), AL = ad libitum intake, DOF = days on feed, SBW = shrunk BW, EBW = empty BW, EWG = empty weight gain, SWG = shrunk weight gain, HCW = hot carcass weight, FIG = fat in gain, PIG = protein in gain, MEI = ME intake, RE = retained energy, and HP = heat produced.

^bLinear regression between a variable on EBW, treatment, and its interaction. *** $P < 0.001$. ** $P < 0.01$, and * $P < 0.05$. No interaction was found ($P > 0.05$).

^{c,d}Distinct letters in the same row, within slaughter period, differ at $P < 0.05$ by least square means.

Table 6. Effect of stage of growth on body composition and energy balance of Nellore steers^a

Variable	Slaughter period and treatment (Trt)												Regression of variables on EBW and Trt ^b			
	1				2				3				EBW	Trt	EBW × Trt	
	AL	REI1	SEM	AL	REI1	REI2	SEM	AL	REI1	REI2	SEM					
n	7	3	—	7	7	3	—	8	7	6	—	—	—	—	—	—
DOF	81	73	—	124	128	136	—	176	183	190	—	—	—	—	—	—
SBW, kg	398	369	36.3	418 ^c	376 ^d	353 ^d	22.5	472 ^c	426 ^d	390 ^d	18.2	***	—	—	—	—
EBDW, kg	358	329	31.2	373 ^c	332 ^d	309 ^d	20.3	431 ^c	381 ^d	351 ^d	15.8	—	—	—	—	—
EWG, g/d	1,028 ^c	524 ^d	118	875 ^c	562 ^d	329 ^e	94	805 ^c	528 ^d	288 ^e	39	—	—	—	—	—
ACDG, g/d	1,061 ^c	537 ^d	172	949 ^c	631 ^d	364 ^e	110	819 ^c	562 ^d	291 ^e	52	—	—	—	—	—
HCW, kg	235	220	21.4	244 ^c	218 ^{cd}	207 ^d	14.6	288 ^c	254 ^{cd}	234 ^d	12.5	***	***	***	***	***
Fat, %EBW	22.5 ^c	17.2 ^d	1.36	24.7 ^c	19.1 ^d	17.6 ^d	1.55	27.0 ^c	21.0 ^d	19.0 ^d	1.61	—	—	—	—	—
Protein, %EBW	17.5 ^d	18.3 ^c	0.335	16.9 ^d	17.9 ^{cd}	18.1 ^c	0.418	17.1 ^d	17.6 ^{cd}	18.4 ^c	0.515	—	—	—	—	—
Water, %EBW	56.0 ^d	60.2 ^c	1.05	54.6 ^d	58.7 ^c	59.2 ^c	1.20	52.0 ^d	57.1 ^c	58.2 ^c	1.56	—	—	—	—	—
Ash, %EBW	4.02	4.53	0.301	3.87 ^d	4.25 ^d	5.21 ^c	0.283	3.90	4.35	4.49	0.319	*	*	*	*	*
FIG, %EWG	56.5	48.9	11.9	54.5	41.8	58.2	8.5	55.8	45.2	49.1	6.0	—	—	—	—	—
PIG, %EWG	11.8	11.5	2.50	11.6	14.4	10.6	2.13	13.0	13.5	16.4	1.94	—	—	—	—	—
DML, kg/d	8.60 ^c	5.36 ^d	0.782	8.43 ^c	5.58 ^d	4.39 ^e	0.493	8.90 ^c	6.02 ^d	4.56 ^e	0.357	—	—	—	—	—
DML, g/kg ^{0.75} EBW	114 ^e	78 ^d	5.13	112 ^c	78 ^d	64 ^e	3.80	108 ^c	77 ^d	59 ^e	3.13	—	—	—	—	—
MEI, kcal/kg ^{0.75} EBW	243 ^c	174 ^d	9.94	239 ^c	182 ^d	148 ^e	5.70	234 ^c	182 ^d	147 ^e	4.40	—	—	—	—	—
RE, kcal/kg ^{0.75} EBW	80.7 ^c	34.8 ^d	9.21	66.0 ^c	37.0 ^d	26.0 ^d	6.36	58.4 ^c	33.5 ^d	20.3 ^e	4.64	—	—	—	—	—
HP, kcal/kg ^{0.75} EBW	162	140	9.80	173 ^c	146 ^d	119 ^e	6.09	176 ^c	149 ^d	127 ^e	3.50	—	—	—	—	—

