

Nutrient requirements of energy and protein for Holstein × Zebu bulls finished in feedlot

Requerimentos nutricionais de energia e proteína em bovinos Holandês × Zebu não castrados terminados em confinamento

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Abstract

The objective of this study was to estimate the nutritional requirements of energy and protein in crossbred (Holstein × Zebu) bulls. An experiment of comparative slaughter was conducted with 44 (24 months old) crossbred bulls of 338 ± 39 kg. Bulls were randomly separated as follows: four bulls to the control group, four bulls to the maintenance level group and 36 bulls were fed *ad libitum*. Corn silage (CS) and sugar cane *in natura* (SC) at 60 or 40% of dry matter (DM) of total diets were utilized in the diets. The bulls of the last group were randomly assigned to one of six different diets: 1) 60CS:40C (84 days); 2) 60CS:40C (42 days) and 40CS:60C (42 days); 3) 40CS:60C (84 days); 4) 60SC:40C (84 days); 5) 60SC:40C (42 days), and 40SC:60C (42 days), and 6) 40SC:60C (84 days). At the end of the experiment, bulls were slaughtered at Universidade Federal de Viçosa for estimation of the empty body weight. One sample located between the 9th and the 11th ribs of each bull was taken and completely dissected for estimation of the empty body composition using equations developed by BR-CORTE 2010. The data were analyzed as nonlinear models built by means of command NLIN of SAS (version 9.2), adjusted by the method of Gauss-Newton. For all the tests, 0.05 was utilized as critical level for probability of type I error. The net (NE_m) and metabolizable (ME_m) energy requirements for maintenance were 78.7 and 114.2 kcal/EBW^{0.75}/day, respectively. The equations obtained for NE_g and NP_g were: NE_g (Mcal/day) = $0.0493 \times EBW^{0.75} \times EBWG^{1.0013}$ and NP_g (g/day) = $279.19 \times EBWG - 22.8691 \times RE_g$, respectively. The model obtained for the percentage of retained energy as protein ($\%RE_p$) was $\%RE_p = 1.7202 \times (RE/EBWG)^{-1.351}$.

Key words: Corn silage, deposition, efficiency, net energy, metabolizable energy, sugar cane

Resumo

Objetivou-se com este estudo estimar as exigências nutricionais de energia e proteína em bovinos cruzados (Holandês × Zebu). Um experimento de abate comparativo foi conduzido com 44 (24 meses) bovinos cruzados pesando 338 ± 39 kg. Os bovinos foram aleatoriamente separados como segue: quatro bovinos para o grupo referência, quatro bovinos para o grupo manutenção e 36 bovinos alimentados *ad*

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libitum. Foram utilizadas a silagem de milho (SM) e a cana-de-açúcar *in natura* (CA) nas proporções de 60 ou 40% na base da matéria seca (MS) total das dietas. As seis dietas experimentais foram constituídas da seguinte forma: 1) 60 SM: 40% de concentrado (C) durante 84 dias; 2) 60SM: 40C (42 dias) e 40SM:60C (42 dias); 3) 40SM:60C (84 dias); 4) 60CA:40C (84 dias); 5) 60CA:40C (42 dias) e 40CA:60C (42 dias) e 6) 40CA:60C (84 dias). Ao final do experimento, todos os animais foram abatidos para determinação do peso de corpo vazio (PCVZ). Uma amostra compreendida entre a 9ª e a 11ª costelas da meia carcaça esquerda foi retirada e completamente dissecada para a estimação da composição química do PCVZ utilizando as equações descritas no BR-CORTE em 2010. Os dados foram analisados como modelos não lineares elaborados por médias do comando NLIN do SAS (versão 9.2), ajustados pelo método de Gauss-Newton. Para todos os testes, 0.05 foi utilizado como nível crítico de probabilidade para o erro tipo I. As exigências de energia líquida (EL_m) e metabolizável (EM_m), para manutenção foram de 78,7 e 114,2 kcal/PCVZ^{0,75}/dia, respectivamente. A k_m foi de 0,6891. As equações obtidas para as exigências líquidas para ganho de energia (EL_g) e proteína (PL_g) foram: EL_g (Mcal/dia) = $0,0493 \times PCVZ^{0,75} \times GPCVZ^{1,0013}$ e PL_g (g/dia) = $279,19 \times GPCVZ - 22,8691 \times ER$, respectivamente. A k_g foi de 0,4634. As eficiências de utilização da energia metabolizável para a deposição de proteína e gordura foram de 0,2048 e 0,8848, respectivamente. O modelo obtido para a percentagem de energia retida na forma de proteína ($\%ER_p$) foi: $\%ER_p = 1,7202 \times (ER/GPCVZ)^{-1,351}$.

