MOZART ALVES FONSECA

EVALUATION AND DEVELOPMENT OF MATHEMATICAL MODELS TO EXPLAIN BEEF CATTLE GROWTH, AND ITS RELATIONSHIP WITH NUTRITIONAL REQUIREMENTS OF F1 NELLORE X ANGUS BULLS AND STEERS

Thesis submitted to the Universidade Federal de Viçosa and Office of Graduate Studies in Animal Science as partial fulfillment of the requirements for the degree of *Doctor Scientiae.*

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APPROVED: August 01, 2013

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DEDICATION

To my parents Mozart Dias da Fonseca and Roseli Alves da Fonseca, who had always supported and inspired me with their hard work, honesty, dedication and love above all. You have always been my way back home. To my siblings Ana Paula and Emilio whom with me have shared every tear of effort.

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BIOGRAPHY

MOZART ALVES FONSECA, son of Mozart Dias da Fonseca and Roseli Alves da Fonseca was born in São Gonçalo do Sapucaí, Minas Gerais, in February 7th 1983. In January 2008, graduated in Agronomic Engineering from Universidade Federal de Viçosa.

In February 2008, started the Master's program at the Department of Animal Science of the Universidade Federal de Viçosa focusing his research in Ruminant Nutrition and Beef Cattle Production, submitting to thesis defense in July 29th of 2009.

In August 2009, started the Doctorate program at the Department of Animal Science of the Universidade Federal de Viçosa focusing his research in Ruminant Nutrition and Beef Cattle Production.

In March 2011, started collaborative research at Texas A&M University through the sandwich program under the guidance of Dr. Luis Orlindo Tedeschi, focusing his research in Mathematical Modeling and Model Evaluation for Ruminants.

In July of 2013 submitted to dissertation defense under the guidance of Prof. Sebastião de Campos Valadares Filho and Prof. Luis Orlindo Tedeschi with Prof. André Soares de Oliveira, Prof. Mario Fonseca Paulino and Prof. Mario Luiz Chizzotti.

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ABSTRACT

FONSECA, Mozart Alves, D.Sc., Universidade Federal de Viçosa, August, 2013. **Evaluation and development of mathematical models to explain beef cattle growth, and its relationship with nutritional requirements of F1 Nellore x Angus bulls and steers.** Adviser: Sebastião de Campos Valadares Filho. Co-advisers: Luis Orlindo Tedeschi and Mario Luiz Chizzotti.

This present study was performed in five interconnected steps as follows: first a comparative slaughter trial was conducted with 48 F1 Nellore x Angus bulls (B) and steers (S), to assess the net requirements of protein and energy for growth and maintenance. The animals used had 12.5±0.51 mo of age, and average shrunk BW (SBW) 233±23.5, and 238±24.6 kg for B and S respectively. Animals were fed 60:40 ratio of corn silage:concentrate. Eight animals were slaughtered at the beginning of the trial and the remaining animals were randomly assigned in a factorial 2 (genders) x 3 (slaughter weights) arrangement. The remaining animals were slaughtered when the average BW of de group reached 380 (6B and 5S), 440 (6B and 5S), and 500 kg (5B and 5S). The cleaned gastrointestinal tracts, organs, carcasses, heads, hides, tails, limbs, blood, and tissues were weighed to measure empty BW (EBW). These parts were ground separately and sub-sampled for chemical analyses. For each animal within a period, DMI was measured daily and samples of feces were collected to determine diet digestibility. There were no differences ($P > 0.05$) in net energy required for maintenance (NEm) among genders. The combined data indicated a NEm of 70 kcal/kg$^{0.75}$ of EBW/d, with a partial efficiency of use of ME to NE for maintenance of 0.72. The MEm observed was 96.96 Mcal/kg$^{0.75}$/d. The partial efficiency of use of ME to NE for growth was 0.41 for bulls and steers. The metabolizable protein requirements for maintenance were 2.14 g/BW0, 75/d. The net requirements had coefficients ‘a’ and ‘b’ for the allometric equation NPg (g/kg EBW/d) = a. EBW^{b}, ranging from -0.722 to -0.6118 for ‘a’ and from 1.0047 to 0.9586 for ‘b’, for bulls and steers, respectively. Thirdly, equations developed in the studies of Hankins and Howe (1946), Marcondes et al. (2010), Marcondes et al. (2012), and Valadares Filho et al. (2006) were evaluated in attempt to predict the body physically separable and chemical composition of F1 Angus x Nellore bulls and steers, as wells for empty body and non-carcass components, through the use of the 9-11th Rib section and non-carcass measurements. After slaughter, the 9–11th Rib cut was dissected into muscle, fat and

bone fractions. The remaining carcass was similarly dissected. The others variables evaluated as partial predictors included the empty body weight, the dressing percentage, the visceral fat percentage, the organ and viscera percentage and the composition of the non-carcass components. The values estimated with prediction equations were compared to the observed values and among models. Regarding the physically separable carcass composition only the model devised by Marcondes et al. (2012) estimated precisely and accurately the amount of muscle and fat tissue present in the carcass. The models devised by Valadares Filho et al. (2006) and Marcondes et al. (2010) estimated accurately and precisely the amount of carcass chemical components, along with the model devised by Hankins and Howe (1946) which could only explain the amount of crude protein content in the carcass. The models used to predict carcass chemical composition failure in estimate the correct amount of chemical contents present in the empty body weight, except for Valadares Filho et al. (2006) that can be used for the estimation of the crude protein content in the empty body weight. The model devised by Marcondes et al. (2010) was not able to explain most of the chemical composition variation present in the non-carcass components, being recommended only for ashes and water contents in the blood and hide, and furthermore crude protein and ashes content in the organs and viscera. The fourth step was conducted in an attempt to evaluate current devised models to estimate the body and empty body physically separable fat, and chemical composition through biometric (BM) and 9-11th rib section measurements taken in 40 out of the 48 F1 Nellore x Angus bulls (B) and steers (S). Before the slaughter, the animals were lead through a squeeze chute in which BM were taken, including hook bone width (HBW), pin bone width (PBW), abdomen width (AW), body length (BL), rump height (RH), height at withers (HW), pelvic girdle length (PGL), rib depth (RD), girth circumference (GC), rump depth (RuD), body diagonal length (BDL), and thorax width (TW). Additionally, post mortem measurements were included: total body surface (TBS), body volume (BV), subcutaneous fat (SF), internal fat (InF), intermuscular fat (ImF), carcass physical fat (CF), empty body physical fat (EBF), carcass chemical fat (CFch), empty body chemical fat (EBFch), fat thickness in the 12th rib (FT), and 9 – 11th rib section fat (HHF). The values estimated with prediction equations were compared to the observed values and among models. Among all evaluated equations to predict the body composition and its paths to do so, only equations [7] and [8], for body volume prediction, and [27]

and [32], for empty body physically separable fat prediction can be devised to be used while estimating their contents using F1 Nellore x Angus bulls and steers. The fifth step was an attempt to answer the questions generated at the fourth step and for that a study was conducted in attempt to assess the body and empty body fat physical and chemical composition through biometric (BM) and postmortem measurements taken in 40 F1 Nellore x Angus bulls (B) and steers (S). The same 40 animals within its biometrical measurements were used to develop the predictive equations. The equations were developed using a stepwise procedure to select the variables that should enter in the model. The r^2 and root mean square error (RMSE) were used to account for precision and accuracy. For TBS r^2 ranged from 0.852 to 0.946 and RMSE from 0.06 to 0.100 kg; for BV r^2 ranged from 0.942 to 0.998 and RMSE from 0.004 to 0.022 kg; for SF r^2 ranged from 0.767 to 0.997 and RMSE from 2.70 to 3.24 kg kg; for InF r^2 ranged from 0.816 to 0.900 and RMSE from 3.04 to 4.12 kg; for CF r^2 ranged from 0.830 to 0.988 and RMSE from 3.44 to 8.39 kg; for EBF r^2 ranged from 0.861 to 0.998 and RMSE from 2.98 to 10.98 kg; for CFch r^2 ranged from 0.825 to 0.985 and RMSE from 5.96 to 8.46 kg; and for EBFch r^2 ranged from 0.862 to 0.992 and RMSE from 5.54 to 12.19 kg. Our results indicated that the BM could be used to either increase the goodness of fit or as alternative to predict the different fat depots of confined F1 Nellore x Angus bulls and steers.

RESUMO

FONSECA, Mozart Alves, D.Sc., Universidade Federal de Viçosa, agosto de 2013. **Avaliação e desenvolvimento de modelos matemáticos para explicar o crescimento de bovinos de corte, e sua relação com os requirementos nutricionais de animais F1 Nelore x Angus inteiros e castrados**. Orientador: Sebastião de Campos Valadares Filho. Coorientadores: Luis Orlindo Tedeschi e Mario Luiz Chizzotti.

O presente estudo foi realizado em cinco etapas interligadas da seguinte forma: primeiramente um experimento de abate comparativo foi realizado com 48 F1 Nelore x Angus machos inteiros (MNC) e castrados (MC), para avaliar as exigências líquidas de proteína e energia para o crescimento e manutenção desses animais. Os animais utilizados tinham 12.5 ± 0.51 meses de idade, e média massa corporal em jejum (MCJ) 233 ± 23.5 e 238 ± 24.6 kg de MNC e MC, respectivamente. Animals foram alimentados com proporção de 60:40 silagem de milho: concentrado. Oito animais foram abatidos no início do experimento e os restantes foram distribuídos aleatoriamente em delineamento inteiramente casualisado perfazendo um esquema fatorial 2 (classe sexual) x 3 (pesos de abate). Os animais restantes foram abatidos quando a média da massa corporal (MC) do grupo chegou a 380 (6MNC e 5MC), 440 (6MNC e 5MC), e 500 kg (5MNC e 5MC). O trato gastrointestinal foi esvaziado e limpo sendo órgãos, carcaças, cabeças de, couros, caudas, membros, sanguíneos, e tecidos posteriormente pesados para medir peso de corpo vazio (PCVZ). Estas peças foram moídas separadamente e sub-amostrados para análises químicas. Para cada animal dentro de um período, consumo de matéria seca foi medido diariamente e as amostras de fezes foram coletadas para determinar a digestibilidade da dieta. Não houve diferenças (P> 0,05) no requerimento de energia líquida exigidos para de manutenção (ELm) entre os as classes sexuais testadas. Os dados combinados indicaram uma ELm de 70 kcal/kg$^{0.75}$ de PCVZ/d, com uma eficiência parcial de utilização da energia metabolizável para líquida de 0,72. Os requerimentos de energia metabolizável para mantença observados foram de 96,96 Mcal/kg$^{0.75}$/d. A eficiência parcial de utilização do ME para NE para o crescimento foi de 0,41 para os touros e novilhos. As exigências de proteína metabolizável para mantença foram 2,14 g/BW^{0,75}/d. As exigências líquidas de proteína (PLg) apresentaram coeficientes 'a' e 'b' para a equação alométrica, PLg (g/kgPCVZ/d) = a.

$PCVZ^b$, variando de -0,722 a -0,6118 para 'a' e de 1,0047 a 0,9586 para 'b', para os MNC e MC, respectivamente. Em terceiro lugar, as equações desenvolvidas nos estudos de Hankins e Howe (1946), Marcondes et ai. (2010), Marcondes et al. (2012), e Valadares Filho et ai. (2006), foram avaliadas na tentativa de predizer a composição física e química do corpo de animais F1 Angus x Nelore e novilhos, assim como a de PCVZ e dos componentes não-carcaça, através do uso da secção de da 9 a 11^a costelas (HH) e componentes não carcaça. Após o abate, o corte da HH foi dissecada nas frações músculo, gordura e osso. O restante da carcaça foi igualmente dissecado. As outras variáveis avaliadas como preditores parciais incluíram o peso do corpo vazio, o rendimento de carcaça, a percentagem de gordura visceral, o órgão e vísceras percentual e da composição dos componentes não-carcaça. Os valores estimados com as equações de predição foram comparados com os valores observados e entre os modelos. No que diz respeito o composição da carcaça fisicamente separáveis apenas o modelo elaborado pela Marcondes et al. (2012) estimaram acurada e precisamente a quantidade de músculo e tecido adiposo presente na carcaça. Os modelos desenvolvidos por Valadares Filho et al. (2006) e Marcondes et al. (2010) estimaram com acurácia e precisão a quantidade de componentes químicos da carcaça, juntamente com o modelo elaborado por Hankins e Howe (1946), que só pôde explicar a quantidade ou teor de proteína bruta na carcaça. Os modelos de usados para predizer a composição química da carcaça falharam em estimar a quantidade correta dos componentes químicos no peso de corpo vazio, exceto para Valadares Filho et al. (2006), que podem ser usadas para a estimativa do teor de proteína bruta em relação ao peso do corpo vazio. O modelo recomendado por Marcondes et al. (2010) não foi capaz de explicar a maioria da variação observada na composição química dos componentes não carcaça, podendo ser recomendado apenas para estimativa dos conteúdos de cinza a água no sangue e couro, e conteúdo de proteína bruta e cinzas presentes no órgãos e vísceras. O quarto passo foi realizado na tentativa de avaliar os modelos desenvolvidos para estimar a composição física e química da carcaça e do corpo vazio de bovinos por meio de mensurações biométricas (BM) coletadas ao longo do corpo do animal e secção HH. Foram utilizados de 40 dos 48 animais F1 Nelore x Angus MNC e MC. Antes do abate, os animais foram conduzidos através do tronco de contenção onde as BM foram tomadas, incluindo a largura de íleo (HBW), a largura de ísquio (PBW), arqueamento de costela (AW), comprimento corporal (BL), altura da garupa (RH),

altura na cernelha (HW), comprimento de garupa (PGL), profundidade de costela (RD), perímetro toráxico (GC), profundidade de garupa (RuD), comprimento da diagonal do corpo (BDL), e largura do tórax (TW). Além disso, foram incluídos post mortem medições de: Superfície de total do corpo (TBS), volume corpo (BV), gordura subcutânea (SF), gordura interna (InF), intermuscular (FMI), gordura física da carcaça (CF), gordura física no corpo vazio do animal (EBF), gordura química na carcaça (CFch), gordura química no corpo vazio (EBFch), espessura de gordura na altura da 12 ª costela (FT), e gordura na secção entre a 9 - 11 ª costelas (HHF). Os valores obtidos pelas estimativas dos modelos foram comparados com os valores observados e entre modelos. Dentre todas as equações avaliadas para predizer a composição corporal e seus caminhos para o fazer, apenas equações [7] e [8], usadas para estimar o volume corporal, e equações [27] e [32], para estimativas da gordura fisicamente separável no corpo vazio pode ser recomendado para ser usado para estimar os seus conteúdo usando F1 Nellore x Angus MNC e MC. A quinta etapa foi uma tentativa de responder às perguntas geradas na avaliação de modelos da quarta etapa, e para isso foi realizado um estudo na tentativa de avaliar os teores físicos e químicos de gordura presentes na carcaça e no corpo e vazio por meio BM e medidas pós-morte tomadas em 40 touros (B) e novilhos (S) F1 Nelore x Angus. Os mesmos 40 animais foram usadas para desenvolver as equações preditivas. As equações foram desenvolvidas através de um processo passo a passo para selecionar as variáveis que devem entrar no modelo. O r^2 e a raiz do quadrado médio do erro (RMSE) foram usadas para acessar a precisão e acurácia dos modelos. Para TBS r^2 variou de 0,852 a 0,946 com RMSE variando de 0,06 a 0,100 kg, para BV r^2 variou 0,942 a 0,998 e RMSE de 0,004 a 0,022 kg, para SF r^2 variou 0,767 a 0,997 e RMSE 2,70 a 3,24 kg, para InF r^2 variou de 0,816 a 0,900 e RMSE de 3,04 a 4,12 kg; para CF r^2 variou de 0,830 a 0,988 e RMSE de 3,44 a 8,39 kg; para EBF r^2 variou de 0,861 a 0,998 e RMSE 2,98 a 10,98 Kg; para CFch r^2 variou de 0,825 a 0,985 e RMSE de 5,96 a 8,46 kg, e para EBFch r^2 variou de 0,862 a 0,992 e RMSE de 5,54 a 12,19 kg. Nossos resultados indicaram que BM poderiam ser usadas para aumentar o ajuste dos modelos ou ainda como alternativa para predizer os diferentes depósitos de gordura de animais confinados F1 Nellore x Angus inteiros e castrados.

INTRODUCTION

The word efficiency denotes, in general, the extension in which a resource is utilized to perform a task, job or purpose. The obtained result takes into account, as parameter, a prior connection with the losses inherent to the transformation processes (inputs/outputs). As every other field of science, animal nutrition has its own definition of efficiency, and for that, the focus of its understanding should be driven to explain the quantitative ratios between outputs and inputs used to express the results of the system's performance. After several years of research, it has been reported several ratios or indexes to express animal production. These coefficients will typically either be smaller or greater than one, but it does not necessarily imply energy generation or loss; instead transformation in its conceptual form, related to products of human interest. The first law of thermodynamics that describes the changes in the total energy of the universe can be used to explain such processes. Being forms of energy altered by changing its physical and/or chemical compositions (Metzler and Metzler, 2003; Nelson and Cox, 2011).

The point is, in animal nutrition, every efficiency carries alongside its reciprocal, the inefficiency, and should actually be understood as a time changing transformation process in which every unity of animal product not been formed represents a migration of the energy towards the trophic levels, and not just product being randomly lost. The consequences will reflect on system's stability whether in productivity levels, profitability, or environmental concerns.

The intake of energy is directly related to its ingestion and absorption (Darnell, 1968). The non-utilized energy for production is assumed to be energy being lost, or inefficiency, through metabolic processes related to digestion. The

energy accumulated (gain) is measured as growth (final – initial) and is just a fraction of the real energetic input of the system.

