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Double-muscled and conventional cattle have the same net energy requirements if these are related to mature and current body protein mass, and to gain composition[1]

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ABSTRACT: The hypothesis tested in this paper is that double-muscled (DBM) and conventional cattle, considerably differing in body composition, have similar NE requirements when: a) NE_m is scaled as a function of current (P_i) and adult (P_m) protein mass; and b) ME for gain (ME_g) is estimated from protein (Pr) and lipid (Lr) retention and their partial ME use efficiencies, the k_p and k_l values, respectively. First, 2 databases were examined: 1 was developed combining well known literature information from comparative slaughter trials conducted on British beef steers; the other was based on a trial conducted using extremely lean DBM Piemontese bulls. From the first database, NE_m was calculated to be $1.625 \times P_i \div P_m \times P_m^{0.73}$ (MJ/kg$^{0.73}$). From the second database, the daily ME_g was determined as 22.8 MJ × Pr ÷ k_p + 38.74 MJ × Lr ÷ k_l, assuming (from prior reports) that $k_p = 0.20$ and $k_l = 0.75$. Thereafter, ME_m was defined as ME intake minus ME_g, and, hence, NE_m was predicted as $1.625 \times P_i \div P_m \times P_m^{0.73}$ (where 1.625 was the value obtained from the first dataset). The resulting k_m (NE_m/ME_m) averaged 0.67. This k_m value did not differ from that (0.65; $P = 0.12$) predicted by Garrett's equation, which uses dietary ME content as the only predictive variable. Second, the procedure was tested for the ability to detect effects on k_m caused by increasing BW and dietary factors not estimable from the dietary ME content only. Data were gathered from a trial involving 48 DBM Piemontese bulls divided into 4 groups fed 1 of 4 diets differing in CP content (145 or 108 g/kg DM), with or without addition of 80 g/d of rumen-protected CLA (rpCLA). Bulls were examined at 3 consecutive periods of growth, corresponding to 365, 512 and 631 kg of average BW. All energy balance items were influenced by increasing BW, except k_m ($P = 0.61$), in agreement with the expectation that NE_m requirement depends on the degree of maturity (P_i/P_m) and the $P_m^{0.73}$ of an animal, whereas k_m reflects characteristics of the feed provided. The k_m value was also influenced by the CP × rpCLA interaction ($P = 0.013$). We conclude that DBM and British beef steers have similar NE requirements when these are scaled as a function of P_i and P_m, and gain composition, considering Pr, k_p, Lr and k_l. The proposed procedure will be useful to predict the energy requirements and feed use in cattle of different types that vary in BW, provided that body and gain compositions are known or accurately predicted.

Key words: body composition, cattle, conjugated linoleic acid, double-muscling, energy requirements, Piedmontese breed

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INTRODUCTION

Maintenance energy requirements have been defined by the NRC (1996) in terms of a basic equation $NE_m = 0.322$ MJ × empty BW$^{0.75}$ (**EBW$^{0.75}$**), adjusted for some multiplier factors, primarily to take into account gender and breed. Reports reviewed by the NRC (1996) allowed the Council to conclude that, per unit of EBW$^{0.75}$, considerable variation in NE_m exists among cattle germplasm resources. The energy requirements of double-muscled (**DBM**) bulls remain unclear; some

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reports have calculated values greater than those of the NRC (1996), probably because the animals studied were extremely lean (Schiavon et al., 2010a; De Campeneere et al., 2001a). Robelin and Daenicke (1980) suggested that energy requirement may differ among breeds because of divergent amounts of protein and lipid deposited. Evidences support the hypothesis that the use of $EBW^{0.75}$ as a size-scaling factor does not fully account for differences among immature cattle with different patterns of protein and fat accretions (Geay, 1984; Oldham and Emmans, 1990). It is attractive to seek to scale NE_m requirements in terms of mature, or adult (**P_m**), and current (**P_i**) protein masses (Emmans and Fisher, 1986), and to quantify NE_g values on the base of protein (**Pr**) and lipid (**Lr**) retentions and their partial ME efficiencies (Geay, 1984). The hypothesis tested in the present work is that DBM and conventional (**CONV**) British beef steers, which differ greatly in terms of body and gain compositions, have similar NE requirements when: a) NE_m is scaled to a function of P_i and P_m; and b) the ME for growth is estimated from Pr and Lr values and the partial ME efficiencies for protein (**k_p**) and lipid (**k_l**) retentions. We further explored whether the proposed procedure of energy balancing is useful to detect differences of energy efficiency in DBM Piemontese bulls fed diets of similar ME content but with suboptimal nutrients content or supplemented with metabolic modifiers.

MATERIALS AND METHODS

This project followed the Guideline for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (Consortium, 1988) and was approved by the Ethical Committee for the Care and Use of Experimental Animals of the University of Padova (Legnaro, Italy).

Data from reports on CONV British beef steers were re-evaluated to express NE_m as a function of P_i and P_m. Data from a feeding trial conducted on DBM Piemontese young bulls were analyzed using a procedure that permitted the comparison with CONV steers information. Thereafter, we used the new approach to analyze energy efficiency changes due to an increase in the BW of DBM Piemontese bulls fed diets with conventional or reduced CP content, with or without addition of rumen-protected CLA (**rpCLA**) which is supposed to be a metabolic modifier. In this paper the term mature BW and P_m will be used to indicate the adult BW and the adult protein mass, respectively, or the BW at which protein accretion is completed.

Expression of the Energy Requirements of Beef Cattle as a Function of Current and Mature Body Protein Mass

The British Breed Database. In this work the data used to quantify NE requirements for maintenance were those published by Lofgreen and Garrett (1968) regarding comparative slaughter experiments conducted on 31 groups of steers and heifers, with 6 to 8 heads/group. Lofgreen and Garrett (1968) did not provide empty body composition at different BW of their animals. However, Simpfendorfer (1974) developed predicting equations for body components at various weights of British beef steers by compositing data of a number of experiments (NRC, 1996). Data varied from a few days to 57 mo of age at slaughter, with BW ranging from 18 to 891 kg. Other data later reviewed by Fox and Black (1984) and quoted by NRC (1996), indicated that body composition predicted by the Simpfendorfer (1974) equations can be considered typical of British beef steers of average frame size. In practice these equations cannot be used to predict EBW composition of a given type of cattle because many factors influence EBW composition of cattle at given BW (Fox and Black, 1984; NRC, 1996). This paper was not aimed to propose a system to predict EBW composition under practical conditions; we used these equations only to achieve a representative body composition at different EBW of medium frame British beef steers, because from this information the energy requirements for maintenance calculated according to Lofgreen and Garrett (1968), can be scaled to different units and compared with those of DBM bulls.

The computation procedure is detailed in Table 1. Empty BW is the predictor variable in the equations proposed by Simpfendorfer (1974) to estimate current P_i and lipid (**L_i**) masses of CONV steers from birth to maturity: P_i (kg) = $0.235 \times EBW - 0.00013 \times EBW^2 - 2.418$ and L_i (kg) = $0.037 \times EBW + 0.00054 \times EBW^2 - 0.610$, respectively. In the present report, these equations were used to estimate P_i and L_i values at EBW of 337 and 479 kg. The Simpfendorfer (1974) equation was also used to estimate the value of P_m. In line with the general model for mammals proposed by Emmans and Fisher (1986), the protein size-scaling unit (**P_{im}**) was computed as follow: $P_{im} = P_i \div P_m \times P_m^{0.73}$ ($kg^{0.73}$), where the P_i/P_m ratio represents the degree of maturity, which is 1.00 for an adult animal. Such a suggestion implies that maintenance needs for fatty tissue are 0 and that protein mass in the body determines maintenance needs on a scale which, at a given protein mass, differentiates between maintenance needs of animals achieving different mature protein masses (Oldham and Emmans, 1989). This approach considers that the energy costs for maintenance are mainly associated to the continual process of synthesis, degradation and replacement of those

Table 1. Procedure used to estimate the NE_m as a function of current (P_i) and mature (P_m) body protein mass on British breed steers