Palavras-chave: Deposição, eficiência, energia líquida, energia metabolizável

Introduction

Since the 13th century, researchers have been inquired about the search for information on the utilization of energy by animals. Thus, over the years, models for studies and prediction of the energy and protein requirements of animals have been developed (FERREL; OLTJEN, 2008).

The higher operational cost of production in beef cattle is due to nutrition, so the accurate knowledge of the nutritional requirements of the animals, and the knowledge of the nutritional value of the feedstuffs, are essential for the formulation of adequate diets and the consequent increase in the productive, economic and environmental efficiency of the activity (GIONBELLI, 2010).

Most of the balancing of diets for beef cattle in Brazil was, until recently, performed based on information reported by international councils (AFRC, 1993; NRC, 2000). These councils utilize in its database, animals with different characteristics from those raised in Brazil. Therefore, Valadares Filho et al. (2010) published the 2nd edition of the Brazilian Table of Nutritional Requirements of Zebu Cattle (BR-CORTE), whose database is based on animals with similar characteristics and conditions to those reared in Brazilian territory.

However, estimates of the nutritional requirements of energy and protein for crossbred Holstein \times Zebu animals are scarce in the database from BR-CORTE. When taking it into account, in some regions of Brazil, the utilization of systems in which Holstein \times Zebu animals are utilized for production of meat is significant, the nutritional requirements of these animals become necessary to optimize the production.

Therefore, the objective of this experiment was to estimate the nutritional requirements of energy and protein in crossbred feedlot Holstein \times Zebu bulls.

Material and Methods

The experiment took place at the animal feedlot of the Department of Animal Science of Universidade Federal de Viçosa, MG, Brazil.

Forty-four crossbred Holstein \times Zebu bulls at average age of 24 months and average body weight of 338 ± 39 kg were utilized in the experiment, which designed as a completely randomized, with a total duration of 84 days, divided in four periods of 21 days.

Animals were confined in individual concrete-floored pens, provided with concrete bunks and

waterers, with a total area of 30 m², of which 8 m² were covered.

Bulls went through a 30-day period of adaptation to the experimental facilities and received a diet based on shredded elephant grass as roughage *ad libitum*, and 2 kg concentrate with 200 g/kg crude protein daily. During this period, animals were identified and treated against ecto- and endoparasites. After this adaptation period, they were weighed at a 14-hour solid fasting and randomly distributed to three groups: reference (n=4), maintenance (n=4) and fed *ad libitum* (n=36).

Animals fed *ad libitum* were once again randomly distributed to six groups (six bulls in each one), which received the experimental diets. After this distribution, the animals were subjected to a 14-day period of adaptation to the experimental diets, with gradual increase of the level of concentrate in the diet. In the first week 50% of the concentrate was given and in the second week 100% of the concentrate was given to the bulls.

The four bulls set to the reference group were slaughtered in the beginning of the experiment. Bulls of the maintenance group were fed 1.2% of their body weight. Before the beginning of the experiment, the animals were weighed again at solid fasting of 14 hours and distributed to the following experimental diets (dry matter basis):

- 1) 60% corn silage + 40% concentrate (during 84 days);
- 2) 60% corn silage + 40% concentrate (first 42 days) and 40% corn silage + 60% concentrate (last 42 days);
- 3) 40% corn silage + 60% concentrate (during 84 days);
- 4) 60% sugarcane *in natura* + 40% concentrate (during 84 days);
- 5) 60% sugarcane *in natura* + 40% concentrate (first 42 days) and 40% sugarcane *in natura* + 60% concentrate (last 42 days);

- 6) 40% sugarcane *in natura* + 60% concentrate (during 84 days).

Each one of the bulls fed at maintenance level was randomly subjected to one of the following diets:

- 1) 60% corn silage + 40% concentrate (during 84 days);
- 2) 40% de corn silage + 60% concentrate (during 84 days);
- 3) 60% de sugarcane *in natura* + 40% concentrate (during 84 days);
- 4) 40% de sugarcane *in natura* + 60% concentrate (during 84 days).

At the end of periods two and four, the animals were weighed after a solid fasting of 14 hours, for evaluation of the average daily gain.

The corn silage was collected from a trench-type silo one hour prior to its delivery to animals, and sugarcane (whole plant) was shredded daily before feeding. Corn silage and sugarcane had the dry matter (DM) content evaluated daily for adjustment of the amount of concentrate and urea + ammonium sulfate supplied to animals. The mixture of urea + ammonium sulfate (9:1) was utilized to elevate the contents of crude protein (CP) of roughages to 120 g/kg. Dry matter was evaluated by using a conventional microwave oven, according to recommendations of the National Forage Testing Association (1993).