Bioenergetics brought the same concepts paraphrased as respiration while related to what has been excreted. In this context, respiration can be understood as a fraction of the energy present in feedstuffs not harnessed, and being dependent of level of animal production, within its rumen microbes metabolism, whether aerobic or anaerobic (Hungate, 1966).

The energy going through the system follows the thermodynamic laws dealing with measurable variables having numerical values and exclusively determined by the state of the system in question (Metzler and Metzler, 2003). The system is part of the physical universe of the observer's interest, which is delimited by borders that represent its limit with the environment (Bergethon, 2010). Thus, system and environment, together, will form the universe (Metzler and Metzler, 2003; Nelson and Cox, 2011). It follows the classical energy flow system explained by the first law of thermodynamics.

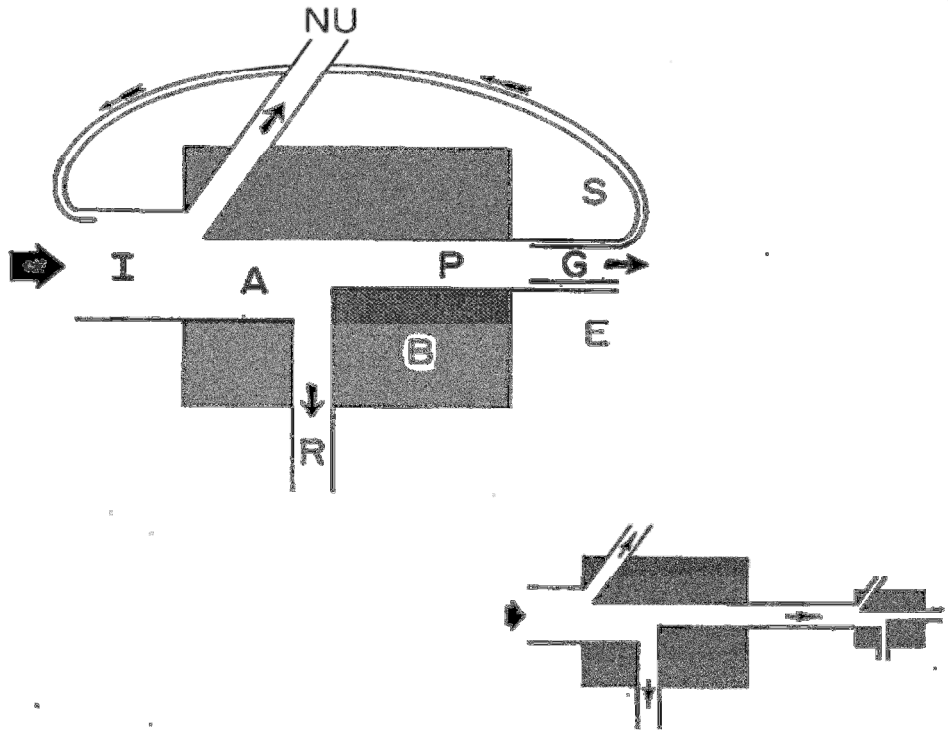

Figure 1 – Energy flow scheme (Adapted from Odum, 1968)

The above energy flow represents the theoretical model of energy behavior proposed by (Odum, 1968). It represents all live component whether individual (i.e. animal), population (i.e. feedlot group) or trophic level (i.e. meat being available for human consumption). The acronyms are energetic inputs (**I**) (i.e., dry matter intake), production (**P**), respiration (**R**), biomass (**B**), non-utilized energy (**NU**), assimilated energy (**A**), growth (**G**), excretion (**E**) and retention (**S**).

Odum (1968) describes each sub-compartment of the model as having its own biological meaning. Energy in its primarily state (Gross energy) would enter representing the summation of **P** and **R**, or with part being retained, which will be transformed in this very environmentand the remaining,the respiration, transformed in the next compartment (universe), where energy can be utilized in the same trophic level. The **I** of a system can be interpreted either as the amount of light that feeds an autotrophic system (i.e. pasture), or the intake of nutrients used in a beef cattle

production system. The **B** component can be understood as some variable passible of measurement as body weight, body composition, retained protein, production, and so forth. From the bioenergetics' point of view, the energy is measured either in calories or joules, and is related to body composition of an animal with energy flowing through the system with an efficiency of use of the resources (input) measured as ratios, coefficients, and yields in general.

Not all **I** is transformed into **B**, in that way, part of B passes through the biological structure of an animal as happens with the feedstuff being consumed and consequently manure being produced daily at the paddocks in a feedlot yard. This feedstuff passes through the gastrointestinal tract suffering digestive action and then it is eliminated without being fully digested. The portion utilized is assimilated or retained (**A**) and the rest is discarded (**NU**). The relation **A/NU** represents the concepts of a first form of measuring efficiency being modified along the way depending on what kind of index it is being used in the current evaluation.

If the evaluated efficiency is the luminous energy fixation in a pasture system, the output can be as low as 6% as observed in photosynthesis (Miyamoto, 1997), or if an a electric engine takes place in the evaluation that efficiency can be as high as 99.99% (over 200 W of power). In this brief introduction and so forth in these dissertation' upcoming discussions, **A** should be understood as the assimilated metabolizable energy, being passible of fractionation in **P** and **R**.

The fraction of the metabolizable energy which is lost as heat is the heat increment or heat production, and it is represented by **R** in the diagram. The assimilated or retained portion of **A**, represents the net energy required for gain and it is designated by **P** in the diagram. This energy available in the sub-compartment **P** represents the energy available for the next trophic level (i.e.: human consumption). That same energy will be used in different ways to maintain the regular life cycle of

a superior animal. Yet, **P** can be fractionated in **R** (net energy required for maintenance) and **P** (net energy required for production) and so forth (lower right corner Figure 1). In climax populations and bigger organisms such animals, the proportion of energy used for maintenance is higher compared to the active populations of microorganisms which present a higher **P** instead. Thinking in evolutionary terms, it becomes easy to understand that as bigger the animals are, such as dinosaurs, it is more difficult to fill the maintenance requirements which have to be fulfilled through diet. Even though if cataclysmic events had not come to take place on Earth at the time, those animals would have to adapt decreasing their body frame or would be led anyways to extinction since the efficiency of resources used were small. The consequence is that, for large animals as dinosaurs, the capacity of adaptation decreased lower than a simple strain of microorganisms.

Now comes the point of relevance, how is this related to beef cattle production. The answer is in breeding programs that realized that animals were too large, eating too much and not producing so well. So, smaller animals had become important in detriment of those huge large continental breeds. Nellore cattle by itself represent exactly this same picture in a different scenario. With smaller animals and more efficient in using the resources available, Since 2004, Brazil has become the largest exporter of meat and the main supplier of red meat protein in the world (USDA-FAS, 2010) and holding the top positions ever since.

Thinking about animal product, the **P** component, is nothing more but the summation of **G**, **E** and **S**. For example, in the case of biomass of body tissues: weight gain, biometrical growth, milk production, wool production, and so forth it is added to the system energy (**G**), part of it is retained, and the rest can be reutilized in other conditions such as tissue mobilization during a negative energetic balance (**S**), where part becomes animal product (**G**) and other is excreted (**E**) in other forms

available for the next trophic levels as amino acids, sugars, urea, and so forth. The point is that everything seems relative depending on the basis in which it is compared, and every process in life follows a pattern, whether understood or not yet, though eligible to be described. The point of trying to explain these chaotic sequences of events is to improve human nutrition, therefore its path towards evolution, and that has become an Animal Science responsibility. If there is a pattern, phenomenon can be described and within the simulation of new possible outcomes, nothing seems better than numbers to do so.

With all that been said, the only intent of the author within this discussion and further dissertation, was to understand beef cattle growth towards as many different points of view as science makes available to us. Therefore, the objectives of this study conducted at the Department of Animal Science of the Universidade Federal de Viçosa, were:

• Assess differences in intake, performance, efficiency, and carcass characteristics of bovine F1 Angus x Nellore bulls and steers slaughtered at different weights;

• Determine nutritional requirements for protein and energy of F1 Angus x Nellore bulls and steers slaughtered at different weights;

• Evaluate the prediction of body composition using the 9-11th rib section (Hankins & Howe) of F1 Angus x Nellore bulls and steers;

• Evaluate the former and current proposed models of the Brazilian system of Nutrient Requirements of Zebu Beef Cattle BR-CORTE (Valadares Filho et al., 2010; Valadares Filho et al., 2006), concerning beef cattle growth using an independent dataset;

• Evaluate the use of different mathematical and biometric models to describe beef cattle growth of F1 Angus x Nellore bulls and steers;

• Develop mathematical models of biometric measurements that can be used to predict the body composition of F1 Angus x Nellore bulls and steers;

The following chapters have been prepared in accordance with the standards of the Journal of Animal Science.

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Chapter I

Relativeness of performance and efficiency in F1 Nellore x Angus bulls and steers[1]

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Relativeness of performance and efficiency in F1 Nellore x Angus bulls and steers

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ABSTRACT: A comparative slaughter trial was conducted to determine possible differences in growth and efficiency among 48 F1 Nellore x Angus bulls (B) and steers (S). The animals had 12.5±0.51 mo of age, and average shrunk BW (SBW) of 233±23.5, and 238±24.6 kg for B and S, respectively. Animals were fed diet containing 60:40 of corn silage:concentrate. Eight animals were slaughtered at the beginning of the trial and the remaining animals were randomly assigned in a factorial 2 (genders) x 3 (slaughter weights) arrangement. The remaining animals were slaughtered when the average BW of de group reached 380 (n = 6B and 5S), 440 (n = 6B and 5S), and 500 kg (n = 5B and 5S). The emptied gastrointestinal tract, organs, carcasses, heads, hides, tails, limbs, blood, and tissues were weighed to determine the empty BW (EBW). The daily DMI and its nutrients partitioning were used to compute efficiency indexes. Variance analysis was used to determine the relationship between slaughter weights, gender, and their interaction on efficiency traits. The analyses of all variables of interest were performed using the PROC GLIMMIX of SAS (SAS Inst. Inc., Cary, NC) assuming a completely randomized design with a 3 × 2 factorial arrangement of treatments. Except for mineral matter intake and neutral detergent fiber corrected for ash and protein, it was not observed gender effect (P>0.05) in any of the studied variables concerning the nutrient intakes. Animal performance variables indicated significant gender effect (P<0.05) on carcass, yield, and head, hide and feet proportions to EBW. For hot carcass yield it was observed interaction effect (P<0.05) with 500 kg animals presenting a higher yield. It was observed a gender effect on feed conversion,efficiency and partial efficiency of growth(P<0.05) in which bulls being more efficientBulls were also

more efficient from the point of view of the efficiency of weight gain and relative growth rate. Despite of the different slaughter weights the efficiencies maintained their same behavior being higher for bulls, which means that from growth and body composition points of more bulls should be explored laying diet manipulation compensate for differences between fat proportions in the animals body.

Key Words: beef cattle, comparative slaughter, digestible energy, net energy, net protein, nutritional requirements

1. Introduction:

There are several ways to express and measure efficiency. Feedstuff utilization and growth-related body parts within their economic relevance are some of them. Each measurement carries its own limitations and their use will be limited to whether or not they will be applicable regarding its practicality or economic and biological meaning.

The most widely used efficiency index has been the feed conversion ratio and its reciprocal feed efficiency. Their simplicity makes them an easy and reproductible index. Although, they do not take into account existent differences in maintenance and growth requirements between animals. The point of using feed efficiency indexes is that they might have a tremendous influence on the unit costs of production. (Gibb and McAllister, 1999) have reported that a 5% improvement in feed efficiency has an economic impact four times greater than a 5% improvement in average daily gain. In addition, the cost of feed is second only to fixed costs in importance to the profitability of commercial beef operations (Basarab, 1999) and 70-75% of the total dietary energy cost in beef production is used for maintenance (Ferrell and Jenkins, 1985; NRC, 2000). Therefore information on at which point the animal product is more efficient appears to be a fundamental tool for the modern

livestock production making the difference not only in profitability but in longevity in the activity as well.

Thus, the aim with this work was to compare the intake, performance, feed efficiency and carcass characteristics of three slaughter-weight based groups of F1 Nellore x Angus bulls and steers to understand differences in partial efficiencies along with animals' growth.

2. Material and Methods:

The dataset utilized was obtained at the Federal University of Viçosa, Brazil, between December of 2009 and August of 2010. Laboratorial analyses were performed at the Ruminant Nutrition Laboratory located at Department of Animal Science, Federal University of Viçosa, Brazil.

The diet was formulated according to Valadares Filho et al. (2006) to contain 11 % CP. Animals were fed a diet containing 60% corn silage and 40% concentrate. The concentrate contained corn, soybean meal, urea, ammonium sulfate, sodium chloride, limestone, and mineral mix (Table 1). Animals were fed either *ad libitum* (slaughter-weigh based groups) or at maintenance level (control).

The dataset was composed by forty-eight F1 Nellore x Angus bulls (B) and steers (S), with 12.5±0.51 mo old, and initial shrunk BW (SBW) of 233±23.5 and 238±24.6 kg for B and S, respectively. The trial was design in a completely randomized 2 genders x 3 slaughter weights factorial arrangements of treatments. The animals were randomly assigned into five slaughter groups based on weight: baseline, maintenance, 380, 440, and 500 kg. The trial started after a 45 d of adaptation (diet and facilities) period in which animals were fed with the same diet used during the feeding trial. The experiment started at the baseline group's slaughter (n = 4 bulls and n = 4 steers). The other groups were slaughtered when the group of animals reached an average BW of 380 (n = 6 bulls and n = 5 steers), 440

(n = 6 bulls and n = 5 steers), and 500 kg (n = 5 bulls and n = 5steers). The maintenance (n = 4 bulls and n = 4 steers) group was slaughtered at the same time as the 500-kg's group. The animals were housed in individual pens covered with concreted floors, provided with feeders and concreted bunks, in a total available area of 30 m^2, of which 8 m^2 were sheltered. Every 28 d period, for seven periods, the animals were weighed after a 16 to 18 h of feed withdrawal. With the weights, it was obtained the average daily gain (**ADG,** kg/d), calculated by dividing the difference between final and initial BW by the number of days in confinement.

The feed regime was twice daily (at 600 and 1600), fed as a total mixed ration and daily adjusted to maintain orts up to 10% of the as-fed offered basis. Water was permanently available.

The intake was measured and adjusted daily, with roughage, concentrate and orts been collected, and properly identified and stored in a freezer at -20^{o}C. At the end of each week, a composite sample was prepared and dried (60^{o}C). Thereafter, another composite sample representing the 28 d period was performed, weighing based on the proportion of DMI of each week period.

All samples, except those with less than 15% moisture, were air-dried in a forced draft oven (60^{o}C) and ground to pass a 1-mm screen in a Wiley mill (Model 4, Thomas scientific, Swedesboro, NJ 08085). Laboratory analyzes followed the (AOAC, 2000) methods for DM (method 930.15), ash (method 942.05), fat (method 2003.05), CP (method 990.09), NDF (1-mm) with thermostable α-amylase and without sodium sulfite (Van Soest et al., 1991) corrected for ash and crude protein as described by Licitra et al. (1996). Non-fiber carbohydrates (NFC) were calculated as 100 – [(%CP - %CP from urea + % of urea) + %NDF + %EE + %ash] (Hall, 2000) and apparent TDN was calculated as (CP intake – fecal CP) + (NDF intake – fecal

NDF) + (NFC intake – fecal NFC) + [2.25 × (EE intake – fecal EE)] (Sniffen et al., 1992). The summary of the analysis is described in Table 1.

During the trial two digestibility assays were performed to estimate the nutrient digestibility coefficients. The metabolizable energy intake (**MEI**) was calculated by multiplying the daily intake of each nutrient by its respective digestibility coefficient, and then by 0.82 and 4.409. The 0.82 represents the conversion of digestible energy (**DE**) into metabolizable energy (**ME**) as proposed by (NRC, 2000) and devised by (Tedeschi et al., 2002). The value 4.409 represent s the energy content (Mcal) of 1 kg of TDN.

All slaughters followed the same procedure. The animals were fasted for 16 h before the slaughter. At the chute the animals were desensitized with a non-penetrating stunner and killed by exsanguination on the jugular vein using conventional humane procedures. The gastro-intestinal tract (**GIT**) was cleaned and weighed with the other organs to determine the empty BW (**EBW**). The difference between final and initial EBW was used to estimate the empty body gain (**EBG**, kg/d). The relation obtained by dividing EBW and shrunk BW (**SBW**) from the reference group was used to estimate the EBW of the remaining animals. Carcasses were separated in two halves and weighed (**HCW**), then chilled (1 to 4 ^{o}C) for 18 h and then re-weighed to obtain the chilled carcass weight (**CCW**). By dividing the carcasses weights by the SBW, we obtained the hot (**HCY**, %) and cold (**CCY**, %) carcasses yields. The hide and organs and viscera were weighed. Also the carcasses gains (kg/d) were obtained by the difference between the final and initial hot (**HCG**) and cold carcasses (**CCG**) weights, being the initial carcass weight estimated according to the composition of the reference animals.

Several dimensionless ratios related to DMI were evaluated to attest efficiency, such as the crude efficiency or relation between ADG and DMI (**ADGEBW**) EBG related

to DMI (**EBGDMI**), HCG related to DMI (**HCGDMI**), CCG related to DMI (**CCGDMI**), ADG related to DMI in percentage of the BW (**ADGDMIBW**).

Furthermore, some noncarcass ratios were analyzed to justify whether or not prediction equations to estimate those components would be applicable. The analyzed ratios (%) were the weights (kg) of body parts related to EBW such as organs and viscera (**OVEBW**), ratio between the hide weight related to the EBW (**HDEBW**), ratio between the weight of the feet related to the EBW (**FEBW**), ratio of the head related to EBW (**HEBW**).