Line	Units	BW, kg 394	BW, kg 560	Notations	Reference
1	EBW, kg	337	479	EBW = 0.891 × 0.96 × BW	NRC (1996)
2	Body protein mass (P_i), kg	62	80	$P_i = 0.235 \times EBW - 0.00013 \times EBW^2 - 2.418$	Simpfendorfer (1974)
3	Mature body protein mass (P_m), kg	103.0	103.0	Maximum P_i value from equation at line 2	-
4	Protein size-scaling unit (P_{im}), $kg^{0.73}$	17.74	22.97	$P_{im} = P_i \div P_m \times P_m^{0.73}$	Emmans and Fisher (1986)
5	Body lipid mass (L_i), kg	73.2	141.1	$L_i = 0.037 \times EBW + 0.00054 \times EBW^2 - 0.610$	Simpfendorfer (1974)
6	NE_m per unit of[1]:				-
7	$EBW^{0.75}$, $MJ/kg^{0.75}$	0.365	0.365	$NE_m = 0.365$	From data of Lofgreen and Garrett (1968)
8	P_{im}, $kg^{0.73}$	1.620	1.630	$NE_m = 0.365 \times EBW^{0.75} \div P_{im}$	-

[1]The NE_m estimates from 208 British breed heifers and steers of the comparative slaughter experiments of Lofgreen and Garrett (1968) were recomputed using empty $BW^{0.75}$ ($EBW^{0.75}$), and not $BW^{0.75}$, as size-scaling factor.

parts of the body which "turn over", particularly body protein, and to energy expenditure of organs, which also are related to body protein mass, whereas the fat tissues appear to have a very low turnover. This approach also implies that 2 bulls with different P_m values but with the same current protein mass will have slightly different energy requirements for maintenance because their physiological maturity (P_i/P_m) is different (Oldham and Emmans, 1990).

The original BW data provided by Lofgreen and Garrett (1968) were expressed in terms of EBW assuming that EBW = 0.891 × 0.96 × BW (NRC, 1996). The data of Lofgreen and Garrett (1968) were re-analyzed using the same logarithmic regression approach originally performed by the cited authors to estimate the NE_m requirements, but scaled to $EBW^{0.75}$ and not to $BW^{0.75}$. Thus, the heat production/$EBW^{0.75}$ values were regressed against the natural logarithms of ME intake/$EBW^{0.75}$, and NE_m per unit of $EBW^{0.75}$ was computed as the anti-logarithm of the intercept of the resulting equation. Data of steers and heifers were pooled, as there were no differences in the equations resulting from a separate analysis, like in the original paper of Lofgreen and Garrett (1968). From this analysis resulted that NE_m requirement was 0.365 MJ/d per unit of $EBW^{0.75}$. Then, the NE_m requirements of the CONV steers in Simpfendorfer (1974) at various EBW were calculated as 0.365 × $EBW^{0.75}$ (MJ/d); thereafter the daily NE_m requirements were expressed per unit of P_{im}.

Database on Double-Muscled Piemontese Bulls. A database constructed during a feeding trial using 48 extremely lean DBM Piemontese bulls housed in 12 pens of initial BW 237 ± 24 kg, to evaluate the effects of dietary CP, rpCLA addition, and their interaction (Dal Maso et al., 2009; Schiavon et al., 2010b, 2011), was accessed. Rations ingredients and chemical composition are given in Table 2. Dry matter intake was recorded daily on a per-pen basis, orts were collected weekly, and bulls were weighed monthly. Fecal grab samples were collected from each animal during a first (229 to 349 d of age), a central (350 to 462 d of age), and a final (463 to 562 d of age) growing period, when the animals weighed (on average within period) 376, 532, and 640 kg, respectively. Samples of each feed ingredient of the diets, orts and feces were analyzed for their proximate composition (AOAC, 2000) and their NDF, ADF and ADL contents (Van Soest et al., 1991). Starch content was determined, after its hydrolysis to glucose (AOAC, 2000), by liquid chromatography (Bouchard et al., 1988). Acid detergent lignin levels were used to estimate the apparent digestibility of OM (**OMd**) and of other nutrients, and the results are detailed in Schiavon et al. (2012). The dietary gross energy (MJ/kg DM) of the diets was computed as: GE = 17.3 + 0.0617 × CP + 0.2193 × EE + 0.0387 × CF − 0.01867 × ash, where **EE** and **CF** represent ether extract and crude fiber, respectively, expressed in % of DM (Sauvant et al., 2004). Energy digestibility (%) was computed as **Ed** = OMd – 3.94 + 0.104 × CP + 0.149 × EE + 0.022 × NDF – 0.244 Ash, DE was computed as GE × Ed/100 (Sauvant et al., 2004), and ME was computed as 0.82 × DE (NRC, 1996). An automated gas production equipment (Ankom Gas Production System, Ankom technology, NY) described by Tagliapietra et al. (2010), was used to estimate in vitro the ME contents of diets following the procedures described by Tagliapietra et al. (2011). The ME content of the diet was estimated using the relationship proposed by Robinson et al. (2004) from 24 h gas production and from the chemical constituents of the diets. The test was conducted using 4 independent samples of 0.500 ± 0.0001 g for each diet and for each of 2 separate periods of incubation. Rumen liquor was collected from 3 dry Holstein Frisian donor cows which were fed hay ad libitum and 2 kg/d of concentrates for 2 wk, buffered and treated as described by (Tagliapietra et al., 2012).

The ambient temperature measured continuously over the trial with a digital thermometer (Opticom MCC-10, Opticom, Venlo, the Netherlands) was aver-

Table 2. Ingredient and chemical composition of experimental diets used for double-muscled Piemontese bulls

Item	Diets[1]	
	HP and HP_{rpCLA}	LP and LP_{rpCLA}
Total mixed ration ingredients, g/kg DM:		
Corn grain, ground	360	400
Corn silage	250	276
Sugar beet pulp, dried	102	113
Soybean, meal (480 g/kg CP solvent)	126	33
Wheat, bran	63	70
Wheat, straw	60	66
Vitamins and minerals mixture[2]	24	26
Calcium soap[3]	8	9
Soybean oil, hydrogenated	7	7
Chemical composition, g/kg DM[4]:		
Starch	357	393
NDF	287	303
ADF	137	145
CP	145	108
Ash	49	48
Ether extracts	41	42
ME, MJ/kg DM	11.8	11.7
NE_m, MJ/kg DM	7.9	7.8
NE_g, MJ/kg DM	5.2	5.1
ME from in vitro gas test, MJ/kg/DM[5]	11.5 ± 0.17	11.5 ± 0.18

[1]HP and LP diets contained 145 and 108 g of CP/kg, respectively; rpCLA = 80 g/d of top dressed rumen protected CLA (product coated with hydrogenated soybean oil; SILA, Noale, Italy; fatty acid composition and CLA profile is given by Schiavon et al., 2011).

[2]Containing per kilogram: 120 g of calcium, 56 g of sodium, 17 g magnesium, 16 g phosphorous, 240,000 IU of vitamin A, 15,000 IU of vitamin D3.

[3]Product based on hydrogenated palm oil (Hidropalm; NOREL, Madrid, Spain).

[4]Values computed from actual chemical composition of feed ingredients, ingredient composition and tabular ME values provided by NRC (1996). Net energy contents for maintenance (NE_m) and growth (NE_g) were computed according to NRC (1996).

[5]The in vitro gas test was conducted according to Tagliapietra et al. (2011), data are the mean and the SD of 4 replications for each of 2 separate periods of incubations.

aged on a daily basis and expressed in Celsius degrees (**T °C**). Expenditure of ME for cold (**ME_{cold}**) was quantified as (Johnson, 1986): $ME_{cold} = [4.184 \times 0.00115 \times (20 - T°C) \times BW^{0.75}] \div k_m$, where **$k_m$** is the ME use efficiency for maintenance computed, according to NRC (1996), from actual ME dietary content, as detailed later. The ME available for maintenance and growth was defined as ME intake (**MEI**) – ME_{cold}.

All bulls were slaughtered after 332 d of trial (average final BW: 668 ± 56 kg; age at slaughter: 562 ± 18 d) and, 24 h post mortem, the 5th rib cut was collected and analyzed in terms of moisture, protein, fat, and ash content, as detailed in Schiavon et al. (2011).