The brix degree of sugarcane was measured on the 10th day of each experimental period. Three samples of sugarcane were randomly collected and the brix degree was estimated using a manual refractometer. The average value observed for the brix degree of sugarcane during the experiment was 22±1.

A single concentrate composed of 90.40% corn meal; 7.90% soybean meal; 0.85% mineral mixture and 0.85% common salt was supplied; its composition is shown in Table 1.

Table 1. Chemical composition of feed used in experimental diets.

Feed	DM ¹	OM ²	CP ³	EE ⁴	NDFap ⁵	NFC ⁶	iNDF ⁷
	g/kg DM						
Corn silage	300.80	947.10	65.70	32.44	515.70	333.30	140.20
Sugar cane	281.60	973.80	28.30	15.76	458.70	471.04	222.06
Corn	901.90	989.40	94.80	35.70	144.40	714.50	1.71
Soybean meal	875.00	951.80	528.00	14.80	124.20	284.80	0.64
Mineral mix ⁸	975.40	160.00	0	0	0	0	0
Salt	933.10	114.90	0	0	0	0	0
Urea + ammonium sulfate	950.60	984.90	2630.80	0	0	0	0

¹DM = Dry matter; ²Organic matter; ³Crude protein; ⁴Ether extract; ⁵Neutral detergent fiber corrected to ash and protein; ⁶Non-fibrous carbohydrates; ⁷Indigestible neutral detergent fiber; ⁸Mineral mixed composition = 266 g/kg of calcium; 147 g/kg of phosphorus; 7 g/kg of magnesium; 3 g/kg of potassium; 7 g/kg of sulfur; 2 g/kg of sodium; 118 mg/kg of chrome; 1,191 mg/kg of copper; 5,070 mg/kg of iron; 1,728 mg/kg of manganese; 4,198 mg/kg of zinc; and 136 mg/kg of cobalt.

Source: Elaboration of the authors.

Isoprotein diets (120 g/kg crude protein) according to Valadares Filho et al. (2010) were formulated for a gain of 1.20 kg/day, (Table 2).

Table 2. Proportions of feed in concentrate and diet and concentrate and diet composition in dry matter basis.

Items	Concentrate	Corn silage		Sugar cane	
		60:40	40:60	60:40	40:60
	g/kg				
Roughage	-	600 ¹	400 ¹	600 ²	400 ²
Corn	904.00	361.60	542.40	361.60	542.40
Soybean meal	79.00	31.60	47.40	31.60	47.40
Mineral mix	8.50	3.40	5.10	3.40	5.10
Salt	8.50	3.40	5.10	3.40	5.10
Chemical composition (g/kg)					
Organic matter	973.40	957.60	962.90	973.60	962.90
Crude protein	126.20	124.60	129.40	117.60	129.10
Ether extract	33.50	33.00	20.60	13.20	19.80
Neutral detergent fiber ³	140.30	366.60	295.50	324.10	262.50
Non-fibrous carbohydrates	673.40	453.55	530.83	552.80	574.24
Indigestible NDF	3.31	97.60	75.40	144.76	106.80

¹20.60 g of urea + ammonium sulfate kg/DM of roughage intake; ²34.87 g of urea + ammonium sulfate kg/DM roughage intake, ³corrected to ash and protein

Source: Elaboration of the authors.

The roughage (corn silage or sugarcane) was supplied in full at 08h00 along with the mixture of urea + ammonium sulfate and half of the daily quantity of concentrate. At first, urea + ammonium

sulfate was incorporated to the roughage, and after, the concentrate was added. At 15h00, the other half of the roughage was supplied to animals. The amounts of roughage, concentrate and urea +

ammonium sulfate supplied, as well as refused feed, were recorded daily. The diet supplied to animals was adjusted to keep leftovers at around 5 to 10% on a natural matter basis, with water permanently at their disposal.

Roughages and leftovers from each animal were sampled daily and subsequently conditioned in freezer (-20 °C). A composite sample of corn silage, sugarcane and composite samples of the leftovers from each animals were sent to drying in forced-ventilation oven (55 °C) and ground in knife mill (1 and 2 mm) weekly for the periods in which digestibility trials were conducted.

Afterwards, the total DM of these samples was evaluated according to National Forage Testing Association (1993). Based on the DM content of the leftovers from each animal, or on the amount of DM from the corn silage and sugarcane supplied, composite samples were made for each three weeks, totaling four samples of leftovers and roughages.