2.1. Net energy:

The NEm was assessed by the intercept of the exponential equation of heat production (HP) on MEI in a metabolic weight basis ($kg^{0.75}$). No difference was observed neither for HP and MEI ($P>0.05$) between genders, nor the intercept of the fitted equations for bulls and steers so it was adopted a single value for NEm which was calculated as 0.070 Mcal/$kg^{0.75}$EBW/d (Chapter 2).

The NEg had gender effect ($P<0.05$) so two equations were adjusted separately, one for bulls: RE (Mcal/d) = $0.0516 \times EBW^{0.75} \times EBG^{1.0992}$, and one for steers: RE (Mcal/d) = $0.0640 \times EBW^{0.75} \times EBG^{1.0992}$.

From these values, it was calculated the net energy of the consumed diet (Mcal/kg) for gain (**DNEg**) and maintenance (**DNEm**) according to (Zinn and Shen, 1998) following the equations:

DNEm (Mcal/kgDM) = (-(0,877 x NEm + 0,41 x DMI + NEg) –((0,877 x NEm + 0,41 x DMI + $NEg)^2$ – (4 × (-0,41 x NEm) × (-0,877 x DMI)))^{0,5}))/(2 ×(-0,877 x DMI))

DNEg (Mcal/kgDM) = 0,877 x ELm – 0,41

Where DNEm is the net dietary energy intake used for maintenance, NEm is the net energy required for maintenance, NEg is the net energy required for growth, DMI is the dry matter intake, and DNEg is the net dietary energy intake used for gain.

2.2. Efficiency variables:

The tested parameters for feed efficiency were: FCR, FE, partial efficiency of growth (**PEG**), maintenance efficiency (**MnE**), efficiency of weight gain (**GnE**), relative growth rate (**RGR**), Kleiber index (**IK**) and residual feed intake (**RFI**).The feed conversion ratio was obtained by dividing the DMI (kg/d) by the ADG(kg/d). The average FE was obtained by the reciprocal of this relationship. The PEG was estimated by dividing the average DMI for average daily intake for gain (Arthur et al., 2001).

The efficiency of weight represents the animal's ability to use the metabolizable energy required for weight gain was calculated by dividing ADG by the MEI (Mcal/d). To calculate the relative growth rate (RGR), was take into account the initial SBW (**SBWi**), final SBW (**SBWf**), and d of confinement as: RGR = 100 * (log final BW - log LW)/d (Fitzhugh and Taylor, 1971). The KR was calculated dividing the ADG by the average metabolic weight (Kleiber, 1936).

The RFI was calculated as the difference between the observed and predicted values of DMI. Two RFIs were calculated, the $RFI_{BRCORTE}$ and RFI. The predicted values of DMI were generated either by the model of Valadares Filho et al. (2010) or by the fitted equation using the observed DMI through the REG procedure of the SAS statistical package (SAS Institute, 2009), following the model:

$$DMI = \beta_0 + \beta_1 \times ((SBWf - SBWi)/2)^{0.75} + \beta_2 \times (ADG) + \varepsilon$$

Where the random error, ε, represents the RFI.

2.3. Statistical analysis:

Statistical analyses were performed using SAS (SAS Inst. Inc., Cary, NC). The analyses of all variable of interest were performed by PROC GLIMMIX assuming a completely randomized design with a 3 × 2 factorial arrangement of treatments (3 slaughter weights and 2 genders), as per the following statistical model:

$Y = \mu + \alpha + \beta + \alpha\beta + \varepsilon$

where μ is the mean, α is the effect of gender, β is the effect of slaughter weight, $\alpha\beta$ is the interaction effect of gender and slaughter weight, and ε is the random error. Outliers were identified using the plot of studentized residuals against the predicted values and Cook's D coefficients (Neter et al., 1996). The least square means were obtained using the LSMEANS statement. It was used the Tukey-Kramer test in the contrast between the means of the variables of interest adopting 5% for the type I error control.

3. Results and discussion:

Despite of fact that there was no effect in DMI, while plotting the DMI on time of confinement, it was observed a quadratic effect of intake with point of maximum around the 4th experimental period. At that point, only the heavier animals, 440 and 500 kg groups, animals were still on trial. The 380-kg group was slaughtered before it reached the average maximum point of DMI. So every comparison in this paper has to take into consideration its relationship with the design used instead of a current growth behavior. In other words, the three groups were too heterogeneous with 380 and 440 kg groups ranging their BW's at about 100 kg (lighter and heavier animals) and 500 kg ranging from a 150 kg. So the averages analyzed, were just giving a clearly understanding of what might have happened concerning the animals' nutritional requirements, which was why this trial was designed for. Furthermore, the means might not be the better measure of position while comparing the growth curve of those animals. Instead, the median and the quartiles would

answer it better such questions while the objective is to evaluate the growth in its classical approach. For the sake of this discussion, the mean still represents more the variation between groups and less within. Thus, a crucial difference between analyzing with the animals reaching the specific slaughter weight instead of using the average of the group would generate regressions with less steeper slopes that might be a constraint while encountering differences between the groups. The second approach and the adopted one would allow inferring more about the animals' physiological maturity.

With that stated, Table 2 shows the mean intake of the nutrients. There was no effect of gender ($P>0.005$) in any of the studied variables. As expected, cattle fed at maintenance level had the lowest intake of all nutrients and was not taken into account while comparing animals or contrasting treatments. The only evaluated variables that presented significant effect on slaughter weight ($P<0.05$) were NDFap expressed either as in kg/d or in % of the BW, and mineral matter intake (**MMI**, kg/d). The 500 kg group presented the highest means, not differing from the 440 kg group. Clearly the animals were heavier and consuming more. Regarding the effect of interaction between gender and slaughter weight, the only variables that presented significant effect ($P<0.05$) were DE, expressed as % of the diet (Mcal/kg), and TDN, expressed as percentage of the DMI. The 380 group presented the higher DE, for both genders, followed by the bulls from 440 group, and the steers from 500 group that was not different from the steers 440 and the bulls 500. The percentage of TDN have shown a higher DM digestibility for the 380 group followed by the bulls from the 440 which did not differ from the both 500 kg group. Those, in other hand, did not differ from the 440 steers. In agreement of the higher means observed for DE (Mcal/kg of the diet) and TDN (%), it is suggested that the 380 group being more efficient concerns its DM digestibility due to lower intakes of NDFap, concomitant

with a higher values of DE and TDN. This is probably due to the 380 groups being more selective with the intake of concentrate concomitant with a slightly higher digestibility proportionated by the smaller change in its ratio along with roughage intake. In agreement with that hypothesis, the observed reduction of the intake after it reached the maximum point of the adjusted quadratic equation seems to explain the closer estimates of TDN (Table 2) of heavier animals and the animals from the baseline groups. Baseline animals were under feed restriction and because of that would slow down its passage rate in attempt to maximize the nutrient utilization, presenting then a higher DM digestibility while comparing within the *ad libitum* animals. Since those animals where not different (P>0.05) from the heavier, concerning DM digestibility, it seems that concentrate selection might have had increased such parameters. It has been reported in the literature an increase in dry matter intake with increasing levels of concentrate in the diet and some studies showed positive linear responses (Marcondes, 2010), though what might have happened here is more likely related to an almost subclinical difference in concentrate due selectivity since the animals were fed a single same diet.

Table 3 shows the means and some efficiency ratios of body components of the animals. Except for the relation EBW:SBW, there were no effects of interaction between gender and slaughter weight (*P*>0.05) for any of the studied variables. The higher observed ratio was for the bulls 500 which did not differ from the bulls 440 or all steers. Yet, the steers did not differ from the lowest bulls 380 group, though the last, in this trial, have shown the trend to have higher gut content proportionate to its BW. The higher ratio EBW:SBW was attributed to a smaller intake for heavier animals while plotting the all observed instead of group means. Probably due to a higher fat content in the body, therefore a higher amount of leptin being produced by

the adipose tissue since its adipose-derived nature that would control the appetite, energy control, and so forth (Brennan and Mantzoros, 2006).

As expected, baseline group had the lowest indexes and did not enter while comparing the means of treatments. Separate effects of SBW and EBW presented, obviously, only significant effect of slaughter weight ($P<0.05$), corroborating with the design intent. Another slaughter weight significant effect was CCY (P = 0.0082), HDEBW (P = 0.0007), FEBW (P = 0.0001), HEBW (P = <0.0001). The 500 kg animals, for both steers and bulls, presented a higher CCY, although did not differed from the 440. That is likely due to the big range of weights observed within groups.

The HCY have shown an interaction effect of gender and slaughter weight. The highest HCY observed was for the 500 kg bulls which did not differ from the 440 kg or all steers, which did not differ among the own gender or the lighter 380 kg bulls. In agreement, the 380 group presented a smaller CCY among all indicating the trend of heavier carcasses pursue a higher yield. Concerning the noncarcass components ratio it was observed that organs and viscera (**OVEBW**) have gender effect being bulls presenting a smaller ratio compared to steers. After castration animals tend to deposit more fat in internal depots while compared to bulls (Berg and Butterfield, 1976). The hide, feet and head grows in different proportions related to EBW. For hide the 500 animals had the highest proportion, not differing from 440, with 380 presenting the lowest ratio. For feet, it was observed the inverse relation with the 380 animals heaving the higher proportion of feet related to EBW, not differing from 440 and followed by 500. For the HEBW the effect is even more complex since it combines gender and slaughter weight effects. The data says that bulls have higher HEBW and a heavier head then steers, and lighter animals have the highest HEBW followed by 440, which did not differ from the 500 group. That is mainly because there is difference related to body growth and chemically more related to

protein deposition as shown in the models devised by Marcondes et al. (2010). For all the non-differences between the 440 and 500 it might indicate that either the huge range of weight is affecting the results or that variation in higher BW is very smooth. Thus, that gives a hint why the models devised by (Marcondes et al., 2010) to estimate the noncarcass chemical composition did not explained the variation in chemical composition hereby observed. The equations developed were clearly accounting for just linear effects between body parts and this dataset shows that there is an allometric relation of growth between components and EBW. Even though, assuming that accretion of chemical components follows an isometric relation with growth, seems unlikely that chemical composition would be deposit always at the same ratio along the growth curve. Starting with the OVEBW this dataset suggests that there are differences between genders related to it so prediction equations should account for at least gender effects, which was observed by Marcondes et al. (2010). Also the authors reported a 23% difference between genders regarding EE rate of deposition in the visceral fat depot. That rate seems to be right since the slope of the predicted against observed values have shown no significant differences compared to observed data ($P<0.05$) (Fonseca, 2009, unpublished). Although the intercept reveals the weakness in accounting for the fat chemical content because either only a linear effect was considerate or a small common fat content in the parts of OV that are not visceral were underestimated. Furthermore, there is a possibility of an existent allometric coefficient closer, but not equal to one concerning OVEBW growth. If so, data suggests that not just visceral fat is the only responsible for the differences between the genders and fat deposition into organs and viscera mass. Either way, a correction factor for Nellore x Angus seems to be a good alternative. Regarding HDEBW, it seems that the dataset have shown same pattern as described by Marcondes et al. (2010) with hide growing

isometrically related to EBW at a quite constant linear rate along the growth of the body of the animal, as well maintaining the same ratio of deposition between its chemical components. Concerning the FEBW and HEBW, the growth interpretation seems to point out different directions for both variables indicating that individual prediction equations may have to be developed instead grouping the two variables. The constitution of the feet seems to be more homogenous, having the possibility that rate of deposition of chemical components be the similar along growth. The HEBW has a gender effect, and according to Marcondes et al. (2010) that is reflex of protein deposition, which does not seems to be correct since the model evaluation had shown a rejection of the null hypothesis of an identity line (Fonseca 2013, unpublished). Furthermore the difference in proportion of HEBW along growth suggests an allometric deposition of tissues and the equations to explain chemical deposition are isometric, with body weight being responsible for protein deposition variation with the same ratio for an animal with 110 kg and a 500 kg. The only possibility of that being true is if the head of the animal never stops to growth along the way and that growth had to be at the same ratio.

Considering the initial and final BW and performance for the entire experiment, we have estimated the average DMI expected based on equation devised by (Valadares Filho et al., 2010) to crossbred animals. The estimated values were 7.61, 8.16, 8.47, 7.59, 8.09, and 8.47 kg/d respectively for steers (380, 440 and 500) and bulls (380, 440 and 500). The observed values were 7.21, 7.69, 7.82, 7.40, 7.69, and 7.85 kg/d or around 5.25, 5.76, 7.67, 2.5, 4.94, 7.32 % overestimation by the model. While simulating the DMI with the prediction equation also devised by Valadares Filho et al. (2010) for Nellore animals, the model explained better the observed variation regarding the DMI in this dataset. The estimated values were 7.53, 8.06, 8.38, 7.34, 7.81, and 8.25 kg/d respectively for steers (380, 440 and 500) and bulls (380, 440

and 500). Making the difference between the observed and predicted values falls at about 4.25, 4.6, 7.16% of overestimation by the model for steers, and only 0.81% underestimation for 380kg bulls and 1.53, and 4.85 % overestimation by the model for 440 and 500 kg bulls. Despite of the closer values, those results suggest that animals in this dataset were slightly more efficient than the average crossbred animals in the BR-CORTE's database if RFI is considerate. That difference between observed and predicted intakes represents the RFI. The point of using the RFIbrcorte was an attempt to verify if the intakes could be a variable that would explain the differences between the groups of animas. When using the empirical equation devised by Valadares Filho et al. (2010) to estimate the daily DMI, RFIbrcorte, it was not observed (Table 3) significant effects (P>0.05) of gender, BW or the interaction between both on the groups tested. On the other side, that random error is nested to the errors of model and might not really represents the real difference in efficiency between these animals which probably was one of the reasons if the non-detection of differences. As better is the goodness of feet of the predictive equation smaller in the chance to verify RFI differences. Thus, taken that into account we developed a linear equation to predicted DMI along the trial which was used afterwards to calculate the regular RFI. The developed model was:

$$\text{DMI (kg/d)} = -0.01864(\pm 0.91374) + 1.11693(\pm 0.26274) \times \text{ADG} + 0.07272(\pm 0.01237) \times \text{ASBW}^{0.75}$$

Where DMI is the dry matter intake (kg/d), ADG is the average daily gain (kg/d) and $\text{ASBW}^{0.75}$ is the average metabolic weight; the values in parenthesis are the standard error of the mean of the estimated parameters.

Despite of two groups, efficient and inefficient, being able to be identified, those groups were composed by a sorted profile of animals with all slaughter weights and genders composing them. Therefore, while analyzing with the same criteria of the

experimental design, it was not observed (Table 3) significant effects (P>0.05) of gender, BW or the interaction between both tested groups.

Some of the variables of efficiency of animal production were also evaluated (Table 4). There were no effects of interaction between gender and slaughter weight (P>0.05) for any of the studied variables. The FC and its reciprocal FE presented a significant effect of gender (P<0.05). For FC the bulls were more efficient in producing body mass per unit of DM consumed, presenting then smaller values of FC. In average bulls presented FC of 4.26 and steers at about 5.05. Chizzotti (2007) working with Nellore x Angus animals receiving 1 and 2% of the BW as concentrate presented values of 6.03 and 4.41 respectively, and for the steers the observed values were 6.30 and 4.99 for 1 and 2% of BW offered as concentrate, respectively. Despite of the fact that the animals in this dataset were receiving at about 40% of concentrate in the total diet and in average ate 2.15% of its BW making a BW basis offer of concentrate at about 0.86%, the animals were more efficient, in a FC point of view, than those reported by Chizzotti (2007). That behavior was observed even for the animals receiving the double amount of concentrate then ours. That is probably because the animals in this trial were slaughtered way heavier than Chizzotti's and while were still growing in an ascendant rate. While looking at from the FE's point of view, our dataset shows the same gender effect with bulls being more efficient than steers and been respectively, in average, 2.4 and 3.5% more efficient than Chizzotti's. The PEG presented significant effect of gender and BW with again bulls being more efficient than steers. Within gender, the 380 were the most efficient not differing from the 440 kg, and 440 not differing from 500. The PEG measures the efficiency in which the DNEg is converted in ADG. Within sex, bulls were almost 20% more efficient than steers with average PEG of 3.36 compared to 2.71 observed for steers. Within BW it was possible to observe that lighter animals are more

efficient in using the DNEg and that efficiency decreases as the animal grows. The observed values were 3.25, 3.03 and 2.83 for 380, 440 and 500 kg groups of animals.

Concerning the fractions of the dietary energy that would be used whether for maintenance (Mcal/kg DM), it was observed significant effect ($P<0.05$) only for slaughter weight. The 500 kg group of animals was more efficient in using the DNEm and DNEg, which did not differ from 440. The 440 kg group also did not differ from the 380.

The GnE showed only gender effect ($P<0.05$) with bulls being more efficient than steers. Bulls used at about 9.93% of its dietary energy for its ADG and steers used about 8.4%.

The RGR also have shown only gender effect ($P<0.05$) with bulls growing faster than steers. The observed values were 0.2413 for bulls and 0.200 for steers, suggesting that bulls relatively grew 4.13% faster than steers.

The last efficiency measure evaluated was KR, which measure the growth related to time in trial, also have shown only gender effect ($P<0.05$) with bulls growing faster than steers. The observed values were 0.0231 and 0.0190 for bulls and steers respectively, suggesting that concerning BW gain, bulls grow 17.75% faster than steers.

4. Implications:

Variables evaluated to study efficiency of animal production have indicated that bulls are more efficient than steers. Though, taking into account the point of view of producers, more bulls should be explored laying diet manipulation compensate for differences between fat proportions in the animals body.