^aREI = restricted intake (65% of the AL), AL = ad libitum intake, DOF = days on feed, SBW = shrunk BW, EBW = empty BW, EWG = empty weight gain, SWG = shrunk weight gain, HCW = hot carcass weight, FIG = fat in gain, PIG = protein in gain, MEI = ME intake, RE = retained energy, and HP = heat produced.
^bLinear regression between a variable on EBW, treatment, and its interaction. ****P* < 0.001, ***P* < 0.01, **P* < 0.05.
^{c,d,e}Distinct letters in the same row, within slaughter period, differ at *P* < 0.05 by least square means.

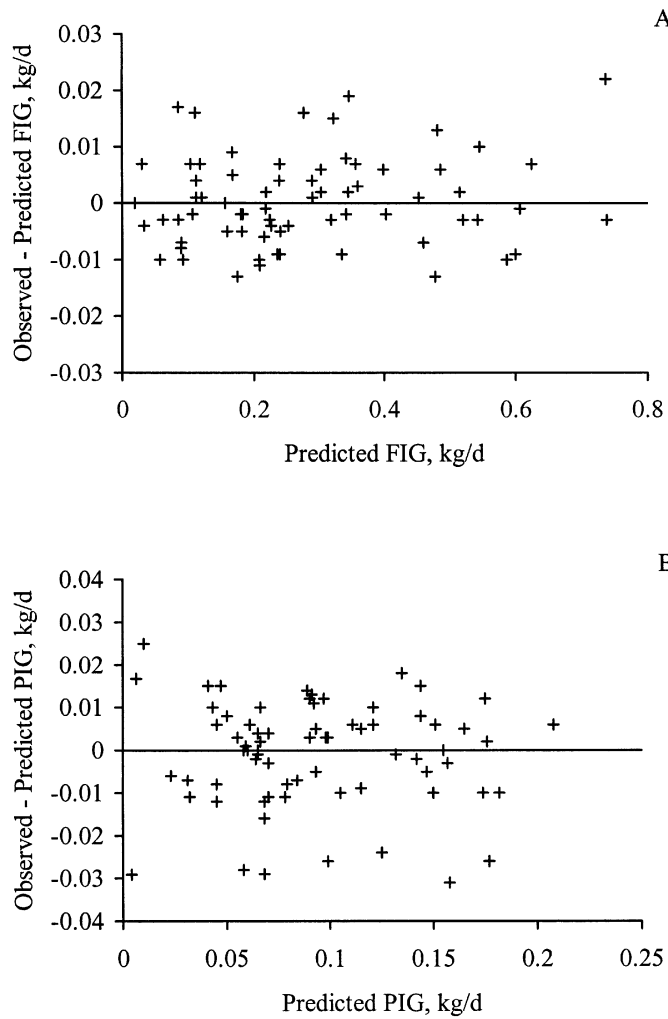


Figure 1. Plot of residual (observed minus predicted) vs predicted values for (A) fat in gain (FIG) and (B) protein in gain (PIG) for Nellore bulls and steers.

where FIG is fat in gain (kg/d), REc is concentration of retained energy (Mcal/kg EWG), EWG is empty weight gain (kg/d), and PIG is protein in gain (kg/d). For bulls, the values of c_1 and c_2 are -0.00859 ± 0.00327 and 0.00941 ± 0.00472 , respectively; for steers, they are zero.