The ingredients which composed the concentrate were sampled on the days of its mixing. During each experimental period (21 days), two mixing of the ingredients were performed.

For the evaluation of total digestibility coefficients, the feces from all animals were collected at a specific time during the last three days of periods two and four. Rectal collections were performed at 6h00, 12h00 and 18h00 of days one, two and three, respectively. Samples of feces were dried in forced-ventilation oven (55 °C) for 72 hours then ground in knife mill to 1 and 2 mm. A composite sample was obtained per collection period for each animal.

Samples of corn silage, sugarcane, ingredients of the concentrate, refused feed and feces were quantified as for the contents of DM, mineral matter (MM), total nitrogen (TN), and ether extract (EE), according to Silva and Queiroz (2002). Crude protein (CP) was obtained by the product between total nitrogen and factor 6.25. The content of neutral detergent fiber (NDF) was obtained according to

Mertens et al. (2002). In the analysis of soybean meal, sodium sulfite was added (UNDERSANDER; MERTENS; THIEX, 1993) to reduce retention of the protein content. The Ankom® system was utilized for evaluations of NDF, by adding thermostable α -amylase. Non-woven fabric (100 g/m²) filtering bags were utilized for the extractions. The NDF content was corrected for ash and crude protein in all samples.

Non-fibrous carbohydrates (NFC) were calculated as proposed by Detmann and Valadares Filho et al. (2010), in which $NFC = 1000 - [(g/kg CP - g/kg CP \text{ derived from urea} + g/kg \text{ urea}) + g/kg NDF_{ap} + g/kg EE + g/kg MM]$. The contents of total digestible nutrients (TDN) of the diets were estimated by $TDN = DCP + 2.25 \times DEE + DNDF + DNFC$ (NRC, 2001). Digestible energy (DE) was obtained from the digestible nutrients multiplied by its respective energy values, as described by the NRC (2001), whereas the concentration of metabolizable energy (ME) was considered 82% of the DE (COELHO DA SILVA; LEÃO, 1979).

Samples of leftovers, feed and feces for periods two and four were analyzed as for the content of indigestible neutral detergent fiber (iNDF). The samples were incubated in the rumen for 288 hours according to Valente et al. (2011) in F57 Ankom® bags. After the incubation period, the determination of the iNDF was done through the treatment of samples with neutral detergent.

At the end of the 84 days of experiment, all animals were slaughtered in experimental abattoir of Universidade Federal de Viçosa. Nine animals were slaughtered per day, randomly selected for each day of slaughter.

Before slaughter, animals were subjected to a solids-fast for 16 hours. The slaughter was performed via stunning and section of the jugular, followed by washing of the gastrointestinal tract (rumen, reticulum, omasum, abomasums and small and large intestines). The weights of heart, lungs, liver, spleen, kidneys, internal fat, industrial meat,

mesentery, tail and trimmings (trachea, esophagus and reproductive system), along with those of the washed gastrointestinal tract, were summed with the other parts of the body (carcass, head, hide, feet and blood) for quantification of the empty body weight (EBW).

After slaughter, the carcass of each animal was separated in two half-carcasses, which were weighed, and then chilled (4 °C; 18 hours). After this time, half-carcasses were removed from the cold chamber for cutting and samples from the left carcass were taken from section between the 9th and the 11th ribs, according to recommendations of Hankins and Howe (1946).

The section comprehended between the 9th and the 11th ribs was divided in muscle, fat and bones; afterwards, each part was individually weighed. Muscle and fat were homogenized and ground. After grinding, a homogeneous sample was removed, thus constituting a single sample of muscle + fat. One homogeneous sample of bones was also taken and placed on aluminum trays to be lyophilized for

evaluation of fat dry matter (FDM) content.

Samples of muscle + fat and bones were lyophilized during 72 hours using standard conditions and partially defatted through successive washings with petroleum ether in Soxhlet extractor, for evaluation of the partially defatted dry matter (PDDM). Next, its were ground in a ball mill for subsequent laboratory analyses. The fat removed at the partial extraction was calculated through the difference between FDM and PDDM, whose result was added to that obtained for residual ether extract in the PDDM, for quantification of the total fat content.

Samples of each animal component were evaluated for the contents DM, MM, TN, and EE, according to Silva and Queiroz (2002). CP was obtained by the product between total nitrogen and the factor 6.25.

The chemical composition of the empty body was estimated by the equations proposed by Marcondes et al. (2010), published on BR-CORTE, described in Table 3.

Table 3. Equations used to estimate the chemical composition of the empty body weight in crossbred bulls.