A very important point about DBM cattle is that its body fat content is minimal in both genders and that very little variations of body composition have been found over a wide range in slaughter weights, despite the use of diets with different ME and CP contents, and different rearing conditions. De Campeneere et al. (1999c) evidenced close linear relationships between body protein and lipid masses and EBW on DBM Belgian blue bulls slaughtered from 276 to 669 kg EBW, and the average body protein and lipid contents of these bulls were 201 ± 6.1 and 63 ± 18.3 g/kg EBW. On the same bulls, De Campeneere et al. (1999b) also reported that the composition of the 8th rib closely reflected the empty body composition, as the protein and lipid rib contents of the 8th were 207 ± 11.0 and 60 ± 20.0 g/kg, respectively. These data are quite similar to those we have found on the rib of the DBM Piemontese bulls of the present dataset, where the rib contained 209 ± 5.1 and 77 ± 19.3 g/kg of protein and lipid, respectively (Schiavon et al., 2011). No significant effects due to the nutritional history on carcass composition of DBM Belgian blue bulls were found by De Campeneere et al. (1999a) in an experiment conducted on 104 DBM Belgian blue bulls fed diets differing for ME and CP contents from 360 to 680 kg BW. De Campeneere et al. (1999a) also found that the longissimus thoracis muscle was composed by 757 ± 13, 225 ± 8, and 10 ± 0.9 g/kg of moisture, protein and fat, respectively. These data are also quite similar to the values found on the DBM Piemontese bulls of the present dataset, as the longissimus thoracis muscle was composed by 755 ± 5, 226 ± 4, and 8 ± 0.3 g/kg of moisture, protein and fat, respectively (Schiavon et al., 2011). A direct comparison of Belgian Blue and Piemontese DBM bulls (Biagini and Lazzaroni, 2005), reared under the same environmental conditions and slaughtered at the same age (557 ± 35.4 and 553 ± 46.9 d old, respectively), indicated that the carcasses of the 2 breeds were very similar in terms of commercial cuts and proportions of separable meat (800 ± 5.3 g/kg), fat (60 ± 8.8 g/kg) and bones (114 ± 9.4 g/kg), although these animals could have been in different stages of physiological maturity. These information allow to conclude, first, that DBM Belgian Blue and Piemontese bulls have very similar body, carcass, rib and muscle compositions, despite different nutritional histories, growth performance, stages of maturity and rearing conditions and second, that chemical body composition changes little over a wide range of BW so that body protein and lipid masses can be linearly related to BW, to the rib chemical composition or by a combination of the 2, as proposed by Fiems et al. (2005) to account for individual differences. The proposition that in DBM Belgian Blue bulls body protein, water, fat and ash are linearly related to BW was used by De Campeneere et al. (2001a) to estimate energy and protein requirements of DBM Belgian Blue bulls, using data from 333 DBM bulls collected during 5 consecutive years.

On this basis, the following computations were done to estimate body and gain compositions and the corresponding energy balances of the DBM Piemontese bulls of the present dataset (Table 3). In this step, only data about the 12 bulls (3 pens) fed the control diet containing 145 g CP/kg DM (**HP**) without addition of rpCLA were used, because these bulls were fed not limiting supply of CP without the addition of possible metabolic modifiers (rpCLA).

In these DBM animals, where the digestive tract as proportion of BW is less than in CONV cattle (Arthur, 1995), EBW was computed as 0.96 × 0.93 × BW (De Campeneere et al., 2001b). Empty body composition at the start of the trial was predicted using the equations proposed by De Campeneere et al. (2001b) based on the use of fasted BW (**fBW** = EBW/0.93) as sole predictor variable. Thus, body protein (**P_{start}**) and lipid (**L_{start}**) masses at start of the trial were estimated using the equations given in Table 3 at line 4 and 9, respectively. Protein mass at the end of the experiment (**P_{end}**) was predicted using the equation given in Table 3 (line 5), which considers the final EBW at the end of the trial (**EBW_{end}**) and the measured CP content of the rib (**CP_{rib}**) as inputs (Fiems et al., 2005). Fiems et al. (2005) did not provide equation with lipid content of rib as predictor variable. However, from the application of the De Campeneere et al. (2001b) equation ($L_i = -22.68 + 0.106 \times EBW \div 0.93$), using as input the mean of 596 ± 50.2 kg EBW_{end} found at the end of current trial (Schiavon et al. 2010b), resulted that the expected ratio between lipid mass (**L_{end}**) and EBW_{end} was 77 ± 3.1 g/kg EBW, comparable to the 77 ± 19.3 g of lipid/kg found in the ribs of current experiment (**$Lipid_{rib}$**). Thus, to exploit experimental data and fully consider individual variability, the value of L_{end} was computed as: $EBW_{end} \times lipid_{rib} \div 1000$. Protein and lipid masses at intermediate periods were computed from the values of body protein and lipid masses estimated at slaughter and from those estimated at the beginning of the trial by assuming linear changes with EBW, as mathematically described in the footnotes 2 and 4 of Table 3. Consequently, body protein and lipid masses at the start and the end of each growing period were used to compute Pr and Lr (Table 3, lines 12 and 13), and averaged to assess P_i and L_i within period (Table 3, lines 6 and 11, respectively).

The relative protein growth (**Pr/P_i**) ratios estimated over the course of the 3 growing periods were regressed against the corresponding natural logarithms of P_i, according to procedure of Emmans and Kyriazakis (2001). As the resulting semi-logarithm regression was linear with an R^2 of 0.978, P_m was computed as the antilog of the P_i logarithm at the point where the Pr/P_i ratio was 0. In this paper the abbreviation P_{im} was used to indicate this term: $P_i \div P_m \times P_m^{0.73}$. The daily NE_g levels were computed on the basis of chemical energy contents of 22.91 and 38.74 MJ/kg of Pr and Lr, respectively (De Campeneere et al., 2001b).

A first energy balance procedure was completed using the equations developed by Garrett (1980), currently accepted by the NRC (1996), which predict the ME use efficiencies for maintenance (**k_m**) and gain (**k_g**) using only dietary ME content as predictor variable; $k_m = [1.37 \times ME \div 4.184 - 0.138 \times (ME \div 4.184)^2 + 0.0105 \times (ME \div 4.184)^3 - 1.12] \div (ME \div 4.184)$; $k_g = [1.42 \times ME \div 4.184 - 0.174 \times (ME \div 4.184)^2 + 0.0122 \times (ME \div 4.184)^3 - 1.65] \div (ME \div 4.184)$. The NE_m requirement was computed as $NE_m = [(\text{ME available} - NE_g \div k_g) \times k_m] \div EBW^{0.75}$.

A second energy balance procedure, that proposed in the current work, was developed assuming fixed partial efficiencies of protein k_p and lipid k_l retention of 0.20 and 0.75, respectively (Geay, 1984). These coefficients were derived from a highly variable set of data, and some caution in their use, because of concern about possible interference due to ME intake and estimates of maintenance requirements, is required. However, as similar figures ($k_p = 0.19$ and $k_l = 0.75$) were given also by Rompala et al. (1987), these values were accepted. Thus, the amount of ME used for growth was quantified as $ME_g = Pr \times 22.91 \div k_p + Lr \times 38.74 \div k_l$, and the level of NE_m was assumed to be 1.625 MJ per unit of P_{im}, the average coefficient found for CONV cattle. The resulting k_m was estimated as $NE_m / (\text{ME available} - ME_g)$. With this procedure, it is assumed that the value of k_g depends only on the composition of the gain, and that the NE_m requirement is a function of current and mature protein masses. The resulting k_m parameter is a variable reflecting characteristics of the rations. The resulting k_m values were compared with those calculated using the equation of Garrett (1980).

Application of the Proposed Energy Balance Procedure on DBM Piemontese Bulls

The proposed energy balance procedure was applied, as an example of possible use, to evaluate the effects of different diets and increasing BW on k_m estimates, using all experimental data collected by Schiavon et al. (2010b) on DBM Piemontese bulls.