Equations to predict percentage of FIG (Eq. [4], $R^2 = 0.99$, RMSE = 1.7, and $n = 70$) and percentage of PIG (Eq. [5], $R^2 = 0.99$, RMSE = 0.005, and $n = 70$) from RE concentration are shown below. The intercept of Eq. [5] is not different from zero ($P < 0.05$).

$$\text{FIG}_{(\%)} = 11.5 \pm 0.189 \times \text{REc} - 12.4 \pm 1.056 + c_3 \quad [4]$$

$$\text{PIG}_{(\%)} = 17.6 \pm 0.0039 \times \text{REc} - 1.65 \pm 0.0003 \times \text{FIG}_{(\%)} + 0.00859 \pm 0.0054 \quad [5]$$

where FIG is fat in gain (% of EWG), REc is retained energy (Mcal/kg EWG), and PIG is protein in gain (% of EWG).

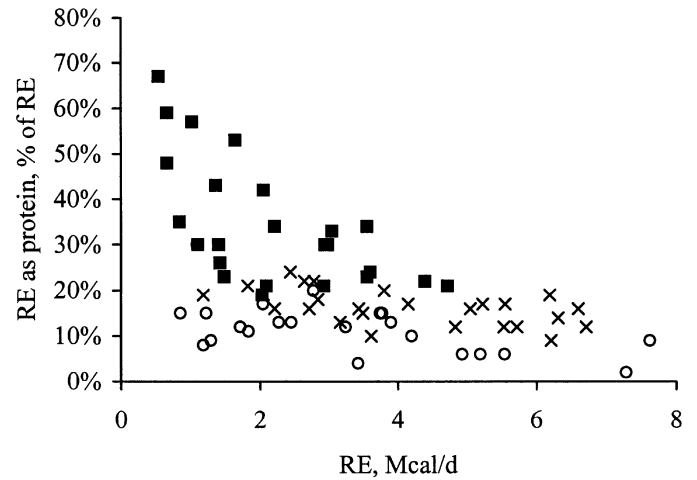


Figure 2. Percentage of energy retained as protein (REp) plotted against retained energy (RE) for bulls (■) and steers (Trial 2, ○; Trial 3, ×).

of EWG). For bulls, the value for c_3 is -2.156 ± 0.567 ; for steers, c_3 is zero.

The equations developed by Garrett (1987) were $\text{FIG, \%} = 12.2 \times \text{REc} - 14.6$ and $\text{PIG, \%} = 24.8 - 2.64 \times \text{REc}$. Equation [4] is very similar to that derived by Garrett (1987) to predict FIG from REc (Mcal/kg); however, Eq. [5] differs from that of Garrett (1987) because FIG and REc were used in our equation as predictors of PIG, whereas in Garrett's (1987) approach only REc was used. Figure 2 shows that, in bulls, the percentage of RE deposited as protein (REp) was higher at lower RE deposition. This agrees with the findings of Geay (1984) in which REp was greater for bulls than for heifers (steers in our case) and REp decreased linearly with RE deposition. In our dataset, the mean EWG was 0.79 kg/d for Trial 3, which tended to have a greater REp than Trial 2, in which EWG was 0.46 kg/d.

Equation [2] indicates that there is an interaction between EWG and REc in prediction of FIG, which is related to the percentage of RE deposited as fat (REf). The equations developed to estimate REf (Eq. [6]) and REp (Eq. [7]) indicated that the maximum value for RE as fat was 84.4% and the minimum value for RE as protein was 14.9%, respectively. These values are similar to those suggested by W. N. Garrett (93.7 and 16.9%, respectively; CSIRO, 1990, p 42).

$$\text{REf} = 0.844 \times (1 - e^{(-1.541 \times \text{RE})}) \quad [6]$$

$$\text{REp} = 0.149 \times (1 + 1.093 \times \text{RE}^{-1.891}) \quad [7]$$

where RE is retained energy (Mcal/d) and REf and REp are RE as fat and as protein, respectively.