Itens	Equations
	Chemical composition of empty body weight
Crude protein	$CP_{Sec} (\%) = 10.78 + 0.47 \times PB_{Sec} - 0.21 \times VF$
Ether extract	$EE_{Sec} (\%) = 2.75 + 0.33 \times EE_{Sec} + 1.80 \times VF$

CP_{Sec} : Crude protein in the section between the 9-11th ribs; EE_{Sec} : Ether extract in the section between the 9-11th ribs; VF: visceral fat percentage (renal, pelvic, cardiac and mesentery in the empty body weight); OV: organs and viscera percentages; W_{Sec} : water in the section between the 9-11th ribs; CPBE: CP in the body empty; EECZ: EE in the body empty

Source: Marcondes et al. (2010).

The evaluation of the body energy was obtained from the body contents of protein and fat and its respective caloric equivalents, according to the equation established by the AFRC (1980):

$$EC = 5.6405 X + 9.3929 Y,$$

in which EC = energy content (Mcal); X = body protein (kg); Y = body fat (kg).

For the conversion of body weight (BW) into EBW, the relations between EBW and BW of animals kept in the experiment were calculated. For the conversion of empty body weight gain (EBWG) into body weight gain (BWG), the relations between them were calculated, and then utilized for conversion of the requirements for EBW gain into requirements for BW.

A regression equation was fitted between retained energy (RE), metabolic EBW ($\text{kg}^{0.75}$) and EBWG (day), for animals under maintenance and performance, by utilizing the following model:

$$\text{RE} = a \times \text{EBW}^{0.75} \times \text{EBWG}^b,$$

in which RE = retained energy (Mcal/EBW^{0.75}/day), EBW^{0.75} = metabolic empty body weight ($\text{kg}^{0.75}$), EBWG = empty body weight gain (kg/day).

The proportion of energy retained in the form of protein (%RE_p) was estimated according to the model suggested by Marcondes et al. (2010):

$$\% \text{RE}_p = \beta_0 + (\text{RE}/\text{EBWG})^{\beta_1}$$

in which %RE_p = percentage of energy retained in the form of protein, RE = retained energy (Mcal/day), EBWG = empty body weight gain (kg/day) and β_0 and β_1 = regression parameters.

To estimate the requirements of energy for maintenance, the exponential method was utilized as recommended by Tedeschi et al. (2002). Thus, the requirement of net energy for maintenance (NE_m, Mcal/EBW^{0.75}/day) was calculated from the intercept (β_0) of the exponential regression between BW and MEI, through the following model:

$$\text{HP} = \beta_0 \times e^{(\beta_1 \times \text{MEI})},$$

in which HP = heat production (Mcal/EBW^{0.75}/day), MEI = metabolizable energy intake (Mcal/EBW^{0.75}/day), β_0 and β_1 = regression parameters and e = Euler number (3.718281).

To estimate the requirement of metabolizable energy for maintenance (ME_m, Mcal/EBW^{0.75}/day), the iterative method was utilized; ME_m was considered the MEI value at the moment MEI equals to BW.

From the ratio between requirements of net and metabolizable energy for maintenance, the efficiency of utilization of metabolizable energy for maintenance was calculated (k_m).

For the calculation of the partial use efficiencies of metabolizable energy for synthesis of protein and

fat, the following model was fitted:

$$\text{MEI} = \text{ME}_m + \beta_1 \times \Delta_{\text{prot}} + \beta_2 \times \Delta_{\text{fat}},$$

in which MEI is the total daily intake of metabolizable energy (Mcal/EBW^{0.75}), Δ_{prot} and Δ_{fat} are the variations of body energy in function of the protein and fat (Mcal/EBW^{0.75}), respectively, and β_1 and β_2 are the coefficients of multiple regression.

The inverse of coefficients β_1 and β_2 account for the efficiencies of deposition of energy in the form of protein and fat (k_{prot} and k_{fat}), respectively.

For the calculation of the requirements of metabolizable protein for maintenance (MP_m), the relation between metabolizable protein intake and average daily gain (ADG) was considered, in which MP_m was the point at which the animal would have zero average daily gain.

For the calculation of net requirements of protein for weight gain, the model involving EBWG and the concentration of energy in the gain was fitted; animals under performance and maintenance were utilized:

$$\text{RP} = \beta_1 \times \text{EBWG} + \beta_2 \times \text{RE},$$

in which RP = retained protein (g/day), EBWG = empty body weight gain (kg/day), RE = retained energy (Mcal/day) and β_1 and β_2 = regression parameters.