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Table 1 - Proportions and chemical composition of the ingredients in concentrate and diet (DM basis).

Ingredients	Concentrate	Diet
Proportion (g/kg DM)		
Corn Silage	-	600.00
Corn	833.50	333.40
Soybean Meal	108.30	43.30
Mineral premix[a]	11.06	4.40
Urea:ammonium sulfate (9:1)	22.11	8.90
Salt	12.30	4.90
Limestone	12.80	5.10
Chemical composition		
Dry matter	885.00	537.30
Organic matter	938.00	944.94
Crude protein	170.50	105.85
Ether extract	32.30	29.08
Neutral Detergent fiber[b]	114.70	340.30
Non fiber carbohydrate[b]	655.90	483.95

[a] Composition: Ca - 24,0%; P - 17,4%; Co - 100,0 ppm; Cu - 1.250,0 ppm; Fe - 1.795,0 ppm; Mn - 2.000,0 ppm; Se - 15,0 ppm; Zn - 5.270,0 ppm; I - 90,0 ppm; [b]corrected for ash and protein contamination; [b] Assuming 260% CP in urea:ammonium sulfate mixture

Table 2 - Variables of feed efficiency used to understanding differences in growth of crossbred F1 Nellore x Angus bulls and steers.

	Steers				Bulls				*P*-Values		
Item[1]	380	440	500	BASELINE	380	440	500	BASELINE	G	BM	G*BM
DMI, kg	7.21 (0.37)	7.69 (0.37)	7.82 (0.37)	2.55 (0.17)	7.4 (0.34)	7.85 (0.34)	7.85 (0.37)	2.671 (0.073)	0.6706	0.2818	0.9733
DMIBW, %	2.03 (0.10)	2.16 (0.1)	2.2 (0.1)	0.72 (0.05)	2.08 (0.09)	2.21 (0.09)	2.21 (0.1)	0.751 (0.021)	0.6706	0.2811	0.9733
EEI, kg/d	0.23 (0.01)	0.22 (0.01)	0.23 (0.01)	0.07 (0.00)	0.25 (0.01)	0.23 (0.01)	0.23 (0.01)	0.08 (0.00)	0.5528	0.4334	0.9111
EEIBW, %	0.07 (0.00)	0.06 (0.00)	0.06 (0.00)	0.02 (0.00)	0.07 (0.00)	0.06 (0.00)	0.06 (0.00)	0.02 (0.00)	0.5563	0.4831	0.899
CPI, kg/d	0.79 (0.04)	0.84 (0.04)	0.85 (0.04)	0.27 (0.02)	0.81 (0.04)	0.87 (0.04)	0.86 (0.04)	0.29 (0.01)	0.6763	0.2805	0.9556
CPIBW, %	0.22 (0.01)	0.24 (0.01)	0.24 (0.01)	0.08 (0.01)	0.23 (0.01)	0.24 (0.01)	0.24 (0.01)	0.08 (0.00)	0.6763	0.2899	0.9579
NDFapI, kg/d	2.12b (0.113)	2.50a (0.113)	2.51a (0.113)	0.86 (0.057)	2.19b (0.103)	2.46a (0.103)	2.54a (0.113)	0.9 (0.025)	0.7911	0.0042	0.867
NDFapIBW, %	0.59b (0.03)	0.70a (0.03)	0.70a (0.03)	0.24 (0.02)	0.61b (0.03)	0.69a (0.03)	0.72a (0.03)	0.25 (0.01)	0.7889	0.0042	0.8662
NFC, kg/d	3.69 (0.19)	3.69 (0.19)	3.8 (0.19)	1.2 (0.08)	3.77 (0.17)	3.85 (0.17)	3.78 (0.19)	1.26 (0.03)	0.6097	0.9491	0.8867
NFCBW, %	1.04 (0.05)	1.04 (0.05)	1.07 (0.05)	0.34 (0.02)	1.06 (0.05)	1.08 (0.05)	1.06 (0.05)	0.35 (0.01)	0.6104	0.9497	0.8881
MMI, %	0.37b (0.02)	0.44a (0.02)	0.43a (0.02)	0.14 (0.01)	0.38b (0.02)	0.44a (0.02)	0.44a (0.02)	0.15 (0.00)	0.6953	0.0038	0.9969
DE, Mcal/kg	2.94a (0.0028)	2.89c (0.0028)	2.90bc (0.0028)	2.89 (0.0003)	2.94a (0.0026)	2.91b (0.0026)	2.89c 0.0028)	2.88 (0.0001)	0.27	<0.0001	0.0015

MEI, Mcal/d	17.41 (0.88)	18.25 (0.88)	18.61 (0.88)	6.04 (0.4)	17.86 (0.81)	18.71 (0.81)	18.64 (0.88)	6.319 (0.173)	0.6556	0.4688	0.9607
TDN	0.668a (0.00063)	0.656c (0.00063)	0.658bc (0.00063)	0.655 (0.00007)	0.668a (0.00058)	0.659b (0.00058)	0.657bc (0.00063)	0.654 (0.00)	0.2019	<0.0001	0.0014

[1]DMI is daily dry matter intake in kg, DMIBW is daily dry matter intake in % of BW; EEI is the daily ether extract intake in kg, EEIBW is the daily ether extract intake in % of BW; CPI is the daily crude protein intake in kg, CPIBW is the daily crude protein intake in % of BW; NDFapI is the daily neutral detergent fiber corrected for ash and protein intake in kg; NDFapIBW daily neutral detergent fiber corrected for ash and protein intake in % of BW; NFC is the daily non fiber carbohydrates intake in kg; NFCBW daily non fiber carbohydrate intake in % of BW; MMI is the daily intake of mineral matter in kg; DE is the digestible energy of the diet; MEI is the daily metabolizable energy intake; TDN is relation of the total digestible nutrients % of dry matter intake, G is gender, BM is body mass or group's slaughter weight; [a, b, c] Distinct lowercase letters, while alone in the same row, differ at $P < 0.05$ by least square means for first observed significant effect detected following the order (G, T and G x T); [A, B, C] Distinct capital letters in the same row, differ at $P < 0.05$ by least square means for second observed significant effect detected following the order (G, T and G x T)* values in parenthesis represent the standard error of the mean.

Table 3 - Variables of tissue deposition efficiency used to understanding differences in growth of crossbred F1 Nellore x Angus bulls and steers**.**

	Steers				Bulls				P-Values		
Item[1]	380	440	500	BASELINE	380	440	500	BASELINE	G	BM	G*BM
SBW, kg	384.2b (20.04)	457.80a (20.04)	510.10a (20.04)	236.94 (18.95)	382.92b (18.29)	456.75a (18.29)	500.90a (20.04)	252.85 (10.64)	0.8108	<0.0001	0.9728
EBW, kg	350.54c (17.56)	417.69b (17.56)	462.50a (17.56)	0.24 (0.05)	345.72c (16.03)	418.66b (16.03)	464.45a (17.56)	0.24 (0.05)	0.9641	<0.0001	0.9771
ADG, kg/d	1.50b (0.13)	1.53b (0.13)	1.52b (0.13)	0.24 (0.04)	1.84a (0.12)	1.87a (0.12)	1.79a (0.13)	0.28 (0.05)	0.0044	0.9455	0.9497
EBG, kg/d	1.44b (0.11)	1.44b (0.11)	1.41b (0.11)	0.14 (0.05)	1.72a (0.10)	1.77a (0.10)	1.73a (0.11)	0.22 (0.08)	0.0012	0.927	0.9621

HCG, kg/d	0.94b (0.118)	0.95b (0.118)	0.91b (0.118)	0.17 (0.054)	1.12a (0.108)	1.15a (0.108)	1.19a (0.118)	0.25 (0.077)	0.0273	0.9712	0.9168
CCG, kg/d	0.98b (0.117)	0.98b (0.117)	0.93b (0.117)	0.90 (0.004)	1.17a (0.107)	1.19a (0.107)	1.21a (0.117)	0.92 (0.007)	0.022	0.9938	0.9234
EBW:SBW	0.913ab (0.004822)	0.913ab (0.004822)	0.907ab (0.004822)	1.017 (0.03354)	0.904b (0.004402)	0.917ab (0.004402)	0.927a (0.004822)	1.182 (0.06704)	0.2282	0.1481	0.0191
EBG:ADG	0.965 (0.01442)	0.949 (0.01442)	0.927 (0.01442)	0.092 (0.01483)	0.944 (0.01316)	0.951 (0.01316)	0.964 (0.01442)	0.090 (0.01624)	0.6171	0.8441	0.1389
CE	0.207b (0.011)	0.199b (0.011)	0.195b (0.011)	0.093 (0.013)	0.246a (0.010)	0.237a (0.010)	0.228a (0.011)	0.104 (0.017)	0.0003	0.3962	0.9625
EBGDMI	0.199b (0.008813)	0.188b (0.008813)	0.181b (0.008813)	0.054 (0.01903)	0.231a (0.008045)	0.226a (0.008045)	0.220a (0.008813)	0.081 (0.02809)	<0.0001	0.246	0.8903
HCGDMI	0.129b (0.0116)	0.123b (0.0116)	0.116b (0.0116)	0.063 (0.019)	0.150a (0.01059)	0.146a (0.01059)	0.148a (0.0116)	0.091 (0.027)	0.0098	0.8007	0.8748
CCGDMI	0.135b (0.0113)	0.127b (0.0113)	0.119b (0.0113)	0.328 (0.0527)	0.158a (0.01032)	0.151a (0.01032)	0.152a (0.0113)	0.319 (0.0577)	0.0066	0.5914	0.8784
ADGDMI%	0.735b (0.03976)	0.709b (0.03976)	0.692b (0.03976)	57.715 (0.87137)	0.876a (0.0363)	0.845a (0.0363)	0.812a (0.03976)	57.753 (0.39356)	0.0003	0.404	0.9596
HCY, %	59.21AB (0.661)	58.69AB (0.661)	58.87AB (0.661)	58.48 (0.953)	57.26B (0.603)	59.58AB (0.603)	60.54A (0.661)	58.64 (0.712)	0.7007	0.0909	0.0226
CCY, %	53.56b (0.941)	56.17ab (0.941)	57.38a (0.941)	14.93 (0.456)	55.91b (0.859)	57.20ab (0.859)	58.28a (0.941)	14.96 (0.464)	0.0661	0.0082	0.6825
OVEBW	16.45a (0.356)	17.29a (0.356)	17.56a (0.356)	5.22 (0.540)	15.87b (0.325)	15.73b (0.325)	15.78b (0.356)	6.25 (0.484)	<0.0001	0.3352	0.2008
HDEEBW	7.66b	9.05ab	10.30a	3.37	8.72b	9.75ab	11.44a	3.14	0.0615	0.0007	0.916

	(0.619)	(0.619)	(0.619)	(0.137)	(0.565)	(0.565)	(0.619)	(0.086)			1
FEBW	2.63a (0.0789)	2.53a (0.0789)	2.21b (0.0789)	4.67 (0.2455)	2.63a (0.0720)	2.43a (0.0720)	2.28b (0.0789)	4.66 (0.1322)	0.8405	0.0001	0.535
HEADEBW	3.58Ba (0.099)	3.22Bb (0.099)	3.04Bb (0.099)	-1.24 (0.287)	3.80Aa (0.090)	3.42Ab (0.090)	3.25Ab (0.099)	-1.37 (0.208)	0.0076	<0.0001	0.9256
RFIBRCORTE, kg	-0.296 (0.250)	-0.384 (0.250)	-0.627 (0.250)		0.021 (0.228)	-0.207 (0.228)	-0.524 (0.250)		0.3244	0.2144	0.9049
RFI, kg	0.153 (0.186)	0.161 (0.186)	0.034 (0.186)		-0.047 (0.169)	-0.044 (0.169)	-0.240 (0.186)		0.1359	0.6095	0.9754

[1]SBW is shrunk BW; EBW is the empty BW; ADG is the average daily gain; EBG is the empty body gain; HCG is the hot carcass gain; CCG is the cold carcass gain; EBW:SBW is the ratio among the variables; EBG:ADG is the ratio among the variables ; CE is the crude efficiency; EBGDMI is the ratio between EBW and dry matter intake (DMI); CCGDMI is the ratio between CCG and DMI; ADGDMI% is the ratio between ADG and DMI in % of body weight; HCY is hot carcass yield; CCY is the cold carcass yield; OVEBW is the ratio between mass of organs and viscera and EBW; HDEBW is the ratio between mass of hide and EBW; FEBW is the ratio between mass of feet and EBW; HEBW is the ratio between mass of head and EBW; RFIBRCORTE is the residual feed intake with predicted DMI using BRCORTE recommendations; RFI is the residual feed intake; [a, b, c] Distinct lowercase letters, while alone in the same row, differ at $P < 0.05$ by least square means for first observed significant effect detected following the order (G, T and G x T); [A, B, C] Distinct capital letters in the same row, differ at $P < 0.05$ by least square means for interaction gender * group's slaughter weight * values in parenthesis represent the standard error of the mean.

Table 4 - Efficiency indexes and variables used in its calculations used to understanding differences in growth of crossbred F1 Nellore x Angus bulls and steers.

	Steers				Bulls				P-Values		
Item	380	440	500	BASELINE	380	440	500	BASELINE	G	BM	G*BM
ADG, kg/d	1.50b	1.53b	1.52b	0.24	1.84a	1.87a	1.79a	0.24	0.0044	0.9469	0.9435
	0.127	0.127	0.127	0.046	0.116	0.116	0.127	0.047			
MBW, $kg^{0.75}$	74.23	80.35	83.93	61.33	74.37	80.15	83.98	63.99	0.9982	0.0022	0.9974
	2.52b	2.52ab	2.52a	3.29	2.30b	2.30ab	2.52a	1.33			
NEg, Mcal/d	7.64	8.66	9.09	0.82	7.36	8.72	9.27	0.81	0.9787	0.1074	0.953
	0.81	0.81	0.81	0.21	0.74	0.74	0.81	0.19			

MEm, Mcal/d	7.20b 0.24	7.79ab 0.24	8.14a 0.24	5.95 0.32	7.21b 0.22	7.77ab 0.22	8.14a 0.24	6.21 0.13	0.9928	0.0022	0.9976
NEm, Mcal/d	5.20b 0.18	5.62ab 0.18	5.87a 0.18	4.3 0.23	5.20b 0.16	5.61ab 0.16	5.88a 0.18	4.48 0.09	0.9987	0.0022	0.9978
FC	4.89a 0.25	5.12a 0.25	5.15a 0.25	12.08 2.63	4.16b 0.23	4.22b 0.23	4.40b 0.25	12.58 2.68	0.0006	0.6183	0.932
FE	0.206b 0.011	0.198b 0.011	0.194b 0.011	0.09 0.014	0.245a 0.01	0.237a 0.01	0.230a 0.011	0.09 0.016	0.0002	0.4647	0.9888
PEG	2.84bA 0.16	2.69bAB 0.16	2.61bB 0.16	0.46 0.07	3.66aA 0.15	3.37aAB 0.15	3.04aB 0.16	0.47 0.08	<0.0001	0.0448	0.4614
DNEm, Mcal/kg	2.2b 0.08	2.3ab 0.08	2.40a 0.08	2.14 0.08	2.14b 0.07	2.30ab 0.07	2.40a 0.08	2.12 0.08	0.5393	0.0396	0.8139
DNEg, Mcal/kg	1.55b 0.07	1.64ab 0.07	1.69a 0.07	1.47 0.08	1.47b 0.07	1.61ab 0.07	1.70a 0.07	1.45 0.07	0.5035	0.0444	0.8131
EFGPC	0.086b 0.005	0.084b 0.005	0.082b 0.005	0.039 0.006	0.102a 0.004	0.100a 0.004	0.096a 0.005	0.038 0.007	0.0002	0.5712	0.9752
RGR, %/d	0.211b 0.015	0.199b 0.015	0.190b 0.015	0.043 0.006	0.260a 0.014	0.243a 0.014	0.221a 0.015	0.041 0.008	0.0016	0.1425	0.8246
KR, $kg/kg^{0.75}$	0.0201b 0.0014	0.0190b 0.0014	0.0181b 0.0014	0.0038 0.0006	0.0247a 0.0013	0.0233a 0.0013	0.0213a 0.0014	0.0038 0.0007	0.0011	0.1592	0.8549

[1]ADG average daily gain, MBW is metabolic body weight; NEg is the net energy requirements for gain, MEm is the metabolizable energy required for maintenance; NEm is the net energy requirement for maintenance; FC is feed conversion ratio – kg of DM consumed/kg of body weight gain; FE is feed efficiency ratio – kg of gain/kg of DM consumed; PEG is partial efficiency of growth – kg of BWgain/kg of DM consumed above maintenance; DNEm is the dietary net energy for maintenance; DNEg is the dietary net energy for gain; ; RGR is the relative growth rate; KR is Kleiber ratio - kg of BWgain/kg of MBW; [a, b, c] Distinct lowercase letters, while alone in the same row, differ at $P < 0.05$ by least square means for first significant effect detected following the order (G, T and G x T); [A, B, C] Distinct capital letters in the same row, differ at $P < 0.05$ by least square means for second observed significant effect detected following the order (G, T and G x T)* values in parenthesis represent the standard error of the mean.