Energy Requirement for Maintenance. The intercept and the slope of the regression of log of the HP on the MEI as well as NE_m requirement are shown in Table

Table 7. Regression of logarithm of heat production on ME intake to describe energy utilization by Nellore bulls and steers^a

Trial	Intercept	Slope (×100)	n	r ²	RMSE	NE _m	ME _m	k _m , %	k _g , %
By trial									
1a	1.84 ± 0.025 ^b	0.180 ± 0.014 ^b	12	0.95	0.016	69.2	107	64.7	38.8
1b	1.84 ± 0.033 ^b	0.185 ± 0.019 ^b	12	0.91	0.020	70.1	111	63.3	36.7
2	1.92 ± 0.041 ^b	0.128 ± 0.021 ^c	22	0.65	0.035	85.1	118	71.9	57.0
3	1.89 ± 0.025 ^b	0.141 ± 0.011 ^c	26	0.87	0.022	79.3	114	69.5	50.0
By sex									
Bull	1.84 ± 0.021 ^b	0.181 ± 0.011 ^b	24	0.92	0.019	69.8	110	63.7	38.5
Steer	1.91 ± 0.022 ^b	0.136 ± 0.010 ^c	48	0.79	0.028	81.2	116	69.9	52.7
By sex with a common intercept									
Bull	1.89 ± 0.016	0.157 ± 0.009 ^b	24	0.83	0.026	77.2	118	65.6	45.9
Steer	1.88 ± 0.016	0.146 ± 0.008 ^c	48	0.83	0.026	77.2	112	68.8	49.7

^aValues are mean ± SE. RMSE = root of the mean square error, NE_m = net energy for maintenance (kcal/kg^{0.75} empty BW) calculated as the antilog of the intercept, ME_m = ME for maintenance (kcal/kg^{0.75} empty BW), which was calculated by iteration assuming heat produced is equal to ME intake at maintenance, and k_m (efficiency of use of ME for NE_m) was calculated as NE_m × 100/ME_m and k_g (efficiency of use of ME for RE) is calculated as the slope of the regression of RE × 100 (kcal/kg^{0.75} empty BW) on ME intake (kcal/kg^{0.75} empty BW).

^{b,c}Different letters in the same column within a class differ at *P* < 0.05.

7. There was no difference in the NE_m between older (Trial 1a) and younger (Trial 1b) bulls (69.2 and 70.1 kcal/kg^{0.75} EBW, respectively). The NE_m of steers from Trial 2 was greater than those from Trial 3 (85.1 and 79.3 kcal/kg^{0.75} EBW, respectively); the value in Trial 2 was similar to that found by Ferrell and Jenkins (1998) for Brahman (82.8). Because differences in the slope and intercepts of the log HP vs MEI regression equations were nonsignificant for age groups within the bull trial and the steer trials, data were pooled to examine the effect of sex. Using the pooled steer data, bulls had a 14% lower NE_m requirement than steers (69.8 and 81.2, respectively), but this difference was not statistically different (*P* > 0.06). Further statistical analysis indicated that the intercepts for sex effect (bull vs steer) of the pooled data did not differ (*P* > 0.05); therefore, equations were developed assuming a common intercept.

The analysis of the pooled intercepts resulted in a common requirement for NE_m of 77.2 kcal/kg^{0.75} EBW, which is nearly identical to the NE_m of 77 reported by Lofgreen and Garrett (1968), the value used by the NRC (1984, 2000). Values reported by Ferrell and Jenkins (1998) for NE_m for steers of *Bos indicus* crossbreds varied from 64.5 (Boran) to 82.8 (Brahman), and averaged 74.5, which agrees with our results.

However, because the slopes were different, the ME_m for maintenance of bulls was 5.4% greater than that for steers (118 and 112 kcal/kg^{0.75} EBW, respectively) (Table 7), which is partially supported by ARC (1980) and CSIRO (1990), which recommended increasing the ME_m for bulls by 15%.

The k_m value (Table 7) was greater (*P* < 0.05) for steers than for bulls (69.9 and 63.7%, respectively), as was the k_g value (52.7 and 38.5% for steers and bulls, respectively). Similar values of k_m (62%) but a lower k_g (34%) were found by Leal de Araújo (1998b) using

Holstein and *Bos indicus* crossbred calves fed diets with varied forage content. These findings (lower k_m and k_g of bulls compared to steers) may be related to body composition, compensatory gain, and composition of the gain.