The estimate of requirement of metabolizable protein for gain (MP_g) was obtained by dividing the net requirements of protein for gain by the utilization efficiency of the metabolizable protein for gain (k), according to equation proposed by Valadares Filho et al. (2010):

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

in which eqEBW is the equivalent empty body weight, for body weights at fasting inferior to 350 kg and constant value of 46.9% for superior weights.

The data were analyzed as nonlinear models built by means of command NLIN of SAS (version 9.2), adjusted by the method of Gauss-Newton. For

all the tests, 0.05 was utilized as critical level for probability of type I error.

Results and Discussion

The average ratio between EBW and BW was 0.8834, which is close to those observed by BR-CORTE (VALADARES FILHO et al., 2010) and in NRC (2000), which are 0.895 and 0.891, respectively. According to the NRC (2000), this ratio can vary from 0.85 to 0.95.

For the conversion of requirements for EBW gain (EBWG) into requirements of body weight average daily gain (ADG), the mean ratio between EBWG and ADG was 1.0511. The NRC (2000) and Valadares Filho et al. (2010) presented EBWG/BWG ratios of 0.951 and 0.936, respectively. These values are 10.53 and 12.29% lower than the ones found in this study, respectively. The highest value observed in this study may be due to the utilization of animals which reached a high weight (489.25 kg) at the end of the experiment.

Relating the daily heat production (HP) with the metabolizable energy intake (MEI), expressed in Mcal/EBW^{0.75}, the following equation was obtained: $HP = 0.0787 \times e^{(3.2611 \times MEI)}$. Thus, the net energy for maintenance value (NE_m) obtained for crossbred Holstein × Zebu bulls was 78.7 kcal/EBW^{0.75}/day. Valadares Filho et al. (2010) suggested a value of 74.2 kcal/EBW^{0.75}/day. Chizzotti, Tedeschi and Valadares Filho (2008), in a study involving the analysis of data from 389 Nellore or crossbred (*Bos taurus* × *Bos indicus*) animals, estimated that the requirement for maintenance would be 75 kcal/EBW^{0.75}/day. Thus, the value observed in this study is close to those observed by the authors previously mentioned.

The requirement of metabolizable energy for maintenance (ME_m) was of 114.2 kcal/day, which is obtained when HP equals to MEI.

The equation obtained for the body energy content (EC) in function of EBW was $EC = 0.3498 \pm 0.1678$

× EBW^{1.3582 ± 0.0792}. As the EBW increases, there is increase in the concentration of energy in the animal due to the increase of body fat. The requirements of net energy (RE) per kg of EBWG can be calculated from the derivative of the equation: $RE = 0.4751 \times EBW^{0.3582}$, in which RE is the requirement of net energy for gain (Mcal/kg EBWG) and the EBW is the empty body weight. The data obtained in this equation can only be considered for the animals of this experiment.

To estimate the requirements of energy for any range of weight and weight gain, the following equation was obtained: $NE_g = 0.0493 \times EBW^{0.75} \times EBWG^{1.0013}$, in which NE_g is the requirement of net energy for gain (Mcal/day) and EBWG is the empty body weight gain (kg/day). The intercept of the equation obtained is close to that suggested by Valadares Filho et al. (2010) for bulls, whose value was 0.053. This demonstrates that the data generated by this experiment is agree with the data described in the national literature for non-castrate crossbred animals.

The main nutritional requirement systems (AFRC, 1993; NRC, 2000; CSIRO, 2007) separate the utilization efficiency of metabolizable energy into utilization efficiency of energy for maintenance (k_m) and utilization efficiency of energy for gain (k_g).

Dividing the NE_m by ME_m, it obtains the k_m value of 0.6891. The k_m values reported by Valadares Filho, Paulino and Magalhães (2006) and Chizzotti, Tedeschi and Filho (2008) were 0.63 and 0.67, respectively. Thus, the value estimated in this study is close to those observed in the literature (VALADARES FILHO; PAULINO; MAGALHÃES, 2006; CHIZZOTTI; TEDESCHI; VALADARES FILHO, 2008).

Some factors can alter the k_m, e.g., the level of dietary fiber, the level of consumption of metabolizable energy, the proportion of absorbed fatty acids, the protein turnover (GARRETT, 1980). CSIRO (2007) reported that other factors

such as sex, breed, age and environment could also affect k_m .

Marcondes et al. (2010) studied the effect of several factors on the k_m and concluded that the partial use efficiency of the metabolizable energy for gain (k_g) and the empty body weight gain (EBWG) could be the reason for alterations in k_m . It suggests that the requirements for maintenance are affected by animals performance. The model recommended for crossbred cattle by Marcondes et al. (2010) is $k_m = 0.513 + 0.173 \times k_g + 0.073 \times \text{EBWG}$, in which k_m is the utilization efficiency of metabolizable energy for maintenance, k_g is the utilization efficiency of metabolizable energy for gain and EBWG is the empty body weight gain, in kg/day.