The trial, more extensively described by Schiavon et al. (2010b, 2011), involved 48 bulls aged 229 ± 18 d, divided into 4 groups and housed in 12 pens, and fed 4 corn silage- and cereal-based rations differing in CP content (145 or 108 g/kg DM), with or without addition of 80 g/d of rpCLA (Table 2). Body composition, and Pr and Lr values, of the bulls were estimated as previously described. In all instances, it was assumed that the P_m was identical to that of bulls receiving the HP control diet (138 ± 3.8 kg). Such assumption was done to avoid bias in the estimation of P_m due to low CP supply, with the low protein diet (**LP**) or to the use of rpCLA as pos-

Table 3. Comparison of different energy balance procedures applied on Piemontese double-muscled young bulls over 3 consecutive growing periods (experimental data)[1]

Line		Age of bulls, mo 7.6 to 11.6	11.7 to 15.3	15.4 to 18.7	Notations	Reference
Estimation of body and gain composition:						
1	Full BW at start, kg	281	470	594	Initial BW for each of 3 consecutive growing periods	Schiavon et al. (2010b)
2	Full BW at the end, kg	470	594	686	Final BW for each of 3 consecutive growing periods	Schiavon et al. (2010b)
3	Mean empty BW of period (EBW_i), kg	335	475	571	$EBW_i = 0.96 \times 0.93 \times$ average BW_i	De Campeneere et al. (2001b)
4	Body protein mass at start (P_{start}), kg	46	[81][2]	[104][2]	$P_{start} = [-9.1 + 0.206 \times EBW_{start} \div 0.93]$	De Campeneere et al. (2001b);
5	Body protein mass at the end (P_{end}), kg	[81][2]	[104][2]	121	$P_{end} = -19.115 + 0.18 \times EBW_{end} + 0.1449 \times CP_{rib}$ (g/kg) [3]	Fiems et al. (2005)
6	Mean body protein mass (P_i), kg	64	93	113	Mean of start and end body protein mass of period	
7	Mature body protein mass (P_m), kg	138	138	138	Estimated mature P mass, for equation see reference	Emmans and Kyriazakis (2001)
8	Protein scaling unit (P_{im}), $kg^{0.73}$	16.91	24.57	29.85	$P_{im} = P_i \div P_m \times P_m^{0.73}$	Emmans and Fisher (1986)
9	Body lipid mass at start (L_{start}), kg	11	[29][4]	[41][4]	$L_{start} = (1.93+0.0086 \times EBW_i \div 0.93)/100 \times EBW_i$	
10	Body lipid mass at the end (L_{end}), kg	[29][4]	[41][4]	49	$L_{end} = EBW_{end} \times lipid_{rib}$ (g/kg)[3] $\div$ 1000	
11	Mean body lipid mass (L_i)[a], kg	20	35	45	Mean of start and end body protein mass of period	De Campeneere et al. (2001b)
12	Daily protein retained (Pr), kg/d	0.291	0.205	0.174	Within period: $Pr = (P_{end} - P_{start}) \div$ period duration	
13	Daily lipid retained (Lr), kg/d	0.151	0.106	0.090	Within period: $Lr = (L_{end} - L_{start}) \div$ period duration	
14	Energy retained (NE_g), MJ/d	12.5	8.8	7.5	$NE_g = Pr \times 22.91 + Lr \times 38.74$	De Campeneere et al. (2001b)
15	ADG, kg/d	1.60	1.12	0.90	Measured within each growing period	Schiavon et al. (2010b)
16	DMI, kg/d	8.18	8.22	10.29	Obtained from daily measurements on pen basis	Schiavon et al. (2010b)
Energy balance based on dietary ME content:						
17	ME dietary content (ME), MJ/kg DM	10.67	10.63	10.76	From diet composition and digestibility, see reference	Sauvant et al. (2004)
18	ME intake, (MEI), MJ/d	87.3	87.4	110.7	MEI= DMI × ME content of diet	
19	ME used for cold, (ME_{cold})[5], MJ/d	5.2	0.0	10.5	$ME_{cold} = 4.186 \times 0.00115 \times (20 - T°C) \times BW^{0.75} \div k_m$	Johnson (1986)
20	ME available, MJ/d	82.1	87.4	100.2	ME available = ME intake – ME_{cold}	
21	ME use efficiency for maintenance (k_m)	0.647	0.646	0.649	Computed from ME at line 17, for equation see reference	Garrett (1980); NRC (1996)
22	ME use efficiency for gain (k_g)	0.408	0.407	0.411	Computed from ME at line 17, for equation see reference	Garrett (1980); NRC (1996)
23	$NE_m/EBW^{0.75}$, $MJ/kg^{0.75}$	0.390	0.384	0.418	$NE_m = [(ME\ available - NE_g \div k_g) \times k_m] \div EBW^{0.75}$	
Energy balance based on body and gain compositions:						
24	ME for gain (ME_g), MJ/d	41.2	29.0	24.6	$ME_g = Pr \times 22.91 \div 0.20 + Lr \times 38.74 \div 0.75$	Geay (1984)
25	Resulting k_g	0.304	0.304	0.304	$k_g = NE_g \div ME_g$	
26	ME for maintenance (ME_m), MJ/d	40.9	58.4	75.6	ME_m = ME available - ME_g	
27	Proposed NE_m/P_{im}, $MJ/kg^{0.73}$	1.625	1.625	1.625	Coefficient estimated from British beef breeds	Present paper Table 1, line 8
28	NE_m, MJ/d	27.5	39.9	48.5	$NE_m = 1.625 \times P_{im}$	
29	Resulting k_m	0.672	0.683	0.641	$k_m = NE_m \div ME_m$ (mean = 0.665)	

[1]Each data is the mean of 3 pen observations (with 4 bulls per pen) and regarded bulls fed diet with 145 g/kg DM without rumen protected CLA (Schiavon et al., 2010b).

[2]The body protein mass at intermediate times was computed as: $P_{intermediate} = P_{start} + (EBW_{intermediate} - EBW_{start}) \times (P_{end} - P_{start}) \div (EBW_{end} - EBW_{start})$.

[3]Measured CP (CP_{rib}; mean= 209 g/kg) and lipid ($Lipid_{rib}$; mean = 81 g/kg) contents of the 5th rib collected at slaughter at the end of the trial (Schiavon et al., 2011).

[4]The body lipid mass at intermediate times was computed as: $L_{intermediate} = L_{start} + (EBW_{intermediate} - EBW_{start}) \times (L_{end} - L_{start}) \div (EBW_{end} - EBW_{start})$.

[5]The environmental temperature outside the open stable (T°C) was measured continuously and averaged on a daily basis over the whole trial with a digital thermometer.

sible metabolic modifier. In fact, over the course of the trial the LP diet and the addition of rpCLA altered the pattern of growth in some periods with respect to the HP diet (Schiavon et al., 2010b, 2012). Thus, the resulting relationships between the relative protein retentions and the logarithms of P_i for these groups were not linear and the semi-logarithm regression approach to estimate P_m was not applicable. However, as at the end of the trial no differences were observed across treatments on the whole trial ADG, and on final BW, carcass weight, rib composition, and longissimus thoracis muscle composition (Schiavon et al., 2010b, 2011, 2012), the assumption of a common P_m value across treatments was considered acceptable.

As intake data were pen-based, all individual animal information was averaged by pen. Data were analyzed using the mixed procedure of the SAS software (SAS Inst. Inc., Cary, NC). We considered the effects of increasing age on trial (**A**), the feeding treatment (**T**), combinations of the 2 levels of CP and the 2 levels of rpCLA, the A × T interaction, and the pen block (**B**) to controls for pens containing animals of slightly lighter, average, or slightly heavier initial BW. The effects of T (3 df) and B (2 df) were considered to be fixed sources of variation to be tested with respect to the pen error term (e_1, 6 df) whereas the effects of A (2 df) and A × T (6 df) were tested on the residual error of the model (e_2, 16 df). Orthogonal contrasts using the e_1 error term were used to test the effects of CP and rpCLA, and the interaction CP × rpCLA.

The resulting k_m estimates were compared with the k_m values predicted using the experimental ME energy contents of the 4 rations, employing the equation of Garrett (1980). The means of the k_m values obtained using the 2 approaches, within each feeding treatment, were analyzed using the SAS NPAR1WAY procedure (the Kruskal-Wallis test).

RESULTS

Energy Balances

British Beef Database. Changes of P_i and L_i with increasing EBW of CONV steers, predicted by the Simpfendorfer (1974) equations are presented in Figure 1, together with those estimated for the DBM Piemontese bulls. The estimated P_i values of the CONV British beef steers were 62 and 80 kg at EBW of 337 and 479 kg (TAble 1). In this range, the relative increase in $EBW^{0.75}$ (from 78.7 to 102.4 $kg^{0.75}$) was similar to that estimated for P_i, being +30.1 and +29.5% respectively. Thus, both in the first and second stages of growth, the ratio of P_i to $EBW^{0.75}$ was close to 0.786. In contrast, the estimated L_i value increased by +93% over this period (from 73.2 to 141.1 kg), which was about 3 times the relative increase in $EBW^{0.75}$. From the application of the Simpfendorfer (1974) equations, a P_m of 103 kg at about 900 kg EBW was predicted.