An alternative method for estimating the requirement of NE_m is to use an exponential relationship between HP and MEI. A nonlinear analysis of the data (Figure 3) showed no difference in the NE_m requirement between bulls and steers (*P* > 0.05), but the relationship between MEI and HP was different (*P* < 0.05). Using the exponential technique, the NE_m was 78.2 kcal/kg^{0.75} EBW for bulls and steers, but the ME_m was 119 and 113

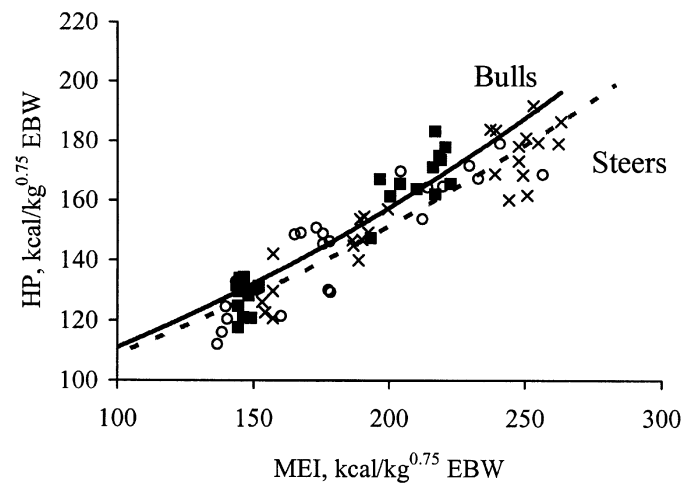


Figure 3. Exponential relationship between heat production (HP) and ME intake (MEI) for bulls (HP = 78.2 × e^(0.0035 × MEI), solid line) and steers (HP = 78.2 × e^(0.0033 × MEI), dashed line). Symbols are data from bulls (■) and from steers (Trial 2, ○; and Trial 3, ×).

Table 8. Coefficients for the standard nonlinear equation to predict retained energy from empty weight gain and empty BW for Nellore bulls and steers

Group	Coefficient ^a		R ²	SEM ^b	n
	a	b			
Steers	0.0726	1.020	0.87	0.089	48
Bulls	0.0485	0.886	0.90	0.076	24
Steers and bulls	0.0661	1.005	0.80	0.084	72
NRC (2000)	0.0635	1.097	0.87	0.292	

^aNonlinear equation: $RE = a \times EWG^b \times EqEBW^{0.75}$, where RE = retained energy (Mcal/d), EWG = empty weight gain (kg/d), and EqEBW = equivalent empty BW (kg).

^bSEM = standard error of the mean of the regressions.

kcal/kg^{0.75} EBW with an efficiency of 63.9 and 67.3%, respectively, for bulls and steers, which is in agreement with the values listed in Table 7, suggesting that either technique is adequate.

Teixeira et al. (1987) reported similar NE_m requirements for Holstein \times Nellore crossbred and Holstein calves (83 and 88 kcal/kg^{0.75} SBW, respectively). Similar requirements were reported by Leal de Araújo et al. (1998a) for Nellore and Holstein crossbred calves (81.3 kcal/kg^{0.75} EBW). In contrast, Gonçalves et al. (1991) reported a greater NE_m requirement for Nellore than Holstein (79 and 75 kcal/kg^{0.75} SBW, respectively), and even greater values for crossbreds of these two breeds (111 kcal/kg^{0.75} SBW).

In a grazing trial with crossbreds of $\frac{3}{4}$ Nellore \times $\frac{1}{4}$ Holstein steers, Martin and Garcia (1995) reported ME_m and NE_m requirements of 124 and 90 kcal/kg^{0.75} EBW, respectively, which are 10.7 and 16.6% greater than our values (112 and 77.2 kcal/kg^{0.75} EBW, Table 7), which is likely due to their higher efficiency of ME to NE_m (72.6%) and energy requirement for physical activity.