Chapter II

Energy and protein requirements of young finished F1 Nellore × Angus [1]

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Energy and protein requirements of F1 Nellore x Angus

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ABSTRACT: A comparative slaughter trial was conducted with 48 F1 Nellore x Angus bulls (B) and steers (S), to assess the net requirements of protein and energy for growth and maintenance. The animals used had 12.5±0.51 mo of age, and average shrunk BW (SBW) 233±23.5, and 238±24.6 kg for B and S respectively. Animals were fed a diet containing 60% silage and 40% of concentrate. Eight animals were slaughtered at the beginning of the trial and the remaining animals were randomly assigned in a factorial 2 (genders) x 3 (slaughter weights) arrangement. The remaining animals were slaughtered when the average BW of de group reached 380 (6B and 5S), 440 (6B and 5S), and 500 kg (5B and 5S). The cleaned gastrointestinal tracts, organs, carcasses, heads, hides, tails, limbs, blood, and tissues were weighed to measure empty BW (EBW). These parts were ground separately and sub-sampled for chemical analyses. For each animal within a period, DMI was measured daily and samples of feces were collected to determine diet digestibility. There were no differences ($P >$ 0.05) in net energy required for maintenance (NEm) among genders. The combined data indicated a NEm of 70 kcal/kg$^{0.75}$ of EBW/d, with a partial efficiency of use of ME to NE for maintenance of 0.72. The MEm observed was 96.96 Mcal/kg$^{0.75}$/d. The partial efficiency of use of ME to NE for growth was 0.41 for bulls and steers. The metabolizable protein requirements for maintenance were 2.14 g/BW$^{0.75}$/d. The net requirements had coefficients 'a' and 'b' for the allometric equation NPg (g/kg EBW/d) = a. EBW^{b}, ranging from -0.722 to -0.6118 for 'a' and from 1.0047 to 0.9586 for 'b', for bulls and steers, respectively.

Key Words: beef cattle, comparative slaughter, digestible energy, net energy, net protein, nutritional requirements

1. Introduction:

The first version of a Brazilian system for nutritional requirements of zebu cattle (*Bos indicus* and crosses) was published in 2006 as the result of an effort of the research group at the Federal University of Viçosa (Valadares Filho et al., 2006b). The core database was composed mainly by data obtained from several trials using the comparative slaughter technique conducted at UFV since the 1990s (Valadares Filho et al., 2006a). The second and revised edition was released in 2010 (Valadares Filho et al., 2010) with an integrated database among the universities and research centers members of the National Institute of Science and Technology -Animal Science (INCT-Ciência Animal). Within the new version, the database was increased especially with the accretion of the crossbreed dataset which represents the exact profile of animals that are confined in Brazil. It has been reported that most beef cattle in Brazil has strong influence of zebu genetics. According to Sainz et al. (2006), 80% of the national cattle carries zebu genetics in its blood. However, the industrial cross appeared for some time as a way to optimize performance and improve levels of productivity in beef systems (Marcondes, 2010).

Thus, a further, continuous and more detailed evaluation of the new Brazilian system is required in order to test the robustness of its prediction equations, to attest its validity in a bigger range of beef cattle production systems.

The objective within this study was to use body composition data from comparative slaughter trial using F1 Nellore x Angus bulls and steers, slaughtered at three different groups of weights to determine net and metabolizable energy and protein requirements, as well its respective efficiencies of use, for maintenance and growth.

2. Material and Methods:

The dataset was obtained at the Federal University of Viçosa, Brazil, between December of 2009 and August of 2010. Laboratory analyses were performed at the

Ruminant Nutrition Laboratory located at Department of Animal Science, Federal University of Viçosa, Brazil.

The diet was formulated according to Valadares Filho et al. (2006) to contain 11 % CP. Animals were fed 60% corn silage and 40% concentrate, containing corn, soybean meal, urea, ammonium sulfate, sodium chloride, limestone, and mineral mix (Table 1). Animals were fed either *ad libtum* (slaughter-weigh based groups) or at maintenance level.

The total mixed ration was fed twice daily (at 600 and 1600h) and adjusted daily to maintain orts up to 10%. Water was permanently available.

The dataset was composed by forty-eight F1 Nellore x Angus bulls (B) and steers (S), with 12.5±0.51 mo old, and initial shrunk BW (SBW) of 233±23.5 and 238±24.6 kg for B and S, respectively (Table 2). The trial was design in a completely randomized 2 x 3 factorial arrangements of treatments (two genders and three slaughter weights). The animals were randomly assigned into five slaughter-weight based groups: baseline, maintenance, 380, 440 and 500. The baseline group was slaughtered at the beginning of the trial (4B and 4S). The other groups were slaughtered when the animals reached an average BW of 380 (6B and 5S), 440 (6B and 5S), and 500 kg (5B and 5S). The maintenance (4B and 4S) group was slaughtered at the same time as the 500-kg group. The animals were housed in individual pens covered with concreted floors, provided with feeders and concreted bunks, in a total available area of 30 m^2, of which 8 m^2 were sheltered.

The intake was measured daily, with roughage, concentrate and orts been collected and properly identified and stored in a freezer at -20^oC. At the end of each week, a composite sample was prepared and dried (60^oC). Thereafter, another composite sample representing the 28 d period was performed, weighing based on the proportion of DMI proportion of each week during period.

All samples, except those with less than 15% moisture, were air-dried in a forced draft oven (60°C) and ground to pass a 1mm screen in a Wiley mill (Model 4, Thomas scientific, Swedesboro, NJ 08085). Laboratory analyzes followed the (AOAC, 2000) methods for DM (method 930.15), ash (method 942.05), fat (method 2003.05), CP (method 990.09), NDF (1-mm) with thermostable α-amylase and without sodium sulfite (Van Soest et al., 1991). Non-fiber carbohydrates (NFC) were calculated as 100 – [(%CP - %CP from urea + % of urea) + %NDF + %EE + %ash] (Hall, 2000) and apparent TDN was calculated as (CP intake – fecal CP) + (NDF intake – fecal NDF) + (NFC intake – fecal NFC) + [2.25 × (EE intake – fecal EE)] (Sniffen et al., 1992). The summary of the analysis is described in Table 1.

The metabolizable energy intake (MEI) was calculated by multiplying the daily intake of each nutrient by its respective digestibility coefficient obtaining the digestible energy intake (DEI) or total digestible nutrients intake (TDNI). The conversion of TDNI into MEI was performed as proposed by (NRC, 2000), according to the equation ME = 0.82 ×DE and reported by Tedeschi et al., (2002). The dietary DE was calculated considering that each kg of TDN has 4.409 Mcal of energy.

All slaughters followed the same procedure. The animals were fasted for 16 h before the slaughter. At the chute the animals were desensitized with a non-penetrating stunner and killed by exsanguination on the jugular vein using conventional humane procedures. The gastro-intestinal tract (**GIT**) was cleaned and weighed with the other organs to determine the empty BW (**EBW**). The relation obtained by dividing EBW and BW from the baseline group was used to estimate the EBW of the remaining animals. Carcasses were separated in two halves and weighed (hot carcass weight), then chilled (1 to 4 °C) for 18 h and then re-weighed to obtain the chilled carcass weight (**CCW**). A section between the 9th and 11th ribs (Rib_{9-11}) was removed from the left carcass and subsequently dissected into bone, fat, and lean tissues. The rest of the left

carcass was completely dissected into bone, fat, and lean tissues and the Rib_{9-11} section was summed, at the end, to obtain the full carcass composition. Samples of bone, fat, and lean tissues from the carcass, head, limbs, hide, blood, and organs and viscera were taken to determine carcass and body chemical compositions. The mesenteric fat was physically separated from the GIT and weighed with kidney, pelvic, and heart fat to compose the visceral fat. Tendons were weighed with the lean tissue, while connective tissues were added to the fat pool. After weighing each component, lean and fat tissues were separately ground, subsampled, and then mixed together to reset their original physically separable proportion. Carcass bones were separated into vertebral, ribs, and long bones, and sawn into 5 x 5 cm pieces to be proportionally sub-sampled and composited as total bone sample. The Rib_{9-11} bones were also sawn into small pieces (5 x 5 cm) and sampled. The head and feet were sampled in two animals per group and then separated into hide, bone, and soft tissues, which represented the respective slaughtered group composition. The hide was weighed, sampled (25 x 25 cm) from the left rump of each animal and assumed to be representative of the rest of the body. Viscera and organs were ground together and sub-sampled. Blood was sampled during the exsanguination. The hide was sampled (25 to 25 cm) from the left croup of each animal and ground. Except for blood samples, which were dried at 60 ^{o}C for 72 h, all samples were preliminary freeze dried and partially defatted by washing it successively with petroleum ether in a Soxhlet apparatus (Fernandes et al., 2010a; Marcondes et. al., 2012; De Paula et al., 2013). The amount of fat lost during this procedure was computed by weight differences. Then, all samples were ground using a ball mill and analyzed for moisture (method 934.01; AOAC, 1990), protein (method 920.87; AOAC, 1990), ether extract (EE; method 920.85; AOAC, 1990), and ash (method 924.05; AOAC, 1990) in order to determine the chemical composition of the Rib_{9-11} section,

carcass, and empty body. The final EE was corrected by adding the fat lost during the partial defatting process.

The determination of the energy content in the body was obtained by multiplying its contents of protein and fat by their calorific equivalents of 5.6405 and 9.3929 as suggested by ARC(1980). The energy content in the animal's body was estimated by its energy content following the model: $EC = a \times EBW^{b}$.

Empty body gains (**EBG**) of body components were calculated as the difference between initial and final weights of the respective body components, similar to Tedeschi et al.(2002). Heat production (**HP**, kcal/$kg^{0.75}$ of EBW/d) was calculated as the difference between ME intake (MEI, kcal/$kg^{0.75}$ of EBW/d) and retained energy (**RE**, kcal/$kg^{0.75}$ of EBW/d). The net energy required for maintenance (**NEm**) was estimated using the intercept of the exponential regression equation of HP on MEI, following the model $HP = \beta_0 \times e^{\beta 1 \times CEM}$, where HP is the heat production (Mcal/$EBW^{0.75}$), MEI is the metabolizable energy intake (Mcal/$EBW^{0.75}$), β_0 and β_1 are the parameters of the regression and 'e' is the number of Euler. The parameter β_0 represents the net energy required for maintenance (Mcal/kg of $EBW^{0.75}$). The maintenance requirement for ME (**MEm**) was calculated by iterative process when MEI and HP were numerically equivalent. The efficiency of energy utilization for maintenance (**Km**) was calculated as NEm/MEm. The slope of the regression of RE on MEI was assumed to be the efficiency of energy utilization for growth (**Kg**). Meanwhile, the net energy requirements for growth (**RE**, Mcal/$EBW^{0.75}$/d) was obtained with a regression between retained energy (RE) and EBW gain (**EBG**) for a given metabolic EBW using the following model: $RE = a \times EBW^{0.75} \times EBG^{b}$. Where 'a' is the antilog of the intercept and b is the slope of the linear regression of the logarithm of RE (Mcal/$kg^{0.75}$EBW/d) on the logarithm of EBG (kg/d),

The metabolizable protein intake (**MPI**) was calculated as the summation of the true digestible microbial protein (**MCP**) and the digestible rumen undegradable crude protein (RUPd). Microbial protein was calculated from TDN intake considering that each kg of TDN ingested produces 120 g of MCP (Valadares Filho et al., 2010), being adopted as a true fraction of 80% with a digestibility of 80% (NRC, 2001). The intake of RUP was estimated as the CP intake subtracted by microbial protein, considering digestibility of 80% as well.

The net protein requirement for growth (**NPg,** g/kg$^{0.75}$ of EBW/d) was calculated as:

$$NPg\ (g/kg^{0.75}\text{of EBW/d}) = 10^{a} \times b \times EBW^{b-1} \quad [1]$$

Where 'a' is the intercept and 'b' is the slope of the linear regression of the logarithm of body protein (kg/kg EBW) on the logarithm of EBW.

2.1. Statistical analyses.

Statistical analyses were performed using SAS (SAS Inst. Inc., Cary, NC). The analyses of intake, diet energetic concentration, performance, and body composition were performed by PROC GLM assuming a 3 × 2 factorial design of diet (3 slaughter weights and 2 genders) and gender (bulls, steers, and heifers), as per the following statistical model:

$$Y = \mu + \alpha + \beta + \alpha\beta + \varepsilon$$

Where μ is the mean, α is the effect of gender, β is the effect of slaughter weight, $\alpha\beta$ is the interaction effect of gender and slaughter weight, and ε is the random error. Outliers and systematic bias were identified using the plot of studentized residuals against the predicted values and by the leverage and Cook's D coefficients (Neter et al., 1996).

The comparison of intercept and slope among diets and gender was performed by using the PROC GLM procedure using the sum of squares type 3 and PROC MIXED. The interaction or the main effects were removed from the statistical model if, and only if, P

> 0.05. The comparisons of means were performed using least square means at P = 0.05.

3. Results and discussion

Table 3 shows the mean intake of the nutrients. There was no effect of gender in any of the studied variables. As expected, cattle fed at maintenance level had the lowest intake of all nutrients and was not taken into account while comparing animals or contrasting the treatments. Although all evaluated variables presented significant effect on interaction gender x treatment. That behavior is probably due to the way that the animals were distributed to the treatments. At the design, a picture of an average body weight of the group of animals seemed to be more appropriate in explaining better the growth curve. The found constraint was that within each group, the range of weight was practically the same; with heavier and lighter than average group weight were among the animals' categories which could lead to a misinterpretation of the results. That effect was more pronounced between the groups 440 and 500kg. Indeed there was no difference between any of the analyzed variables concerning DMI and intake itself or nutrients in general. Though while comparing the body composition contrasts the dynamics of tissue deposition pointed out the differences.

The first contrast of interest was testing the group of animals weighing 380 kg against the 440 kg group. The significant differences were found for CPI (P = 0.102) in kg/d, NDFap (P = 0.002) in kg/d, and in mineral matter intake or ash (P = 0.000) in kg/d. Despite of not being significant, the differences in DMI were indeed numerically superior, so probably this is the reason for such difference. Also, it was observed a decrease in the pre-dried corn silage DM along the trial with values ranging from as high as 40.25% at the first experimental period and as low as 28.26% at the end of the trial. As the intake was adjusted according to it, the lesser DM would increase the as fed basis intake and the concentrate intake what could explain the increased the CPI

and mineral matter intake for the 440 animals, besides there where heavier and the DMI, in kg/d, still was ascendant at the time. The SBW ranged from 322 kg as lowest and 436 kg as highest for the 380 kg group, and 402.5 kg as lowest and 457.2 kg as highest for the 440 kg group.

The second contrast of interest tested was the group of animals weighing 380 kg against the 500 kg group. Turns out that the 500 kg group was the most heterogeneous concerning the range of weights of those animals. With SBW varying of 157 kg, ranging from 437 kg to 588 kg for the 500 kg group, and varying of 114 kg, ranging from 322 to 436 kg for the 440 kg group. By the huge differences in SBW it was expected that the 500 kg group presented higher intake of all. Though, the only variables that presented significant effect on its intakes were mineral matter ($P = 0.001$) and NDFap ($P = 0.001$). The huge interval concerning the SBW of the 500 kg brought a lot of heterogeneity. Prove of that is the DMI range for the 500 kg group presenting a range of 3.5 kg between the highest and lowest intake, while the 380 kg the range was only about 1.9 kg which leads to believe that the median might be a better measure of position, instead the mean, when analyzing this dataset. Furthermore the quartiles investigation could bring a better understanding of what might have happened.

The third contrast of interest tested was the group of animals weighing 440 kg against the 500 kg group. Concerning the intake of nutrients and energy concentration of the diet, none of the variables presented significant effect while compared among each other.

Again, the same three contrasts were compared concerning the performance of the animals, body composition and energy balance amongst the treatments (Table 4).

Except for EE and Water contents (%) in the EBW, there were no effects of gender in any of the studied variables. Indeed, it was observed a 18% less EE for bulls and 8% more water present in the EBW of those animals, supporting the idea that steers have a

higher content of fat in the EBW while comparing with bulls raised in the same condition, same diet and same range of weights. Probably the higher amount of water for bulls is due to its affinity with muscle representing up to 70% of its content (Berg and Butterfield, 1976), therefore a higher amount of muscle could be observed. As expected, cattle fed at maintenance level had the lowest body condition smaller contents of CP, and EE, as well for the retained energy in the body and HP. Probably the reason for a lower HP is due to smaller its intake, maintenance animals tend to decrease the passage rate to be able to absorb more efficiently the feedstuffs which is limited. As digestibility is a consequence of the digestion and passage (Van Soest, 1994) a smaller intake produced a better use of the diet. As HP is the result of the difference between MEI and RE, for a smaller RE much more of the MEI would be redirected to HP or maintenance activities. Clearly there were significant differences (P<0.05) regarding the SBW and EBW among the groups showing that the main objective of creating as representative as it could be a growth curve actually did work. The same is valid for HCW, which shown that even with the big observed range of BW within each group of animals, the carcasses followed a ascendant pattern of growth as the animals grew from 380 to 500 kg.

The percentage of EE in the EBW might not be a better way to express the real amount of fat in the body while comparing animals' performance and composition of gain. Instead, kg of fat seems to be more accurate since it could avoid the loss of normality (Fernandes et al., 2010a) caused by the division of the variables. Although, for the sake of this discussion, the percentage of EE could be interpreted as the proximity with the chemical maturity of the animal (Berg and Butterfield, 1976), which should be reached at 22% of EE at the EBW according to Tedeschi et al. (2002). While comparing the animals 380 and 440 kg, it was not observed significant difference (P = 0.0829) among the means of treatments. The interesting fact is that when compared in separate, bulls

seems to have reached the physiological maturity which would decrease its CP deposition in the carcass and increase the EE deposition. That was observed by the small content of CP while comparing the 440 against 500 kg group of animals (P = 0.022) by the third contrast. While comparing the same 380 against 440kg groups for steers, such difference runs smaller, indicating the slower rate of growth of steers compared to bulls. As expected while contrasting the 380 against 500 kg group it was observed a significant difference (P = 0.0005) among groups, with a hard influence from steers that reached a very high EE content (%) in the empty body. Such difference could be attributed to castration that interferes on a regular growth making animals to start the fat deposition sooner along with a higher rate.