The daily requirement for NE_m at various BW, recomputed from the Lofgreen and Garrett (1968) dataset, was 0.365 MJ/kg $EBW^{0.75}$, which is greater than the basic value of 0.322 MJ/kg $EBW^{0.75}$ proposed by the NRC (1996). NE_m expressed per unit of P_{im} averaged 1.625 $MJ/kg^{0.73}$ and was constant with increasing BW, because the relative increase in $EBW^{0.75}$ was similar to that of P_i.

Database on Double-Muscled Piemontese Bulls. The estimated P_i values of the DBM Piemontese bulls fed the HP diet of Schiavon et al. (2010b) were 64, 93, and 113 kg at average EBW of 335, 475, and 571 kg (Table 3), respectively; the first 2 EBW values are almost the same as those of CONV steers (Table 1). At maturity, such animals had an estimated P_m value of 138 ± 3.8 kg, thus about 34% greater than estimated for CONV steers. The degrees of maturity (the P_i/P_m ratios) at EBW of 335, 475 and 571 kg were 0.46, 0.67 and 0.82 for DBM cattle, whereas those for CONV steers at 337 and 479 kg EBW were 0.60 and 0.77, respectively. Unlike what was observed in CONV steers, the relative increase in average $EBW^{0.75}$ (+30%) between the first and second growing period of DBM bulls was much less than the relative increase in P_i (+45%). The same trend was evident between the second and third growing period; the relative increase in average $EBW^{0.75}$ was only +15% whereas that of P_i was +21.5%. Between the first and second period of growth, the relative increase in L_i (+76%) was somewhat less than the 92.8% observed for CONV steers, but, although the EBW were similar, the absolute L_i contents of animals of the 2 breeds were different (Table 3 and Figure 1). These ranged from only 20 to 35 kg for DBM bulls but from 73 to 141 kg for CONV steers. These data show that, with increasing BW, the body and gain composition of animals of the 2 breeds increasingly diverge because of

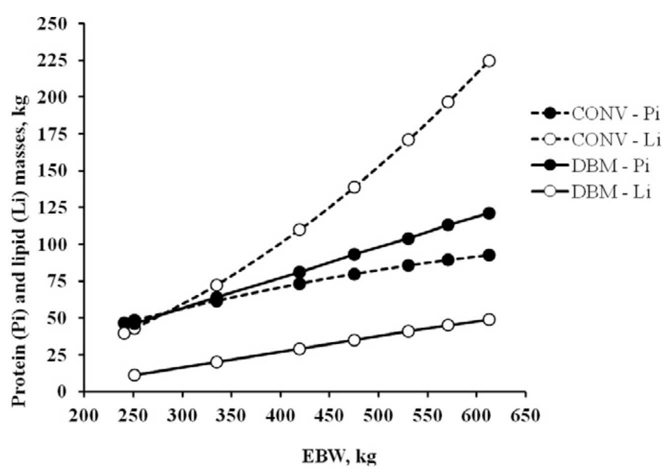

Figure 1. Predicted body protein (P_i) and lipid (L_i) masses with increasing empty body weight (EBW) in medium frame British beef steers (CONV) and in double-muscled Piemontese bulls (DBM).

differences in the amounts of protein and lipid deposited. In DBM animals, the daily NE_g decreased with increasing BW because the daily protein gain decreased and the daily lipid gain ranged only from 0.150 to 0.090 kg/d, notwithstanding the fact that the bulls were fed high-energy diets ad libitum.

The measured dietary ME contents (Table 3, line 17) were on average about 10% less than those computed from the NRC (1996) tabular values (11.8 MJ/kg DM) and less than the 11.5 MJ/kg DM resulting from the in vitro gas test presented in Table 2. However, the DM intakes of these DBM bulls were high (86 ± 9.5 g/kg of $BW^{0.75}$ per day over the whole trial) and comparable with the 91 g/kg $BW^{0.75}$ found on Charolaise and Hereford steers fed corn silage based diets with ADF contents similar to those of the current experiment (Woody et al., 1983), and to the 89 g/kg $BW^{0.75}$ which resulted from the application of the NRC (1996) equation (Eq. 7-1) based on the shrunk BW (**SBW** = average full BW × 0.96), the measured NE_m concentration of the ration (7.11 MJ/kg DM), and considering a 6% decrease in DM intake which is suggested when growth-promoting implants are not used (NRC, 1996). This despite the fact that in DBM bulls the digestive tract as proportion of BW is much smaller than in CONV bulls (Arthur, 1995). The NE_m estimates computed from the ME contents of rations given to the DBM bulls (Table 3, line 23) increased between 0.390 and 0.418 MJ/$EBW^{0.75}$ with increasing BW, and these values were on average 11% greater than those of 0.365 MJ/$EBW^{0.75}$ figures computed for CONV steers (Table 1).

Application of the energy balance procedure based on body and gain composition showed that ME_g (Table 3, line 24) decreased markedly with increasing BW because of the obvious decrease in NE_g, (Table 3, line 14). The value of the resulting k_g (Table 3, line 25) was attributable to the ratio of fat to protein deposition: 1g of protein deposited costs 114 kJ ME, but 1g of lipid deposited costs only 52 kJ ME. In DBM cattle, Pr was much greater than Lr, and the resulting k_g estimates were thus much lower (0.30 on average) than were those computed using the traditional energy balance procedure based on dietary ME content (0.41 on average, Table 3, line 22). The latter approach was developed in work on CONV steers; these animals have much greater Lr/Pr ratios. To compare the different k_g estimates, the NRC (1996) equations (Eq. 3-2 and 3-3) were used to estimate the amount of NE retained as lipid (**NE_l**) and protein (**NE_p**) in CONV steers, at the NE_g values that applied in DBM Piemontese bulls during the first growing period (12.5 MJ/d). The resulting amounts of fat and protein deposited were 0.218 and 0.169 kg/d, respectively, corresponding to 8.46 and 3.87 MJ NE/d for lipid and protein gain. Assuming that k_l = 0.75 and k_p = 0.20, the resulting k_g for CONV steers was confirmed to be 0.40 [$k_g = NE_g \div (NE_l \div 0.75 + NE_p \div 0.20) = 12.5 \div (8.46 \div 0.75 + 3.87 \div 0.20) = 0.40$].

The ME_m estimates, obtained as ME available minus ME_g values, increased markedly with increasing age (Table 3). Assuming that NE_m scaled to P_{im} was the same as that computed for CONV steers (1.625 MJ per unit of P_{im}), the resulting k_m value (NE_m/ME_m) for DBM Piemontese bulls (0.665) did not differ on average (P = 0.12) from the value of 0.647 estimated from dietary ME content using the equation of Garrett (1980) that is currently adopted by the NRC (1996).

Effects of Dietary Treatments and Increasing BW on k_m Values

None of the body composition or the daily retention values for protein, fat, and energy appeared to be influenced by dietary treatment (Table 4), even though a numerical difference of 21% in lipid retention was not detected as significant. At an average EBW of 448 kg, the P_i and L_i parameters accounted for 86.9 and 28.9 kg, respectively. Daily accretion of protein was, on average, double that of fat. No between-treatment difference was observed in terms of DMI, MEI, available dietary ME and NE_g. Also, the k_g value was not affected by treatment; this parameter averaged only 0.30, as the Pr term (low efficiency) prevailed over the Lr parameter (high efficiency). Conversely, the estimated ME_m levels were influenced (P = 0.033) by the CP × rpCLA interaction. NE_m averaged 37.0 MJ/d and the resulting k_m averaged 0.64; the effect was significant (P = 0.013) because of the CP × rpCLA interaction. The values of k_m computed using the equation of Garrett (1980) applied to experimental data on dietary ME content averaged 0.65, very close to the previous value, but they were not significantly influenced by treatment (P = 0.09).