Predicting NE_g . Equation [8] shows the form of the equation used by the NRC (2000) to predict RE (Mcal/d) from EWG (kg/d) and EBW (kg), which is used to compute the NE_g (Mcal/d). The NRC (2000) introduced the concept of the equivalent EBW, which is the weight of a medium-frame-size steer used to develop the RE equation used by the NRC (1984). This weight is known as standard reference weight (**SRW**). A simulation similar to that modeled by the NRC (2000) to compute SRW at any given body composition indicated that 22% of EBF would be reached at EBW of 372 kg. The final EBW (**FEBW**) is the actual weight at the same body fat end point of the SRW. Table 8 has the coefficients (*a* and *b*) of Eq. [8] for steers, bulls, pooled steers and bulls, and for the equation used by the NRC (2000).

$$RE = a \times EWG^b \times \left(\frac{EBW \times SRW}{FEBW} \right)^{0.75} \quad [8]$$

where RE is retained energy (Mcal/d), EWG is empty weight gain (kg/d), EBW is empty body weight (kg), SRW is standard reference weight (kg), and FEBW is final empty body weight (kg).

Equation [9] ($r^2 = 0.89$, SEM = 0.047, and $n = 72$) was devised using a maturity degree coefficient (**u**) to adjust for variation in body weight at a specific body composition. The factor *u* is actual EBW divided by the FEBW at 22% EBF. The FEBW was predicted to be 365 kg for steers and younger bulls and 456 kg for older bulls, which were individually obtained by regressing EBF on EBW of the dataset ($r^2 = 0.76$, SEM = 3.77, and $n = 92$; not shown). The values of *u* ranged from 0.49 to 0.83 for bulls and 0.7 to 1.1 for steers; Eq. [9] should be used with caution outside these ranges. The difference in FEBW for older (trial 1a) and younger (1b) bulls suggested an effect of plane of nutrition and age on body composition, which is in agreement with Coleman et al. (1993), who using allometric regression found that younger animals deposited body fat more rapidly than older ones.

$$RE = \left(6.45 - \frac{2.58}{u} \right) \times EWG \times e^{(0.469 \times u)} \quad [9]$$

where RE is retained energy (Mcal/d), *u* is degree of maturity, and EWG is empty weight gain (kg/d).

The form of Eq. [9] resembles an equation developed by Tedeschi (2001) when regressing retained energy and maturity degree from 113 pen means with more than 1,500 Hereford steers and heifers.

Figure 4 shows the comparison of Eq. [8] and [9] to predict retained energy for steers and bulls. Both equations had similar r^2 and standard errors, but the NRC (2000) equation (Eq. [8] and Table 8) underpredicted RE and had a mean bias of 6.8%, whereas the mean bias of Eq. [9] was -0.3% . Despite the underprediction, the NRC (2000) equation had a reasonable agreement with observed retained energy.

Biologically, as an animal reaches maturity, there is a decline in weight and proportion of visceral organs, particularly the liver and the digestive tract (Murray and Slepacek, 1988), which accounts for most of the metabolic activity, resulting in a reduction in energy requirement for maintenance (Ferrell, 1988). Because less energy is required for maintenance proportional to the body weight, more energy can be used for carcass growth, particularly fat deposition (Ryan and Williams, 1989). Thus, it seems that degree of maturity dictates