The third contrast was also used to compare the percentage of EE in the EBW for 440 and 500 kg. It was found significant difference (P = 0.04426) between the groups., again probably because the higher fat content deposited in castrated animals that were slaughtered heavier and with a higher amount of fat in the carcass, especially from the internal depot.

The average ratio between BW and EBW did not differ (P>0.005) among gender nor BW, so the average value observed was 0.9135. (Marcondes, 2010) working with different crossbred, being Nellore x Angus one of them, found a similar value of 0.9171. Valadares Filho et al. (2006) and NRC (200) recommended fixed values of 0.896 and 0.891, respectively. (Chizzotti et al., 2008), working with a metaregression using *Bos indicus* and its crossbreds found that EBW might represent 92.3% of the BW with a negative intercept of 15.6kg which represents up to 4% discount in this dataset, thus the average ratio would be about 0.892. Though, it is consensus that this ratio can vary from 85 to 95% (NRC, 2000). Secondly, it was not observed any difference (P>0.005) in the ratio between ADG and EBG. The average observed ratio was 0.95 when ad libitum animals were considerate alone and around 0.9871 when maintenance

animals were taken into account. Valadares Filho et al. (2006), NRC (2000) and Chizzotti et al. (2008) have reported ratios of 0,933; 0,951 e 0,961, respectively. The closer values between EBG and ADG hereby observed was attributed to the fact that the animals had the same diet and same proportion of roughage:concentrate for all experimental period and the energy intake was the only determinant able to suppress the intake at any level of production.

The NEm was assessed by the intercept of the exponential equation of HP on MEI (Figure 1). No difference was observed neither for HP and MEI (P>0.05) between genders, nor the intercept of the fitted equations for bulls and steers so it was adopted a single value for NEm which is 0.070 Mcal/kg$^{0.75}$EBW/d. (Turner and Taylor, 1983) suggested that HP would be greater if the animal was fed at an increased plane of nutrition which might elevate the metabolism involved in the synthesis of RE and that was not observed in this trial. (Tedeschi et al., 2002), working with *Bos indicus* animals did not observe differences between NEm for bulls and steers. The classical 0.077 Mcal/kg$^{0.75}$EBW/d proposed by (Lofgreen and Garrett, 1968) was obtained with only *Bos taurus* animals which would be overestimating the animals with *Bos indicus* blood by 10% (NRC, 2000). It has been reported in the literature values around 71.2 Mcal/kg$^{0.75}$EBW/d (Chizzotti et al., 2008), 70.8 Mcal/kg$^{0.75}$EBW/d (Silva et al., 2002), and 74.5 Mcal/kg$^{0.75}$EBW/d (Ferrell and Jenkins, 1998). The MEm was obtained by the iterative process using the exponential relationship between HP and MEI. When the HP is equals to MEI, theoretically, that number represents the MEm. It was observed a value of 0.09696 Mcal/kg$^{0.75}$EBW/d. The partial efficiency of conversion of metabolizable to net energy could be obtained by dividing the NEm by MEm (0.72). Chizzoti et al. (2008) has encountered estimates of MEm of 0.100 Mcal/kg$^{0.75}$EBW/d working with Nellore x Angus animals. Also, the authors have reported similar values of Km of 0.713. Marcondes (2010) found Km of 0.68 for Nellore x Angus and

observed values of MEm of 0.100, 0.821 and 0.936 Mcal/kg$^{0.75}$EBW/d for Nellore, Nellore-Angus and Nellore-Simmental. When analyzing the exponential equation and estimating by iterative process the values ranged from 0.114 to 0.105 Mcal/kg$^{0.75}$EBW/d. (Valadares Filho et al., 2006) found estimates around 0.108 Mcal/kg$^{0.75}$EBW/d.

The NEg presented gender effect ($P<0.05$) so two equations were adjusted separately for bulls (Eq. [2]) and steers (Eq. [3]).

$$\text{Bulls: RE (Mcal/d)} = 0.0516 \times \text{EBW}^{0.75} \times \text{EBG}^{1.0992} \quad [2]$$

$$\text{Steers: RE (Mcal/d)} = 0.0640 \times \text{EBW}^{0.75} \times \text{EBG}^{1.0992} \quad [3]$$

Both parameters of the fitted equations were pretty similar to those reported by (Valadares Filho et al., 2010) of 0.064 for 'a' and 1.0995 for 'b', concerning steers, and 0.053 for 'a' and 1.0995 for 'b' concerning bulls. The coefficients suggested that steers require 20% more NEg than bulls for the same rate of gain. According to NRC (2000), bulls with similar parents as the steers require 18% less NEg.

The plot of the regression of RE on MEI produce an intercept with biological meaning which could be interpreted as the efficiency of use of NEm. The value obtained was 41.29%. In agreement, Marcondes (2010) has reported values of 41.22% for general, and 38.53% specifically for Nellore x Angus. Tedeschi et al. (2002) found 45.9 and 49.7% for Nellore bulls and steers.

Using the model proposed by NRC (2000) it was possible to estimate the metabolizable protein requirements for maintenance (Figure 3). Dividing the intercept, 157.88, of the model described by the observed average metabolic weight of the animals (73.75 kg$^{0.75}$), we obtained a requirement of 2.14 g/BW$^{0,\ 75}$/d, estimate below the values recommended by (Wilkerson et al., 1993) of 3.09 g/BW$^{0.75}$/d, by the (INRA, 1988) of 3.25 g/BW$^{0.75}$/d, which were assessed by nitrogen balance. Yet, the findings were not

too distant from the values observed by AFRC (1993) of 2.30 g/$BW^{0.75}$/d, Chizzotti et al. (2008) of 2.28 g/$BW^{0.75}$/d, or (Véras, 2006) of 2.69 3.09 g/$BW^{0.75}$/d.

The content of protein was estimated by the equation $Y = a. X^b$, where X is the empty body weight, and 'a' and 'b' are the parameters of the allometric equation. Its derivative gives the net protein requirement for gain. It was found 'a' ranging from -0.722 to -0.6118 and 'b' ranging from 1.0047 to 0.9586 for bulls and steers, respectively. So for the BW of 300, 350, 400, 450 and 500 kg the net protein requirements for gain, in g/kg EBW, would be respectively 185.8, 184.6, 183.6, 182.7, and 181.9, for steers; and 195.7, 195.8, 195.9, 196.0, and 196.1 for bulls. Marcondes (2010) has reported, for the same *Bos indicus* crossbred, values of 154.36, 151.50, 149.06, 146.94, and 145.07; and 168.44, 168.34, 168.26, 168.19, and 168.13 for Nellore x Simmental. Valadares Filho et al. (2006) working with Nellore animals reported 130.97, 124.78, 118.82, 113.03, and 107.41 g/kg of EBG. The interesting fact is that our dataset have shown a different behavior than those authors. For Marcondes (2010) and Valadares Filho et al. (2006) there was a decrease in net protein requirements as body weight increased, due to a decrease in the growth rate of the animal approaches physiological maturity, with a consequent change in the animal's metabolism to decrease the flow of nutrients to the deposition of lean tissue and increase body reserves. For early animals the fall should be steeper and for late or large frame animals, such as Simmental and its crossbreeds, the fall should be less steep since for those conditions this breed would still be in the growing stage of development, since for this range of weights these animals probably would not have the maturity being reached. In the other hand, in this present work, even with an increase in BW the protein requirements tend to maintain. That is reflex of the high amount of fat deposited in those animals during the trial, making the animals reached in average 22.21% of EE in the EBW, which according Tedeschi et al. (2002), is the point where

maturity is established, and the rate of protein deposition or the percentage of the RE deposited as protein tend to zero (Chizzotti et al., 2018).

With the obtained values for maintenance and gain requirements for this dataset of animals, a simulation of an animal weighing 300 kg with ADG of 1.25 kg was performed. First Eq. [1] and Eq. [2] (Table 5) were used to estimate the EBW and EBG. Secondly, the EBWeq was obtained thorough Eq. [3] (Table 5) and NEm was obtained by Eq [4] and Eq. [5] (Table 5). The MEm was then estimate by Eq. [6] (Table 5). Next step was to determine NEg which was accomplished through the use of Eq. [7] and Eq. [8] (Table 5) for steers and bulls respectively. The Metabolizable energy required for gain was obtained through Eq. [9] (Table 5) and the total metabolizable energy required daily was obtained by Eq. [10] (Table 5). The TDN daily required was calculated assuming 82 % of efficiency of conversion of DE into ME (Eq. [11] in Table 5). For that same very animal, a daily net energy requirement for gain was estimated as 4.17 Mcal for bulls and 5.04 Mcal for steers. Valadares Filho et al. (2010) recommended, for that same category of crossbred animals, that those values should be 4.22 Mcal for bulls and 5.09 Mcal for steers. The total net requirement was obtained by summing the maintenance and gain requirements. The estimative for this situation would be a total daily requirement of net energy of 8.86 Mcal for bulls and 9.73 Mcal for steers. The total metabolizable energy required daily would be 16.60 Mcal for bulls and 18.70 Mcal for steers. Valadares Filho et al. (2010) recommended, for that same category of crossbred animals, that those values should be 17.89 Mcal for bulls and 19.08 Mcal for steers. Simulating the same situation with the recommendations from another nutritional committees such NRC (2000), (CSIRO, 2007) and (AFRC, 1993), brought estimates for bulls around 23.65 Mcal, 24.16 Mcal and 19.7 Mcal, respectively. For steers the estimates were around 22.32 Mcal, 24.16 Mcal and 21.2 Mcal, respectively for the American (NRC, 2000), Australian (CSIRO, 2007) and British (AFRC, 1993)

recommendations. Regarding required for maintenance and growth. The values obtained were 4.7 kg/d of TDN for bulls and 5.28 kg/d of TDN for steers. The estimates of the Brazilian system (Valadares Filho et al., 2010) were 4.95 kg/d of TDN for bulls and 5.28 kg/d of TDN for steers. The American system daily requirements of TDN were 6.56 kg for bulls and 6.19 kg for steers. The Australian estimates were 6.68 kg for bulls and steers and the British system estimates were around 5.5 kg for bulls and 5.9 kg for steers.

4. Conclusions

The requirement of net energy for maintenance was similar for bulls and steers. The growth requirement for NE was 20% less for bulls than for steers. The NEm was estimated as 70 kcal/$kg^{0.75}$ of EBW/d and MEm 96.96 Mcal/$kg^{0.75}$/d. The NEg as, RE (Mcal/d) = 0.0516 × $EBW^{0.75}$ × $EBG^{1.0992}$ for bulls, and RE (Mcal/d) = 0.0640 × $EBW^{0.75}$ × $EBG^{1.0992}$ for steers.

The metabolizable protein requirements for maintenance were 2.14 g/$BW^{0,\,75}$/d. The net requirements had coefficients ‘a’ and ‘b’ for the allometric equation NPg (g/kg EBW/d) = a. EBW^{b}, ranging from -0.722 to -0.6118 for ‘a’ and from 1.0047 to 0.9586 for ‘b’, for bulls and steers, respectively.

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Table 1 - Proportions and chemical composition of the ingredients in concentrate and diet (DM basis).

Ingredients	Concentrate	Diet
Proportion (g/kg DM)		
Corn Silage	-	600.00
Corn	833.50	333.40
Soybean Meal	108.30	43.30
Mineral premix[a]	11.06	4.40
Urea:ammonium sulfate (9:1)	22.11	8.90
Salt	12.30	4.90
Limestone	12.80	5.10
Chemical composition		
Dry matter	885.00	537.30
Organic matter	938.00	944.94
Crude protein	170.50	105.85
Ether extract	32.30	29.08
Neutral Detergent fiber[b]	114.70	340.30
Non fiber carbohydrate[b]	655.90	483.95

[a] Composition: Ca - 24,0%; P - 17,4%; Co - 100,0 ppm; Cu - 1.250,0 ppm; Fe - 1.795,0 ppm; Mn - 2.000,0 ppm; Se - 15,0 ppm; Zn - 5.270,0 ppm; I - 90,0 ppm; [b]corrected for ash and protein contamination; [b] Assuming 260% CP in urea:ammonium sulfate mixture

Table 2 - Descriptive statistics of the dataset used to obtain the nutritional requirements

Variable[1]	N	Mean	SD	Min	Max	N	Mean	SD	Min	Max	N	Mean	SD	Min	Max
	Steers														
SBWi, kg	5	240.3	20.55	223	275	5	236.1	24.35	205.0	270.0	5	225.5	24.94	201.5	263
SBWf, kg	5	384.2	42.00	322	436	5	457.8	40.77	402.5	510.0	5	510.1	47.91	462.5	580.5
EBWi, kg	5	211.96	18.14	196.7	242.6	5	208.22	21.47	180.8	238.1	5	198.88	22.02	177.7	232
EBWf, kg	5	350.52	37.31	291.7	392.4	5	417.7	33.36	368.7	453.4	5	462.5	38.40	424.1	517.8
MEBW, $kg^{0.75}$	5	68.64	4.80	61.8	75.2	5	74.4	4.37	67.5	77.7	5	77.5	5.19	72.2	85.2
ADG, kg/d	5	1.5	0.30	1.03	1.82	5	1.528	0.26	1.3	2.0	5	1.524	0.14	1.38	1.7
EBG, kg/d	5	1.44	0.27	0.99	1.72	5	1.446	0.19	1.3	1.8	5	1.41	0.11	1.3	1.53
ER, kcal/$kg^{0.75}$	5	105.72	11.66	90.6	120.2	5	100.62	5.14	95.3	107.0	5	97.32	4.07	93.7	103
MEI, kcal/$kg^{0.75}$	5	214.78	17.33	201.59	244.96	5	197.266	12.97	183.1	216.7	5	186.682	7.34	181.23	198.47
HP, kcal/$kg^{0.75}$	5	109.06	19.77	89.6	137.1	5	96.62	14.82	81.9	120.7	5	89.34	3.88	84.9	95.5
	Bulls														
SBWi, kg	6	243.1	25.2	205.0	267.0	6	234.8	19.6	213.0	260.0	5	235.8	32.9	199.5	270.0
SBWf, kg	6	382.9	37.2	343.0	435.0	6	456.8	31.3	430.0	507.5	5	500.9	66.1	437.0	588.5
EBWi, kg	6	215.1	22.3	181.4	236.3	6	207.8	17.3	188.5	230.1	5	208.7	29.1	176.6	239.0
EBWf, kg	6	345.7	30.6	308.0	388.5	6	418.7	28.2	389.6	462.3	5	464.4	62.3	402.0	541.4
MEBW, $kg^{0.75}$	6	68.5	4.3	61.9	74.3	6	74.4	3.9	70.4	80.3	5	78.5	7.7	70.1	87.7
ADG, kg/d	6	1.8	0.4	1.1	2.3	6	1.9	0.2	1.6	2.1	5	1.8	0.3	1.4	2.2
EBG, kg/d	6	1.7	0.3	1.2	2.1	6	1.8	0.1	1.6	2.0	5	1.7	0.3	1.4	2.1
ER, kcal/$kg^{0.75}$	6	117.7	18.9	96.4	151.0	6	95.9	9.3	83.5	105.6	5	97.1	15.9	80.1	116.3
MEI, kcal/$kg^{0.75}$	6	222.9	19.3	193.6	248.9	6	202.2	7.9	192.7	212.9	5	185.9	9.4	177.1	199.2
HP, kcal/$kg^{0.75}$	6	105.2	25.1	72.8	138.7	6	106.3	8.9	92.2	118.3	5	88.7	7.0	80.1	97.0

1SBWi is the initial shrunk body weight (SBW); SBWf is the final SBW; EBWi is the initial empty body weight (EBW); EBWf is the final EBW; MEBW is the metabolic BW; ADG is the average daily gain; EBG is the empty body gain; RE is the retained energy; MEI is the metabolizable energy intake; HP is the heat production.

Table 3 - Summary of intake of nutrients and energy concentration of the diet.