Utilizing the equation proposed by Marcondes et al. (2010), the mean value for k_m obtained for this experiment would be 0.66. This value is close to that obtained by the division of NE_m by ME_m (0.68). However, the utilization of the k_m variable becomes important, for when low-digestibility feedstuffs are utilized, the ME may present problems to estimate

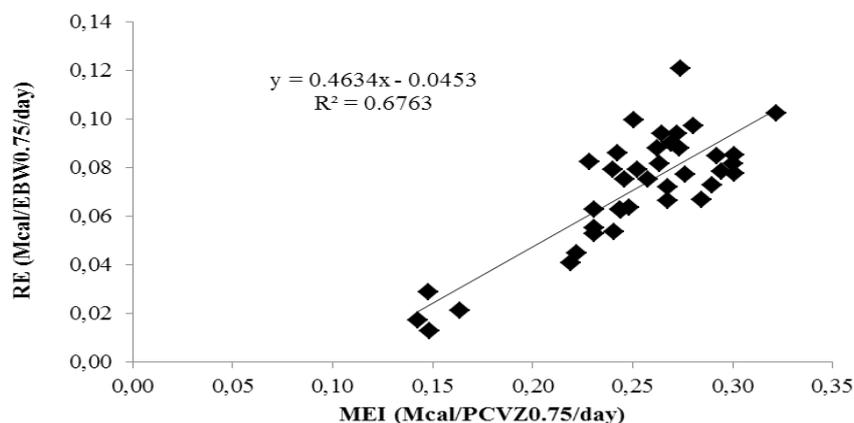
k_m (JOHNSON; LARSON; JAROSZ, 1977).

To convert the requirements of net energy into requirements of metabolizable energy for gain, it is necessary to know the utilization efficiency of the metabolizable energy for weight gain (k_g). Valadares Filho et al. (2010) affirmed that this efficiency can be estimated as the slope coefficient of the regression of RE in function of MEI (Figure 1).

Gionbelli (2010) utilized the same procedure and obtained k_g value of 0.38. This value is below the one found in this experiment, which was 0.4634. Costa e Silva (2011), utilizing the same procedure, obtained inferior value (0.3325) to that observed by Gionbelli (2010) and the one of this experiment.

In most of the studies conducted in Brazil, static values have been estimated for k_g . However, the efficiency with which energy is retained in the body (k_g) depends on the proportions of energy retained in the form of protein and fat. Because the efficiency of deposition of fat is superior to that of protein and the proportion of protein and fat are variable, there is the need to obtain a k_g also variable.

Figure 1. Retained energy (Mcal/EBW^{0.75}/day) in function of the metabolizable energy intake (Mcal/PCVZ^{0.75}/day) in crossbred bulls.



Source: Elaboration of the authors.

For the calculation of the partial use efficiencies of metabolizable energy for the synthesis of fat and protein, the following equation was obtained:

$\text{MEI} = 114.2 + 4.88 \times \Delta_{\text{prot}} + 1.13 \times \Delta_{\text{fat}}$, in which MEI is the daily metabolizable energy intake for maintenance (Mcal/EBW^{0.75}) and Δ_{prot} and Δ_{fat} are

variations of body energy in function of protein and fat (Mcal/EBW^{0.75}).

From this model, the efficiencies of deposition of energy in the form of protein (k_p) and fat (k_f) were calculated. Thus, k_p was equal to 0.2048, and k_f to 0.8848. Chizzotti, Tedeschi and Valadares Filho (2008), evaluating 16 experiments with 369 animals, obtained k_p of 0.35 and k_f of 0.79. Gionbelli (2010) obtained k_p of 0.25 and k_f of 0.83. The values observed for k_p and k_f by Costa e Silva (2011) were 0.18 and 0.71, respectively.

The proportion of energy retained in the form of protein (%RE_p) was estimated according to the potential model proposed by Marcondes et al. (2010). The model obtained was $\%RE_p = 3.0089 \times (RE/EBWG)^{-1.5061}$, in which %RE_p is the retained energy in the form of protein, RE is the retained energy, in Mcal/day, and EBWG is the empty body weight gain, in kg/day.