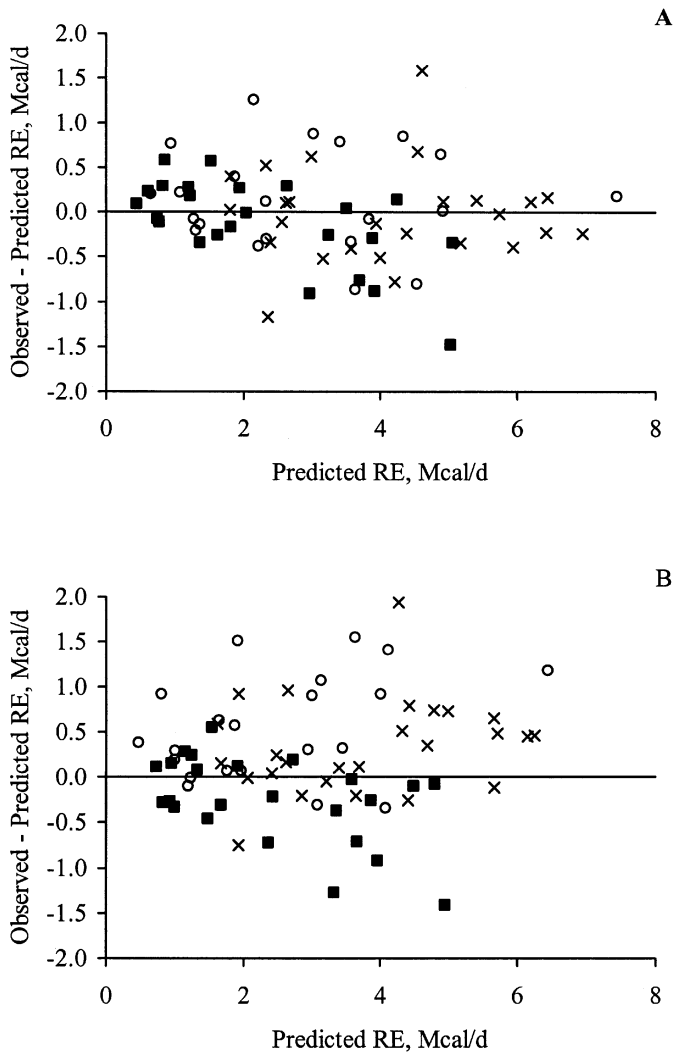


Figure 4. Residual plots of retained energy (RE) predicted by (A) the equation of the NRC (2000) and by (B) Equation 9 for bulls (■) and steers (Trial 2, ○; and Trial 3, ×). The empty standard reference weight at 22% empty body fat (EBF) was assumed to be 372 kg for the NRC (2000) calculations and the empty BW calculated at 22% EBF was 365 kg for steers and younger bulls (Trial 1b) and 456 kg for older bulls (Trial 1a).

the rate of deposition of fat and protein. Thornton et al. (1979) and Schadereit et al. (1995) suggested that fat deposition changes markedly as an animal increases in maturity and this biological effect overcomes that effect of a low rate of gain.

Our Eq. [9] showed that retained energy was more highly correlated with maturity degree than with rate of gain per se; however, it is not easy to separate the confounded effects of degree of maturity (namely mature weight) and rate of gain.

Level of Intake Effects on Composition of Gain. For bulls, there were no differences ($P < 0.05$) between treatments for EBW percentage of protein and water and for FIG and PIG; however, the overall FIG and PIG rate of deposition (g/d) differed between treatments (P

< 0.10). For FIG (g/d), bulls in the ad libitum treatment had greater fat deposition than those in the restricted intake treatment (239 and 87 g/d, respectively). Similarly, PIG (g/d) was greater for bulls in the ad libitum treatment than for those in the restricted intake treatment (157 and 71 g/d, respectively). In contrast, in steers the level of intake affected EBW percentage of protein and fat ($P < 0.05$), but FIG and PIG were not different ($P > 0.05$). However, the overall FIG and PIG rate of deposition (g/d) differed among treatments ($P < 0.05$). For FIG, steers in the ad libitum treatment had greater fat deposition than those in the restricted intake treatments (498, 244, and 151 g/d, respectively for AL, REI1, and REI2). For PIG, steers in the ad libitum treatment differ only from those in the REI2 treatment (110, 72, and 45 g/d, respectively for AL, REI1, and REI2).

We hypothesized that the lack of a consistent effect of intake on composition was due to most of the ADG being in a range (0.3 to 0.9 kg/d) wherein the ability to synthesize protein was not first-limiting. The inconsistencies in the effects of level of intake on composition of gain are likely related to the animals being slaughtered at different body weights, resulting in differences in average weight during the trial. To adequately evaluate the effect of level of intake, the animals need to be slaughtered at the same weight.

Implications

Equations are provided that can be used to compute the NE_m and NE_g requirements of Nellore Bulls and Steers fed high-forage diets, the most common diet type fed in Brazil. The requirement of NE_m was similar for bulls and steers and agreed with the NE_m requirement for beef breed steers recommended by the NRC (2000) (77.2 vs 77 kcal/SBW^{0.75}, respectively). Our findings do not support the hypothesis that Nellore, a *Bos indicus* breed, has a lower NE_m requirement than *Bos taurus* breeds. However, the ME_m requirement for bulls was 5.4% higher than for steers, due to a lower efficiency of utilization of ME for maintenance.

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