	Bulls				Steers				*P*-value				
Item[1]	380	440	500	BASELINE	380	440	500	BASELINE	G	380 VS 440	380 VS 500	440 VS 500	G*BW
EEI, kg/d	0.25	0.23	0.23	0.08	0.23	0.22	0.23	0.07	0.680	0.170	0.277	0.793	<.0001
	(0.0098)*	(0.0098)	(0.0107)	(0.0120)	(0.0107)	(0.0107)	(0.0107)	(0.0120)					
CPI, kg/d	0.81	0.87	0.85	0.29	0.79	0.84	0.85	0.27	0.750	0.102	0.126	0.947	<.0001
	(0.0345)	(0.0345)	(0.0378)	(0.0422)	(0.0378)	(0.0378)	(0.0378)	(0.0422)					
NDFapI, kg/d	2.20	2.46	2.54	0.90	2.12	2.50	2.51	0.86	0.817	0.002	0.001	0.607	<.0001
	(0.0944)	(0.0944)	(0.1034)	(0.1156)	(0.1034)	(0.1034)	(0.1034)	(0.1156)					
NFCI, kg/d	3.77	3.85	3.78	1.26	3.69	3.69	3.80	1.21	0.725	0.786	0.735	0.942	<.0001
	(0.1535)	(0.1535)	(0.1682)	(0.1500)	(0.1682)	(0.1682)	(0.1682)	(0.1400)					
Ash, kg/d	0.38	0.44	0.44	0.15	0.37	0.44	0.43	0.14	0.761	0.000	0.001	0.820	<.0001
	(0.0168)	(0.0168)	(0.0184)	(0.0205)	(0.0184)	(0.0184)	(0.0184)	(0.0205)					
OMI, kg/d	7.02	7.41	7.41	2.52	6.83	7.26	7.39	2.41	0.753	0.166	0.123	0.845	<.0001
	(0.2900)	(0.2900)	(0.3177)	(0.3552)	(0.3177)	(0.3177)	(0.3177)	(0.3552)					
TDNI, kg/d	4.43	4.76	4.53	1.81	4.39	4.66	4.49	1.65	0.737	0.211	0.709	0.392	<.0001
	(0.2397)	(0.2397)	(0.2626)	(0.2936)	(0.2626)	(0.2626)	(0.2626)	(0.2936)					
DMI, kg/d	6.66	7.11	6.82	2.73	6.60	7.03	6.74	2.51	0.757	0.222	0.683	0.428	<.0001
	(0.3627)	(0.3627)	(0.3973)	(0.4442)	(0.3973)	(0.3973)	(0.3973)	(0.4442)					
MEI, Mcal/d	26.02	27.97	27.28	8.79	25.22	26.24	26.77	8.12	0.607	0.194	0.254	0.895	<.0001
	(1.1455)	(1.1455)	(1.2549)	(1.4030)	(1.2549)	(1.2549)	(1.2549)	(1.4030)					
DEI, Mcal/d	21.34	22.94	22.37	7.21	20.69	21.52	21.96	6.66	0.608	0.195	0.255	0.896	<.0001
	(0.9398)	(0.9398)	(1.0295)	(1.1510)	(1.0295)	(1.0295)	(1.0295)	(1.1510)					
DE (Mcal/kg)	3.20	3.23	3.31	2.65	3.14	3.12	3.26	2.66	0.474	0.961	0.164	0.178	<.0001
	(0.0737)	(0.0737)	(0.0807)	(0.0903)	(0.0807)	(0.0807)	(0.0807)	(0.0903)					
MEI(Mcal/kg)	3.90	3.94	4.03	3.23	3.83	3.80	3.97	3.24	0.483	0.960	0.170	0.185	<.0001
	(0.0898)	(0.0898)	(0.0984)	(0.1100)	(0.0984)	(0.0984)	(0.0984)	(0.1100)					
TDN, %DM	66.61	66.98	66.36	66.23	66.57	66.35	66.61	66.02	0.172	0.528	0.496	0.199	0.01
	(0.1348)	(0.1348)	(0.1477)	(0.1651)	(0.1477)	(0.1477)	(0.1477)	(0.1651)					

[1] EE is ether extract intake, CPI is crude protein intake, NDFapI is the intake of neutral detergent fiber corrected for ash and protein contents, NFCI is the nonfiber carbohydrates intake, Ash is the mineral matter intake, OMI is the organic matter intake; TDNI is total digestible nutrients intake, DMI is dry matter intake, MEI is the metabolizable energy intake, DE is digestible energy intake; * values in parenthesis represent the standard error of the mean.

Table 4 - Summary of performance, body composition and energy balance; and the contrast of interest among treatments.

	Bulls				Steers				*P*-value				
Item[1]	380	440	500	BASELINE	380	440	500	BASELINE	G	380 VS 440	380 VS 500	440 VS 500	G*BW
SBW	382.92	457.80	500.90	274.38	384.20	456.75	510.10	262.88	0.993	0.0001	<.0001	0.0097	<.0001
	(17.4379)	(17.4379)	(19.1023)	(21.3570)	(19.1023)	(19.1023)	(19.1023)	(21.3570)					
EBW	345.73	417.70	464.44	252.85	350.52	418.65	462.50	236.93	0.903	<.0001	<.0001	0.0066	<.0001
	(15.4398)	(15.4398)	(16.9134)	(18.9098)	(16.9134)	(16.9134)	(16.9134)	(18.9098)					
EBW:SBW	0.90	0.91	0.93	0.92	0.91	0.92	0.91	0.90	0.070	0.1810	0.0924	0.6932	0.1366
	(0.0044)	(0.0044)	(0.0048)	(0.0054)	(0.0048)	(0.0048)	(0.0048)	(0.0054)					
HCW, kg	219.22	268.41	303.24	158.49	227.40	272.13	299.95	152.04	0.448	<.0001	<.0001	0.0047	<.0001
	(10.1603)	(10.1603)	(11.1301)	(12.4438)	(11.1301)	(11.1301)	(11.1301)	(12.4438)					
OV, kg	54.88	72.30	73.32	37.73	57.75	65.70	81.32	35.27	0.448	0.0002	<.0001	0.0094	<.0001
	(2.8367)	(2.8367)	(3.1075)	(3.4742)	(3.1075)	(3.1075)	(3.1075)	(3.4742)					
ADG, kg/d	1.84	1.53	1.79	0.24	1.50	1.87	1.52	0.24	0.169	0.8307	0.8162	0.6595	<.0001
	(0.1060)	(0.1060)	(0.1162)	(0.1299)	(0.1162)	(0.1162)	(0.1162)	(0.1299)					
EBG, kg/d	1.72	1.45	1.73	0.28	1.44	1.77	1.41	0.24	0.137	0.7747	0.8231	0.6155	<.0001
	(0.0891)	(0.0891)	(0.0976)	(0.1091)	(0.0976)	(0.0976)	(0.0976)	(0.1091)					
EBG:ADG	0.94	0.95	0.96	1.18	0.96	0.95	0.93	1.02	0.209	0.9224	0.7876	0.8616	<.0001
	(0.0221)	(0.0221)	(0.0242)	(0.0270)	(0.0242)	(0.0242)	(0.0242)	(0.0270)					
EE, %	19.67	25.94	22.67	17.48	21.61	20.47	29.07	20.27	0.000	0.0829	0.0005	0.0426	<.0001
	(0.8871)	(0.8871)	(0.9718)	(1.0865)	(0.9718)	(0.9718)	(0.9718)	(1.0865)					
Ash, %	8.81	8.79	8.22	10.37	8.08	8.15	8.22	9.64	0.632	0.8924	0.3912	0.4672	<.0001
	(0.2567)	(0.2567)	(0.2812)	(0.3144)	(0.2812)	(0.2812)	(0.2812)	(0.3144)					
Water, %	52.07	46.45	48.53	52.50	51.79	52.71	43.02	50.13	0.001	0.1044	<.0001	0.0029	<.0001
	(0.7720)	(0.7720)	(0.8457)	(0.9455)	(0.8457)	(0.8457)	(0.8457)	(0.9455)					
CP, %	19.45	18.82	20.58	19.66	18.52	18.67	19.69	19.96	0.472	0.6165	0.0653	0.0220	0.1125
	(0.5582)	(0.5582)	(0.6115)	(0.6836)	(0.6115)	(0.6115)	(0.6115)	(0.6836)					
RE,	117.61	100.64	97.15	32.72	105.72	95.88	97.33	36.31	0.775	0.0063	0.0050	0.8738	<.0001
$Kcal/kg^{0.75}/d$	(4.7064)	(4.7064)	(5.1557)	(5.7642)	(5.1557)	(5.1557)	(5.1557)	(5.7642)					
HP,	207.02	206.49	174.54	106.00	205.53	182.89	171.13	98.39	0.390	0.2282	0.0006	0.0137	<.0001
$Kcal/kg^{0.75}/d$	(8.2551)	(8.2551)	(9.0430)	(10.1104)	(9.0430)	(9.0430)	(9.0430)	(10.1104)					

[1]SBW is shrunk BW; EBW is the empty BW; EBW:SBW is the ratio among the variables; HCW is the hot carcass weight, ADG is average daily gain; EBG is empty body gain; EBG:ADG is the ratio among the variables; EE is amount of EE in the empty body; Ash is the amount of ashes in the empty body; Water is the amount of water in the empty body; CP is the amount of CP in the empty body; RE is retained energy in kg of EBW; HP is heat production in kg of EBW; * values in parenthesis represent the standard error of the mean.

Table 5 – Description of equations used to assess energy requirements.

Item[1]	#	Equations	Unit
EBW	Eq. [1]	0.907 x SBW	kg
EBG	Eq. [2]	0.949 x ADG	kg/dia
EBWeq	Eq. [3]	(EBW/455) x 440	kg
HP	Eq. [4]	$0.070 \times e^{(3.3605 \times MEI)}$	$Mcal/kg^{0.75}$
NEm	Eq. [5]	$0.070*EBW^{0.75}$	Mcal/dia
MEm	Eq. [6]	Iterative proc. (HP=MEI) = 0.096964	$Mcal/kg^{0.75}$/dia
NEg	Eq. [7]	$0.064 \times EBWeq^{0.75} \times EBG^{1.092}$	Mcal/dia
	Eq. [8]	$0.053 \times EBWeq^{0.75} \times EBG^{1.092}$	
Kg		41.29	%
Km		72.00	%
MEg	Eq. [9]	NEg/Kg	Mcal/dia
MEtotal	Eq. [10]	MEm + MEg	Mcal/dia
TDN	Eq. [11]	MEtotal/0.82/4.409	kg/dia

[1]EBW is empty body weight, SBW is the shrunk body weight, EBG is empty body gain, ADG is the average daily gain, EBWeq EBW equivalent, HP is heat production, NEm is the net energy requirement for maintenance, MEm is the metabolizable energy required for maintenance, NEg is the net energy requirements for gain, kg is the partial efficiency of use of metabolizable energy for gain, km is the partial efficiency of use of metabolizable energy for maintenance, MEg is the metabolizable energy requirement for gain, MEtotal is the total metabolizable energy requirement (maintenance + gain), and TDN total digestible nutrients requirement.

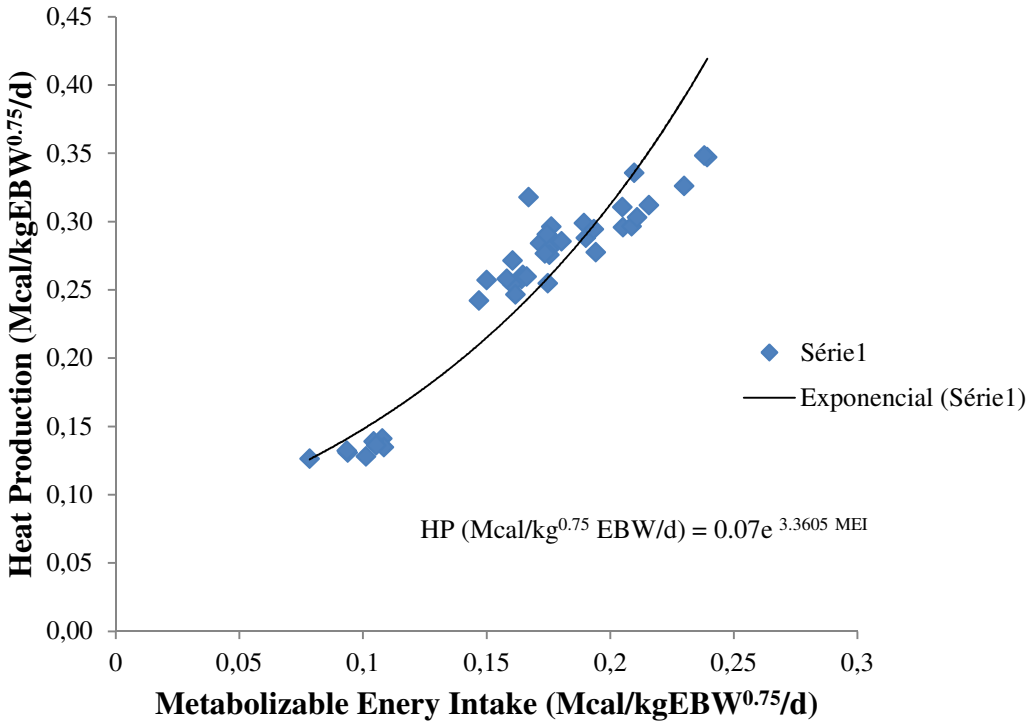

Figure 2 - Relationship among Heat production and Metabolizable energy intake.

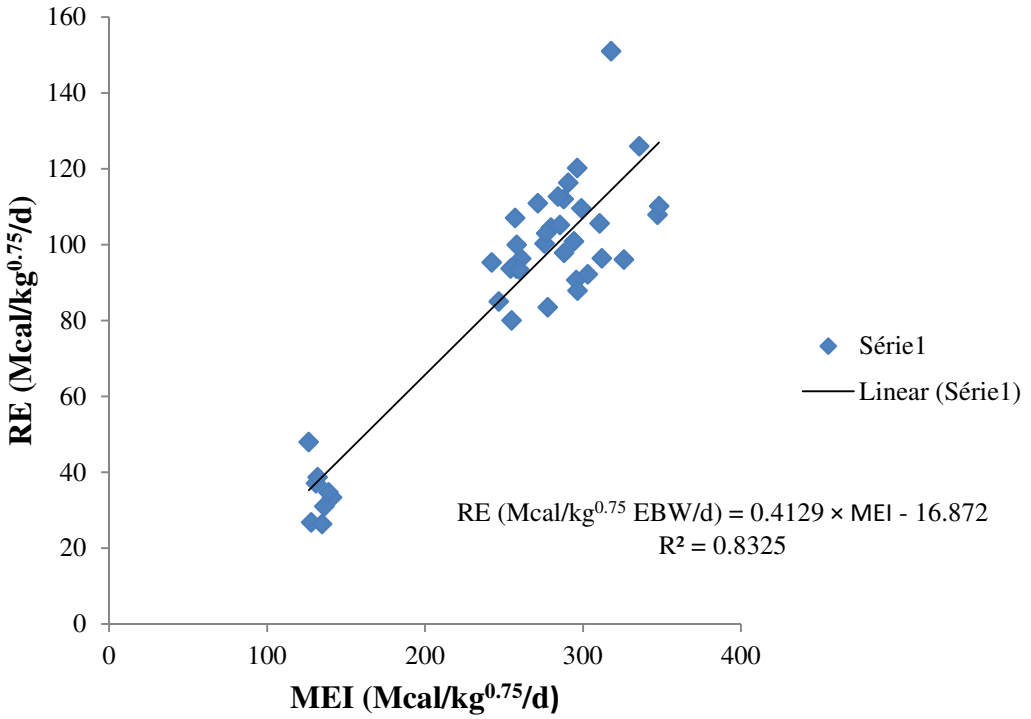

Figure 2 - Relationship among retained energy and metabolizable energy intake.

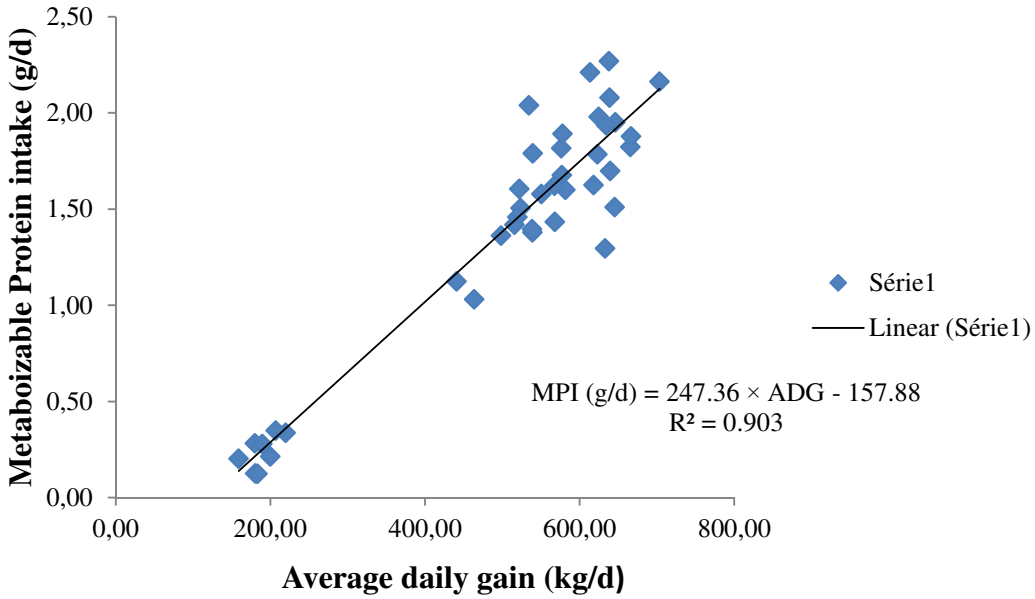

Figure 3 - Relationship among metabolizable protein intake and average daily gain.

Chapter III

Evaluation of predictive equations developed to assess body composition in beef cattle using F1 Nellore x Angus bulls and steers[1]

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Evaluation of predictive equations developed to assess body composition in beef cattle using F1 Nellore x Angus bulls and steers

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ABSTRACT

Equations developed in the studies of Hankins and Howe (1946), Marcondes et al. (2010), Marcondes et al. (2012), and Valadares Filho et al. (2006) were evaluated in attempt to predict the body physically separable and chemical composition of F1 Angus x Nellore bulls and steers, as wells for empty body and non-carcass components, through the use of the 9-11th Rib section and non-carcass measurements. Fourty-eight F1 Nellore x Angus bulls (B) and steers (S), with 12.5±0.51 mo old, and initial shrunk BW (SBW) of 233±23.5 and 238±24.6 kg for B and S, respectively were used in this experiment. The trial was design in a completely randomized 2 x 3 factorial arrangements of treatments (two genders and three slaughter weights). The animals were randomly assigned into five slaughter-weight based groups: baseline, maintenance, 380, 440 and 500kg. The diet was composed of corn silage and concentrate (60:40). After slaughter, the 9–11th Rib cut was dissected into muscle, fat and bone fractions. The remaining carcass was similarly dissected. The others variables evaluated as partial predictors included the empty body weight, the dressing percentage, the visceral fat percentage, the organ and viscera percentage and the composition of the non-carcass components. The values estimated with prediction equations were compared to the observed values and among models. Regarding the physically separable carcass composition only the model devised by Marcondes et al. (2012) estimated precisely and accurately the amount of muscle and fat tissue present in the carcass. The models devised by Valadares Filho et al. (2006) and Marcondes et al. (2010) estimated accurately and precisely the amount of carcass chemical components, along with the model devised by Hankins and Howe (1946) which could

only explain the amount of crude protein content in the carcass. The models used to predict carcass chemical composition failure in estimate the correct amount of chemical contents present in the empty body weight, except for Valadares Filho et al. (2006) that can be used for the estimation of the crude protein content in the empty body weight. The model devised by Marcondes et al. (2010) was not able to explain most of the chemical composition variation present in the non-carcass components, being recommended only for ashes and water contents in the blood and hide, and furthermore crude protein and ashes content in the organs and viscera.