Over the 3 growth periods, the average EBW increased from 326 to 563 kg, the estimated P_i and L_i increased from 61 to 111 kg, and from only about 17 to 41 kg, respectively. Protein retention decreased significantly (P < 0.001) from 273 to 170 g/d between the first and last growing period. A significant influence of the A × T interaction (P = 0.039) was evident because, during the first growth period, the bulls fed LP grew less than did those given HP. No significant differences in Lr values were observed with advancing growth stage; the average value was 107 g/d. Because of the reduction in protein accretion over the course of the trial, the value of k_g increased significantly with increasing age (P < 0.001). With increasing age, the estimated amounts of ME_m and NE_m increased from 42.4 to 74.2 MJ/d and from 26.2 to 47.6 MJ/d, respectively. The resulting k_m averaged 0.64 and did not show any significant change with increasing age (P = 0.61). Neither the feeding treatment nor increasing age significantly influenced the k_m values of Garrett (1980).

Table 4. Application of the proposed procedure to evaluate the effects of different diets and increasing age on the ME use efficiency for maintenance (k_m) of double-muscled Piemontese bulls from 7.6 to 18.7 mo of age (from 278 to 668 kg BW) and slaughtered at the end of the trial

	Treatment (T)[1]				SEM	Age on trial (A)[2], mo			SEM	*P*-values				
	HP	HP_{rpCLA}	LP	LP_{rpCLA}	pen	7.6 to 11.6	11.7 to 15.3	15.4 to 18.7	error	CP	rpCLA	CP×rpCLA	A	A×T
Obs.	9	9	9	9		12	12	12						
Mean full BW, kg[3]	520	501	489	501	9.1	365	512	631	5.4	0.12	0.68	0.12	<0.001	0.31
Mean empty BW, kg[3]	464	447	436	447	7.8	326	457	563	4.8	0.12	0.68	0.12	<0.001	0.31
ADG, kg/d	1.23	1.12	1.15	1.19	0.041	1.43	1.15	0.93	0.036	0.88	0.40	0.12	<0.001	0.049
Body protein (P_i), kg	89.9	86.5	84.3	86.8	1.93	61.1	88.8	110.9	1.20	0.21	0.80	0.17	<0.001	0.31
Body lipid, (L_i), kg	31.1	28.9	27.8	27.7	1.32	16.7	29.1	40.7	1.01	0.13	0.38	0.45	<0.001	0.98
Protein scaling unit[4], (P_{im}), $kg^{0.73}$	23.8	22.9	22.3	22.9	0.51	16.1	23.5	29.3	0.32	0.21	0.81	0.18	<0.001	0.31
Retentions														
Protein (Pr), kg/d	0.228	0.210	0.215	0.222	0.0084	0.273	0.213	0.170	0.0069	0.99	0.52	0.14	<0.001	0.039
Lipid (Lr), kg/d	0.120	0.099	0.105	0.104	0.0116	0.102	0.117	0.102	0.0092	0.68	0.38	0.42	0.41	0.95
Energy (NE_g), MJ/d	9.9	8.6	9.0	9.1	0.49	10.2	9.4	7.8	0.42	0.69	0.31	0.20	0.003	0.45
DMI, kg/d	8.89	8.71	9.00	8.83	0.163	8.03	8.34	10.22	0.099	0.51	0.32	0.98	<0.001	0.39
Dietary ME, MJ/kg DM[5]	10.69	10.91	10.70	10.26	0.155	10.47	10.77	10.69	0.134	0.09	0.50	0.07	0.29	0.86
ME intake (MEI), MJ/d	95.0	95.0	96.3	90.6	1.85	84.1	89.8	109.2	1.35	0.45	0.15	0.16	<0.001	0.37
ME for cold (ME_{cold}), MJ/d	5.2	5.1	5.0	5.2	0.07	5.1	0.0	10.3	0.06	0.61	0.96	0.09	<0.001	0.53
ME available, MJ/d[6]	89.8	89.9	91.3	85.4	1.84	79.0	89.8	98.9	1.29	0.45	0.14	0.13	<0.001	0.41
Resulting k_g [7]	0.311	0.298	0.302	0.297	0.011	0.279	0.309	0.318	0.0069	0.64	0.47	0.74	<0.001	0.92
ME_g, MJ/d[8]	32.3	29.1	30.0	30.9	1.12	36.57	30.43	24.69	1.042	0.82	0.35	0.13	<0.001	0.08
ME_m, MJ/d[9]	57.5	60.8	61.3	54.5	1.89	42.4	59.4	74.2	1.64	0.55	0.35	0.033	<0.001	0.95
NE_m scaled to P_{im}, MJ/d[10]:	38.7	37.2	36.2	37.2	0.83	26.2	38.2	47.6	0.48	0.21	0.81	0.17	<0.001	0.31
Resulting k_m[11]	0.67	0.61	0.59	0.68	0.021	0.62	0.64	0.64	0.021	0.65	0.49	0.013	0.61	0.75
$k_{m\text{-Garrett (1980)}}$[12]	0.65	0.65	0.65	0.64	<0.01	0.64	0.65	0.65	<0.01	0.08	0.51	0.09	0.23	0.86

[1]The high-protein (HP) and low-protein (LP) diets contained 145 and 108 g of CP/kg, respectively; rpCLA = 80 g/d of top-dressed rumen protected CLA (SILA, Noale, Italy). Data are the means of 3 pen observations × 3 consecutive growing periods (with 4 bulls for pen).

[2]Each data is the pen-mean of 4 treatments × 3 pens (with each pen housing 4 bulls).

[3]Data were computed as mean of initial and final full BW (and EBW) of each period.

[4]$P_{im} = P_i \div P_m \times P_m^{0.73}$, where P_m (138 ± 3.8 kg) is the adult body protein mass computed using the data of bulls fed the not limiting conventional HP diets.

[5]Computed from diet composition and organic matter digestibility, according to Sauvant et al. (2004).

[6]ME available for maintenance and gain, computed as MEI – ME_{cold}.

[7]ME efficiency for gain, computed as: (Pr × 22.91 + Lr × 38.74) ÷ (Pr × 22.91 ÷ 0.20 + Lr × 38.74 ÷ 0.75).

[8]ME used for gain, computed as: Pr × 22.91 ÷ 0.20 + Lr × 38.74 ÷ 0.75.

[9]ME used for maintenance, computed as MEI – ME_{cold} – ME_g.

[10]NE used for maintenance, computed as 1.625 × P_{im}.

[11]ME use efficiency for maintenance computed as $NE_m \div ME_m$.

[12]Computed using equation from Garrett's (1980), given by NRC (1996), using as input the experimental dietary ME contents of the 4 experimental rations.

The k_m values calculated using the procedure described in the present report did not differ from the values estimated by application of the equation of Garrett (1980) when data on animals on the HP (*P* = 0.45) and the LP_{rpCLA} (*P* = 0.12) rations were used, but differed in bulls on the HP_{rpCLA} (*P* = 0.015) and LP (*P* = 0.009) rations (Figure 2).

DISCUSSION

Dietary ME Contents and DMI of the DBM Piemontese Bulls

The dietary ME contents (Table 3, line 17, and Table 4) were estimated on all the 48 DBM Piemontese bulls in 3 collecting periods during the trial. This was possible using the technique of the internal marker (ADL) on the fecal samples collected from the bulls maintained in their pens and full fed the experimental diets. The average ME contents obtained were about 10% less than those computed from the NRC (1996) tabular values and about 9% lower than the values resulting from the in vitro gas test. Such discrepancy could have been due to different factors. The ME tabular values are commonly measured at maintenance; and it is commonly accepted that energy digestibility decreases with increasing intakes. Direct analysis of 72 experiments in which level of feeding was varied evidenced that the depression of metabolizability (q = ME/GE) occurred with diets with a q value less than 0.623 MJ/MJ (ARC, 1980). In the current experiment the q-value averaged 0.571 ± 0.0403 at levels of intakes of about 2.0, 1.5, and 1.5 for the 3 consecutive periods of growth, respectively. Thus, according to the relationship (# 3.3) given by ARC (1980), the dietary ME concentrations of the current experiment would be