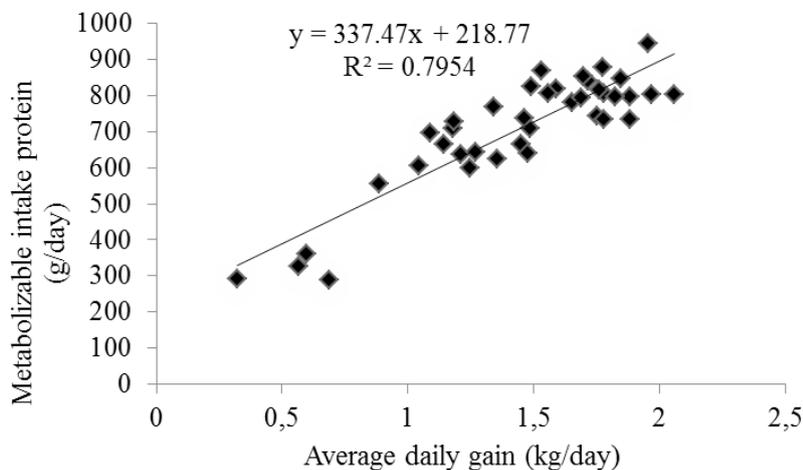
The %RE_p can be utilized in the conversion of net energy into metabolizable energy for being directly correlated to the utilization efficiency

of metabolizable energy for gain (WILLIAMS; JENKINS, 2003; TEDESCHI; FOX; GUIROY, 2004). Marcondes et al. (2010) utilized a database from 752 animals raised under Brazilian conditions and did not observe differences between sex classes or between Nellore and crossbred animals for the %RE_p, which was equal to $\%RE_p = 1.140 \times (RE/EBWG)^{-1.137}$.

Marcondes et al. (2010) suggested the calculation of kg in function of the RE_p, utilizing the equation: $k_g = 0.327 / [0.539 + (\%RE_p/100)]$. Therefore, the utilization of this model, which considers a k_g variable, seems to have more applicability, once there is the combination of the efficiency with the composition of gain.

In this study, the value of 2.72 was observed for the requirement of metabolizable protein for maintenance. This value was obtained by the division of the intercept (218.77) of the regression equation of the metabolizable energy intake (g/day) in function of the weight gain (kg/day) of the animals, by their metabolic live weight (80.36) (Figure 2).

Figure 2. Relation between the metabolizable intake protein (g/day) and the average daily gain (kg/day) in crossbred bulls.



Source: Elaboration of the authors.

The equation obtained to describe the content of body crude protein (BCP) in function of EBW

was $BCP = 1.6100 \times EBW^{0.6575}$, in which BCP is the body content of crude protein, in kg, and EBW is

the empty body weight, in kg.

The net requirements of protein (PR), for one kg of gain of empty body weight, were estimated by the derivative of the following equation: $PR = 1.0586 \times EBW^{-0.3425}$, in which PR is the net requirement of protein for gain, expressed in grams per kg of EBWG.

As the EBW of animals increases, there is a decrease in PR, represented by the negative exponent linked to EBW, resulting in lower gain of protein per kg of EBWG. With an increase in weight, there is reduction in the deposition of muscle tissue and an increase in the deposition of fat tissue for the body reserves.

The net requirements of protein (NP_g) for any range of weight gain were estimated from a model involving the EBWG and the concentration of energy in gain: $NP_g = 279.19 \times EBWG - 22.87 \times RE$, in which NP_g is the net requirement of protein, in g/day, EBWG is the empty body weight gain, in kg/day, and RE is the retained energy, in Mcal/day. The equation recommended by BR-CORTE (VALADARES FILHO et al., 2010) to estimate the net requirements of protein is: $PR = 238.79 \times EBWG - 15.68 \times RE$.

The utilization efficiency of metabolizable protein for gain (k) was calculated as proposed by Valadares Filho et al. (2010), in which: $k (\%) = 84.665 - (0.1179 \times_{eq} EBW)$ for animals of body weight at fasting (BWF) lower or equal to 350 kg and a fixed value of 0.469 for animals above this weight.

Thus, the requirements of net and metabolizable energy for the maintenance of crossbred Holstein × Zebu bulls are of 78.7 kcal/EBW^{0.75}/day and 114.2 kcal/EBW^{0.75}/day, respectively. The net requirements for gain can be obtained through the equation: $NE_g = 0.0493 \times EBW^{0.75} \times EBWG^{1.0013}$. The net requirements of protein for gain can be obtained through the equation NP_g (g/day) = $279.19 \times EBWG - 22.87 \times RE$. The utilization efficiencies of metabolizable energy for deposition of protein

(k_p) and fat (k_f) for finishing crossbred Holstein × Zebu bulls are of 0.2048 and 0.8848, respectively.

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