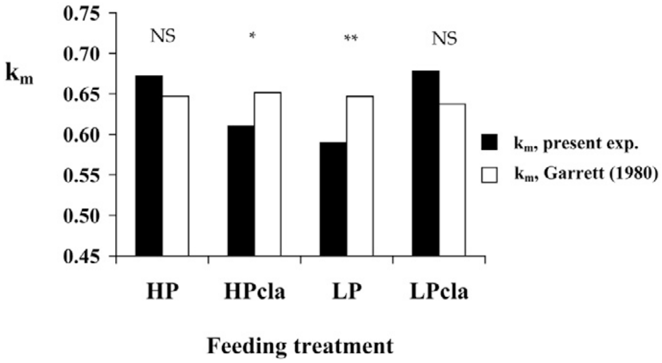

Figure 2. Estimates of efficiency of ME use for maintenance (km; NEm/MEm) based on gain and body compositions (proposed procedure) and on the ME content of rations (Garrett, 1980). The km means resulting from the 2 energy balance procedures within each feeding treatment (HP = high protein ration; HPcla = HP plus 80 g/d of rumen protected CLA; LP = low protein ration; LPcla = LP plus 80 g/d of rumen protected CLA) were analysed using NPAR1WAY procedure (Kruskal-Wallis test; SAS Inst. Inc., Cary, NC); results are presented as means. $^*P < 0.05$; and $^{**}P < 0.01$; and NS = not significant.

underestimated by about 2.9, 1.9 and 1.9% with respect to that expected when measured at maintenance, in the 3 growth phases respectively. On the opposite, some overestimation of digestibility due to the use of ADL as internal marker would be likely to occur. This technique has been found to overestimate digestibility, because of incomplete marker recovery (Sunvold and Cochran, 1991). Undersander et al. (1987) showed that with high quality forages, with digestibility above 55 to 60%, the differences between digestibility values computed from total collection and the use of ADL as a marker are usually small (1 to 3%) and Judkins et al. (1990) show a trend for ADL and for some other indigestible internal markers to accurately predict digestibility of diets containing concentrates. Thus in the current experiment, a possible modest underestimation of the dietary ME content, due to a level of intake above maintenance, would have been compensated by a modest overestimation due to a possible incomplete ADL recovery. Because of the decreased size of viscera due to the pleiotropic effect of the mh-gene, DBM bulls have a small rumen and a very short digestive tract (also reflected by the great dressing percentage of the DBM bulls), which has been considered the cause of low DM intakes, from which the need for a high energy and protein diet has been suggested (De Campeneere et al., 2001a). However, in the current experiment, DM intake ranged between 90 and 100 g/kg $BW^{0.75}$ during the initial period of growth and averaged 86 ± 9.5 g/kg of $BW^{0.75}$ per day over the whole trial, and these values are nearly comparable those of Woody et al. (1983) and to those which were predicted using the NRC (1996) relationship. Because DMI intake is comparable, whereas the size of their digestive tract is much smaller than that of CONV steers, the notable difference between the NRC (1996) tabular values and the present estimates of dietary ME contents was likely due to a reduced digestibility in the DBM Piemontese bulls as a consequence of a reduced permanence of feed in the digestive tract.

Growth Performances of the DBM Piemontese Bulls

Over the whole trial, ADG averaged 1.16 kg/d, whereas dressing percentage averaged 67.3% of full BW. The growth performance obtained in this trial quite accurately represented those commonly achieved on commercial farms of Piemontese bulls, where bulls are commonly fed rations based on hay and concentrates. The average age of the bulls at slaughter was slightly greater (562 vs. 523 d) than the average age at slaughter found in a survey conducted on 804 young bulls from 109 sires fattened in 124 farms of the Piemonte region (Boukha et al., 2007). In the current study, carcass weight was also slightly greater (450 vs. 417 kg) but the carcass weight:age ratio was very similar (0.801 vs. 0.797 kg/d, respectively) to that found in the survey by Boukha et al. (2007). In addition, the growth rate achieved to approximately 1 yr of age in this trial was very similar (1.43 vs. 1.40 kg/d, respectively) to that shown, at the same age by 988 young DBM Piemontese bulls under performance testing (Albera et al., 2001). The average BW at 11.6 mo of age was 448 vs. 434 kg for the bulls in this trial (Schiavon et al., 2010b) and the performance tested bulls, respectively. In addition, the decrease in growth rate of Piemontese bulls after 1 yr of age was expected because this is, based on the hip height, a medium-framed DBM breed.

In this work, a number of basic equations taken from NRC (1996) were used for the proposed energy balance in the DBM cattle, but this energy system, as a whole, was not applicable to predict the energy requirement for growth and the composition of gain of these bulls. This system assumes that cattle have a similar body composition at the same degree of maturity. The concept of equivalent weight is implemented by adjusting the BW of cattle of various body size and sexes to a weight at which they are equivalent in body composition to the steers in the Garrett (1980) database. This adjustment is performed as: EQSBW = SBW × (SRW/FSBW), where EQSBW is the shrunk weight equivalent to the NRC (1996) medium frame size steer, SBW is shrunk body weight being evaluated, SRW is standard reference shrunk weight for the expected final body fat (which 478 kg at 28% body fat), and FSBW is final shrunk body weight at the expected final body fat. The knowledge of EQSBW is required to predict a number of data, among which the energy retained in gain (**RE**), Pr and Lr would be relevant for this work. To use this system the user needs to identify the expected BW (EQSBW) at which the cattle will be at approximately 28% body fat, the

USDA low Choice grade (Tilutki et al., 1994). A 28% body fat was never found in DBM cattle, neither in bulls, nor in DBM mature beef cows. For example Fiems et al. (2005), evidenced that body fat averaged 12.0 ± 3.4% in 5 yr old DBM Belgian Blue cows of 744 kg BW. To our knowledge this kind of DBM cattle are unable to reach 28% body fat, and therefore any values that one would assume for EQSBW, would produce estimates of RE, Pr and Lr with little theoretical and practical value.

Net Energy Requirements for Maintenance and Growth

Current feeding standards have adopted metabolizable or net energy systems to calculate partition of energy between maintenance and growth. Maintenance represents a large part of total energy costs in cattle and most current energy calculation systems feature an energy expenditure term (*a*) calculated per unit of metabolic weight (Cannas et al., 2010). The basic NE_m of beef cattle has been estimated to be 0.322 MJ × $EBW^{0.75}$ (NRC, 1996). This figure was derived principally from comparative slaughter trials conducted on growing steers and heifers of British beef breeds penned in non-stressful environments (Lofgreen and Garrett, 1968; Garrett, 1980). Several studies reviewed by the NRC (1996) indicated that various factors significantly influenced maintenance requirements, as expressed per unit of $EBW^{0.75}$; breed and gender were particularly important. To deal with this problem, the NRC (1996) proposed the use of various multipliers to adjust for differences between gender and of breed. Citing the data of Andersen (1980) and Webster et al. (1982), the NRC (1996) indicated that young Chianina bulls had maintenance energy requirements, expressed per kg $EBW^{0.75}$, about 30% greater than those of Angus and Hereford cattle. De Campeneere et al. (2001a), using a French energy system-based approach (Vermorel, 1978), found that maintenance requirements were surprisingly greater (+57%) in DBM Belgian Blue bulls [compared with the calculation of the NRC (1996)], and a similar figure (+42%) was estimated by Schiavon et al. (2010a) in a work on DBM Piemontese bulls. Differences in NE_m estimates may be expected when different energy systems are used, principally because of variations in the nature of the experimental data (from comparative slaughter trials, from energy balances calculated using respiration chambers, or from feeding trials; Cannas et al., 2010). Such differences also arise because accurate quantification of the energy requirements of immature animals is impaired by the colinearity and interdependency of maintenance and growth and by variations in the partial efficiency values k_m and k_g. The use of a single partial efficiency term linking ME_g to NE_g, adopted by the major energy balance systems currently employed, has probably introduced a further element of inaccuracy.

The concept of metabolic weight applied to studies on immature growing animals is commonly used to explain the average increase in the levels of fatty depots seen with increasing BW and an increasing extent of maturity; both factors combine to decrease energy expenditure per kilogram of BW. However, Oldham and Emmans (1990) considered that it was biologically unreasonable to expect maintenance requirements to be precisely related to scaled BW when the body composition may vary in terms of protein and fat content. The inadequacy of $EBW^{0.75}$ when used as a size-scaling factor is also evidenced by the results of Geay (1984); the cited author showed that the $EBW^{0.75}$-scaled maintenance requirements decreased with increasing BW. The reduction in NE_m per unit of $EBW^{0.75}$ with increasing BW was much more pronounced in Friesian than in Charolais bulls, and in heifers compared with bulls (Geay, 1984), probably because body compositions differed.

An alternative suggestion is that of Emmans and Fisher (1986); the cited authors were of the view that the energy requirements for maintenance of growing mammals could be more precisely quantified if they are scaled to a function of P_i and P_m, rather than to $EBW^{0.75}$. The proposal that maintenance is directly proportional to protein weight is not new (Russel and Wright, 1983; Emmans and Fisher, 1986). Maintenance was found to be directly proportional to body protein weight in growing chickens (Emmans, 1994). In normally-growing sheep, this proposal was found to be equivalent to the assumption that maintenance is scaled to $BW^{0.73}$ (Blaxter et al., 1978; Emmans, 1987). This similarity was seen as a fortuitous outcome of the particular fattening characteristics of sheep that make protein weight proportional to $BW^{0.73}$ during growth (Emmans and Kyriazakis, 2001). A further important indication is that both Geay (1984), and Rompala et al. (1987), working on different cattle breeds, reported k_p and k_l values that were very different, being close to 0.20 and 0.75, respectively. In our present work, we included this information using separate energy efficiency measures for Pr and Lr, as suggested by Geay (1984). We also scaled NE_m on P_i and P_m as suggested by Emmans and Fisher (1986). When we assume that NE_m is proportional to current body protein mass and degree of maturity ($P_i \div P_m \times P_m^{0.73}$) we do expect that the NE_m would be constant at any EBW only in the particular case where P_i is a constant proportion of EBW. This is almost true for DBM, because the P_i/EBW ratio was not constant but slightly changed with increasing EBW, and absolutely not true for the CONV steers. In the case of DBM bulls the NE_m values, computed as ME_m × resulting k_m (Table 4), were 26.2, 38.2 and 47.6 MJ/d in the 3 consecutive growing periods. The NE_m increased from 0.081 to 0.084 MJ/d when expressed per unit of EBW (+ 4.4%), and from 0.343 to 0.410 MJ/d when expressed per unit of $EBW^{0.75}$. In contrast, for CONV cattle current literature suggests that NE_m is constant per unit of $EBW^{0.75}$ (Table 1), or that decreases from 0.085 to 0.078 MJ/d per unit of EBW. Our resulting NE_m estimates, scaled on body protein, were very similar for CONV steers and DBM Piemontese bulls, although British beef and DBM breeds can be considered to lie at the 2 extremes of the biological range of average body fatness and fat gain. In fact, we found that when the NE_m requirement computed using British steers (1.625 MJ per unit of P_{im}; $MJ/kg^{0.73}$) was applied to data on DBM Piemontese bulls, the resulting energy efficiency [$k_m = (NE_m \div (ME\ available - NE_p \div k_p - NE_l \div k_l)$] did not differ from that computed using the original equation of Garrett (1980), which uses only experimental dietary ME content as a predictor variable for k_m. This supports the view that cattle that differ greatly in gain and body compositions have similar energy requirements in terms of growth and maintenance providing that: a) the amount of ME used for growth is estimated employing Pr and Lr and the respective k_p and k_l values; and b) NE_m is scaled to a function of P_i and P_m. These results are based on a small number of observations and more work is needed, but the good correspondence between various items of energy balance seen when cattle of very different breeds were compared and the agreement with theoretical expectations indicate that this approach is promising.

Effects of Dietary Treatments and Increasing BW on Energy Efficiency

A combination of information on body and gain compositions is useful also in a study of changes in energy efficiency (induced by dietary modifications) that are not explicable considering only dietary composition and digestibility.

To show a potential application, the energy balance approach proposed in the present work was applied to experimental data obtained from DBM Piemontese bulls (Schiavon et al., 2010b). In Europe, the DBM breeds, Piemontese and Belgian Blue, supply only a small proportion of the total beef produced, but such animals are widely used for crossbreeding with dairy cows, substituting continental CONV beef breeds (Dal Zotto et al., 2009; Penasa et al., 2009; McHugh et al., 2010). Piemontese bulls are selected for ADG, muscularity, and direct and maternal calving ease (Carnier et al., 2000; Albera et al., 2001; Kizilkaya et al., 2002, 2003; Mantovani et al., 2010). Despite differences in myostatin gene alleles between the 2 DBM breeds (Kambadur et al., 1997), both the Belgian Blue (Clinquart et al., 1998; Fiems et al., 1998; Cuvelier et al., 2006), and Piemontese breeds (Casas et al., 1998; Biagini and Lazzaroni, 2005; Boukha et al., 2007; Ribeca et al., 2009; Boukha et al., 2011) are characterized by a very high potential for lean growth and by very low fat deposition, even at high BW.

Our statistical analysis of energy balance obtained from data gathered using DBM Piemontese young bulls evidenced a significant effect of the CP × rpCLA interaction on the estimated ME available for maintenance, ME_m, and on the resulting k_m. However, ME_m was computed as a difference and so the decreased ME intake observed for the LP_{rpCLA} treatment group, with no apparent difference in weight gain, would have led to an apparent reduction of the ME maintenance requirements for this treatment. Alternatively, assuming that ME maintenance requirements were constant across diets, it also would be possible that this treatment improved the k_g value of the LP_{rpCLA} ration. In any case, this approach was adequate for discriminating the energy efficiencies of diets with similar ME content, but differing for suboptimal nutrient content, such as dietary CP, or that are supplemented with biologically active substances, such as rpCLA.

In addition, our proposed approach suggests that the value of k_m is not influenced by the stage of growth, although almost all items of the energy balance were significantly influenced by increasing age and BW (with the exception of estimated lipid retention because of the very low propensity of DBM bulls to gain fat). This is in agreement with the theoretical expectation that NE_m requirements should be principally influenced by the degree of maturity and mature protein mass, whereas ME use efficiency is associated principally with ration characteristics.

The use of multiplier factors to adjust maintenance requirements scaled on $EBW^{0.75}$ is inadequate to quantify the NE requirement of DBM cattle because, on the basis of the current knowledge, body protein content can be assumed to remain almost constant over extended ranges of EBW (Figure 1). In contrast, in British beef breeds (Continental and dairy breeds are intermediate), the increase in the P_i/P_m ratio is curvilinear with increasing EBW and it is linearly related to the increase in $EBW^{0.75}$ (Figure 1), to the extent that Simpfendorfer (1974) equations adequately estimate body composition. Besides the use of $EBW^{0.75}$ as a size-scaling factor for maintenance requirement, the employment of multipliers is intended to adjust the average requirement of a given breed or gender which is leaner compared with the standard. However, this does not consider that maintenance requirements change with increasing maturity. Thus, a multiplier factor > 1.00 would produce an estimated maintenance energy requirement of a very young DBM calf greater than that of a CONV calf of the same weight, even if their body compositions are likely very similar (overestimation of the DBM maintenance energy requirement). On the opposite, for older animals the adjustment does not consider the divergent body composition of CONV and DBM animals, and therefore the energy requirements for maintenance of DBM cattle would be underestimated.

Conclusions

We conclude that use of metabolic weight as a size-scaling factor does not fully explain the differences among immature cattle that, at similar BW, show different and divergent body and gain compositions. Double-muscled and CONV steers, which differ considerably in body and gain compositions, have similar energy requirements if these are properly related to the degree of maturity, mature body protein mass, gain composition, and ME use efficiency specific for protein and lipid gains. It is to be expected that the same could be true within conventional genotypes (i.e., bulls vs. steers and heifers; British vs. Continental breeds) even if it should be recognized that, for practical purpose, current NE systems explain much of the variation observed in feedlot cattle, except for very lean cattle. Thus, providing that body and gain compositions are known or accurately predicted by reliable tools, we propose: a) that ME_g can be quantified from protein and lipid retention using separate ME efficiencies for protein ($k_p = 0.20$) and lipid ($k_l = 0.75$); b) that NE_m can be predicted as $1.625 \times P_i \div P_m \times P_m^{0.73}$ (MJ/kg$^{0.73}$); and, c) that the k_m value can be predicted by combining information on body and gain composition and the ME content of the diet. This system is conceptually simple; the approach avoids the use of adjustment factors for gender and breed; the equations hold true over a wide range of BW; and the approach can be used to analyze variations in energy efficiency induced by dietary modification. The major problem in application of this approach is the lack of data on body and gain composition. Further efforts seeking to bolster our results are necessary, and the use of data from comparative experiments employing growing calves of breeds differing in propensity for protein and fat gain would be very useful.

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