Key Words: carcass composition, carcass prediction, empty body composition, empty body prediction, modeling evaluation

1. Introduction:

Growth often is measured by the changes in BW over time. Although, that information can be misleading if the amount of fill is unknown, the amount of others highly variable non-carcass components are unknown, and if the proportion of the carcass which is saleable is unknown (Fisher, 1975); (Hedrick, 1983); (Bonilha et al., 2011). Most of the classical equations used to estimate the body's physical and chemical composition have used the 9-11th Rib section (Hankins and Howe, 1946; Valadares Filho et al., 2006; Marcondes et al., 2010), carcass lean tissue, fat and bone contents, dressing percentage, empty body weight, visceral fat, organs and viscera content and so forth. It was observed significant improvements in the goodness of fit of those equations when non-carcass components were added (Marcondes et al., 2010).Though, to be useful one model should be challenged to the widest range of conditions. Furthermore, before the decision of adjusting new models, the current ones should be evaluated to identify their strengths and weaknesses, pondering for its

constraints, and enabling its improvement in a sense of pointing directions in describing more accurately and precisely the variable under study.

The objectives with this study were (1) to evaluate the goodness of fit of prediction equations developed by Hankins and Howe (1946), and Marcondes et al. (2012) to assess carcass physical composition, (2) to evaluate the goodness of fit of prediction equations developed by Hankins and Howe (1946), Valadares Filho et al. (2006), and Marcondes et al. (2010) to assess carcass chemical composition, (3) to evaluate the goodness of fit of prediction equations developed by Valadares Filho et al. (2006), and Marcondes et al. (2010) to assess empty body chemical composition, (4) to evaluate the goodness of fit of predictive equations developed by Marcondes et al. (2010) to assess non-carcass components (blood and hide, head and limbs; organs and viscera) chemical composition.

2. Material and Methods:

2.1. Location

The dataset utilized was obtained at the Federal University of Viçosa, Brazil, between December of 2009 and August of 2010. Laboratory analyses were performed at the Ruminant Nutrition Laboratory located at Department of Animal Science, Federal University of Viçosa, Brazil.

2.2. Diets and feed composition

The diet was formulated according to Valadares Filho et al. (2006) to contain 11 % CP. Animals were fed 60% corn silage and 40% concentrate, containing corn, soybean meal, urea, ammonium sulfate, sodium chloride, limestone, and mineral mix (Table 1).

Feed regime was twice daily (at 6h00 and 16h00), and fed as a total mixed ration, which was daily adjusted to maintain orts up to 10% of the as fed offered. Water was permanently available.

2.3. Animal resource and Study design:

The dataset was composed by forty-eight F1 Nellore x Angus bulls (B) and steers (S), with 12.5±0.51 mo old, and initial shrunk BW (SBW) of 233±23.5 and 238±24.6 kg for B and S, respectively (Table 2). The trial was design in a completely randomized 2 x 3 factorial arrangements of treatments (two genders and three slaughter weights). The animals were randomly assigned into five slaughter-weight based groups: baseline, maintenance, 380, 440 and 500. The baseline group was slaughtered at the beginning of the trial (4B and 4S). The other groups were slaughtered when the animals reached an average BW of 380 (6B and 5S), 440 (6B and 5S), and 500 kg (5B and 5S). The maintenance (4B and 4S) group was slaughtered at the same time as the 500 kg's group. The animals were housed in individual pens covered with concreted floors, feeders and concreted bunks, in a total available area of 30 m^2, and 8 m^2 of sheltered area.

2.4. Slaughter and Dissections

All slaughters followed the same procedure. The animals were fasted for 16 h before the slaughter. At the chute the animals were desensitized with a non-penetrating stunner and killed by exsanguination on the jugular vein using conventional humane procedures. The gastro-intestinal tract (**GIT**) was cleaned and weighed with the other organs to determine the empty BW (**EBW**). Carcasses were separated in two halves and weighed (hot carcass weight), then chilled (1 to 4 ^oC) for 18 h and then re-weighed to obtain the chilled carcass weight (**CCW**). The Rib_{9-11} section was removed from the left carcass and subsequently dissected into bone, fat, and lean tissues. The rest of the left carcass was completely dissected into bone, fat, and lean tissues and the Rib_{9-11} section

was summed, at the end, to obtain the full carcass composition. Samples of bone, fat, and lean tissues from the carcass, head, limbs, hide, blood, and organs and viscera were taken to determine carcass and body chemical compositions. The mesenteric fat was physically separated from the GIT and weighed with kidney, pelvic, and heart fat to compose the visceral fat. Tendons were weighed with the lean tissue, while connective tissues were added to the fat pool. After weighing each component, lean and fat tissues were separately ground, subsampled, and then mixed together to reset their original physically separable proportion. Carcass bones were separated into vertebral, ribs, and long bones, and sawn into 5 x 5 cm pieces enabling to be proportionally sub-sampled and composited as total bone sample. The Rib_{9-11} bones were also sawn into small pieces (5 x 5 cm) and sampled. The head and feet were sampled in two animals per group and then separated into hide, bone, and soft tissues, which represented the respective slaughtered group composition. The hide was weighed, sampled (25 x 25 cm) from the left rump of each animal and finally considered representative of the rest of the body. Viscera and organs were ground together and sub-sampled. Blood was sampled during the exsanguination. The hide was sampled (25 to 25 cm) from the left croup of each animal and ground.

Except for blood samples, which were dried at 60 ^{o}C for 72 h, all samples were preliminary freeze dried and partially defatted by washing it successively with petroleum ether in a Soxhlet apparatus (Fernandes et al., 2010b); Marcondes et. al., 2012; (De Paula et al., 2013). The amount of fat lost during this procedure was computed by weight differences. Then, all samples were ground using a ball mill and analyzed for moisture (method 934.01; (AOAC, 1990), protein (method 920.87; AOAC, 1990), ether extract (EE; method 920.85; AOAC, 1990), and ash (method 924.05; AOAC, 1990) in order to determine the chemical composition of the Rib_{9-11}

section, carcass, and empty body. The final EE was corrected by adding the fat lost during the partial defatting process.

2.5. Equations evaluated

Equations developed by Hankins and Howe (1946), Marcondes et al. (2010), and Marcondes et al. (2012) were used to estimate the carcass physical composition (Table 3) while the equations developed by and Valadares Filho et al. (2006), Marcondes et al. (2010) and Hankins and Howe (1946) were used to evaluate the carcass chemical composition (Table 3). Furthermore the equations developed by Valadares Filho et al. (2006), and Marcondes et al. (2010) were used to evaluate the chemical empty body composition using the The $Rib_{9\text{-}11}$ section (Table 3). Then, the equations developed by Marcondes et al. (2010) were used to estimate the chemical composition of the non-carcass (blood and hide; head and limbs; and organs and viscera) components (Table 4). The present dataset was independently related to the one used while developing the evaluated equations.

Despite of some data been shown as a percentage in some tables (Table 2), the amount of each tissue was used instead to avoid loss of normality when dividing variables.

2.6. Statistical analyses:

The carcass physical composition estimated by the equations developed by Hankins and Howe (1946), and Marcondes et al. (2010), and Marcondes et al. (2012) were tested against the observed values using the following regression:

$Y = \beta_0 + \beta_1 \times X$,

Where x = predicted values; y = observed values; β_0 and β_1 are the intercept and slope, respectively.

The regression was evaluated according to the null hypothesis that states β_0 is equal to zero and β_1 is equal to one, and the alternative hypothesis that is not H_0. A nonrejection of the null hypothesis means that the model explained accurately the

variation that had occurred in the dataset. The precision was assessed by the evaluation of the coefficient of correlation of the linear regression of Y on X, which assumes the value closer to 1 is the best estimative for the purpose.

Furthermore the standard deviation (SD) and Mean squared error of prediction (MSEP) were evaluated to account for the distance between the prediction and its true value, in which a smaller value is better. The Mean bias (MB), described by (Cochran and Cox, 1957), that represents the average inaccuracy of the model (Kohn et al., 1998), was evaluated for attesting the zero proximity which, in other words, would represent a more accurate estimative of the model-predicted values. The Modeling efficiency factor (MEF) which represents the proportion of the variation explained by the line Y = X, was used as an indicator of goodness of fit (Mayer and Butler, 1993). Values closer to 1 are better and lower than zero means that the model-predicted values are worse than the observed mean (Loague and Green, 1991). The Coefficient of model determination (CD) was used to assess the variance of the predicted data, in which a value closer to 1 represents the best estimator of the observed data. The Bias correction factor (Cb), a component of the Concordance correlation coefficient (CCC), indicates the deviation of the model from the regression line in relation to a slope of a unity. The CCC (Lin, 1989) represents the reproducibility index and may account simultaneously for accuracy and precision. For both analyses of fitting errors a value closer to 1 is desirable. Finally, the Corrected Akaike's Information Criterion (AICc), a measure of estimated information loss, was evaluated, in which a smaller value would represent a better goodness of fit of the statistical model. All calculations were obtained using the Model Evaluation System (http://nutritionmodels.tamu.edu/mes.htm, last accessed April 22, 2013; Tedeschi, 2006)

3. Results:

3.1. Carcass physically separable composition

3.1.1. Muscle: The model HH46, devised by Hankins and Howe (1946), was slightly better concerning the variation that could be explained by the plotted observed on model-predicted values (r^2), therefore slightly more precise (Table 5, Figure 1). Although, presented problems regarding the intercept and slope of the regression line (P<0.05), since it was not different from zero. The CCC indicated better reproducibility and higher accuracy for M12, devised by Marcondes et al. (2012), since its Cb was slightly higher. The higher MEF value observed for M12, while compared to its respective r^2, indicated a higher efficiency of prediction. Also HH46 model presented smaller AIC compared to M12 model, but the difference was quite small. Despite of the fact that the model HH46 is 2.4 more likely to be correct than M12 model, neither of its intercept nor slope were equal to zero and one, respectively (P<0.05), and the simultaneous test for intercept equal to zero and slope equal to one rejected the null hypothesis (P<0.01). For M12 both, separate and simultaneous test for intercept equal to zero and slope equal to one, failed to reject the null hypothesis (P>0.05). It also could be observed a slightly higher shift location of HH46 model corroborating with its underprediction. Thus, the equation proposed by Marcondes et al. (2012), accurately and precisely, estimated the proportion of muscle in carcass (P>0.05) and are recommended to be used for F1 Nellore x Angus. Meanwhile, the HH46 model is not recommended.

3.1.2. Adipose: The HH46 model presented problems regarding its slope and respective proximity of a unity (P<0.05), although the intercept did not differ from zero (P>0.05). The M12 model also presented the best goodness of fit regarding the estimation the physically separable carcass fat content. Its r^2 was slightly higher, indicating higher precision, as wells for its MB, closer to zero, and smaller AIC (Table 5). Additionally presented higher model efficiency since a higher proportion of the total variance of the observed values was explained by the predicted data, as seen by the

proximity with its respective r^2. The model proposed by Marcondes et al. (2012), also presented a higher reproducibility index showing a better accuracy (Cb=0.99) and slightly higher precision. Furthermore, HH46 presented higher shift and scale locations (Figure 2), while M12 did not differ from the identity line since neither the intercept nor the slope differed from zero and one, respectively (P>0.05). Thus, model M12 is seven times more likely to be correct than HH46 model. The amount of fat in the carcass was affected as well, since the composition of the dataset changed affecting secondarily the lean tissue proportion.

3.1.3. Bones: Both models presented similar precision (Table 5) since their variation that could be explained by the plotted observed against model-predicted values (r^2) was identical for the carcass bones estimate (P<0.05). Also M12 model presented smaller AIC compared to M12 model. The devised models presented close CCC and Cb indicating similar deviations from the slope of 45^o (Table 5 and Figure 3). For both models MEF was smaller than the regression's r^2 suggesting the model accounted for less variation than the regression line. For both the MSEP partition show a higher participation of random errors components indicating that a higher proportion of the bias is not associated with the model, therefore lack-of-fit has not been totally ensured yet. Despite of the fact that the model M12 is 1.5 times more likely to be correct than HH46 model, neither its intercept nor slope were equal to zero and one, respectively (P<0.05). In addition, the simultaneous test for intercept equal to zero and slope equal to one rejected the null hypothesis (P<0.01), indicating that proposed models might be tested furthermore with re-parameterization needed and not recommended to estimate the amount of bones in the carcass.

3.2. Carcass chemical composition

3.2.1. Crude Protein: All models three models evaluated for the prediction of the crude protein content in the carcass chemical composition (Table 6 and Figure 4) failed to

reject the null hypothesis of a respective intercept and slope equal to zero and one (P>0.05), when both parameters were tested separately. However, the simultaneous test for zero intercept and slope of a unity, shown that only the V06 model failed to rejected the null hypothesis. The three models presented similar precision (0.82; 0.84 and 0.84). The model devised by Marcondes et al. (2010) presented the highest MSEP and smaller bias correction, CCC and AIC. For V06 and HH46 models, roughly 80% of the MSEP was explained by the random component and for M10 half of the MSEP variation was explained by random and half by systematic components. Despite of the fact that all three models were satisfactory in explaining the observed values, HH46 model presented the higher efficiency since its MEF was closest to its r^2. It is 26.8 times more likely that model HH46 is more appropriate than model V06, 16.2 times more likely that model M10 is more appropriate than model HH46, and 433.4 times more likely that model M10 is more appropriate than model V06.

3.2.2. Ether extract: The model V06 failed to reject the null hypothesis when the data were analyzed either separate or simultaneously, since neither of its intercept nor slope differed from zero and one, respectively (*P*>0.05). The V06 model presented the smallest MSEP and over 90% of the prediction error was random indicating that the majority of the prediction error was not associated with the model. The greater MSEP was encountered within the model HH46, in which 49% of that variation was directly associated with the random deviation. A higher MEF was observed by V06, followed by M10 and HH46. The reproducibility was similar CCC for M10 and HH46, with a higher for V06. The AIC was slightly smaller for M10. Thus, model HH46 presented the worst capability to explain the observed data (Table 6, Figure 4), and is 9.9 times less likely to be correct than V06, and 33.8 times less likely to be correct than M10. The model M10 is 3.4 times more likely to be correct than HH46, and presented the better goodness of fit among all tested.

3.2.3. Water: The models V06 and M10 accepted the null hypothesis for intercept equals to zero and slope to a unity, while the parameters were analyzed in separate. When analyzing together only model V06 confirmed the non-rejection. The model HH46 presented problems due its slope different from one (P<0.001), when the parameters were analyzed in separate, and rejecting Ho when analyzed simultaneously (Table 5, Figure 4). The HH46 model accounted for the biggest variation in the error of prediction, MSEP, in which 91% was responsibility of the mean bias showing inadequacy of prediction since the errors are mostly around the mean. For V06 95% of the variation was attributed to random error and for M10 roughly 75% was random component. The three models were equally precise, but only V06 and M10 were high and equally accurate. The smallest AICc observed was for the model described by Marcondes et al. (2010). Model M10 presented the better performance in explained this dataset and is 4.2 times more likely to be correct than HH46, and 1.5 times more likely to be correct than V06. Model V06 is 2.9 times more likely to be correct than HH46.

3.3. Empty body fat chemical composition

For empty body fat chemical composition two models were analyzed: the model devised by Marcondes et al. (2010), here named M10, and the model devised by Valadares Filho et al. (2006), here named V06 (Table 7 and Figure 5).

3.3.1. Crude protein: both models evaluated for the prediction of chemical content of the crude protein in the empty body failed to reject the null hypothesis of a intercept equal to zero (P>0.05). When the null hypothesis tested was a slope of a unity, only the model devised by (Valadares Filho et al., 2006) rejected the null hypothesis (P<0.05). However, the simultaneous test for zero intercept and slope of one, shown that none of the models have failed to rejected the null hypothesis. The model devised by Marcondes et al. (2010) presented higher precision (0.91 against 0.86) and a smaller error of prediction. For both models most of the prediction's errors was associated with

the random component and not with the mean. The model V06 was more likely to present a higher model efficiency and smaller mean bias. The CCC was slightly higher and the AIC slightly smaller for V06. It is 7600.4 times more likely that model devised by Marcondes et al. (2010) explains better the variation in the amount of crude protein present in the empty body than the model proposed by Valadares Filho et al. (2006). However, only the model V06 can be used to estimate the amount of crude protein present in the empty body.

3.3.2. Ether extract: both models evaluated for the prediction of the chemical content of ether extract in the empty body rejected the null hypothesis of an intercept equal to zero ($P<0.05$). When the null hypothesis tested was a slope of a unity, only the model devised by Valadares Filho et al. (2006) failed to reject the null hypothesis ($P>0.05$). However, the simultaneous test for zero intercept and slope of a unity, shown that both models rejected the null hypothesis. Both models presented a higher and similar precision (0.94) and largely differed concerning its error of prediction. For the model devised by Valadares Filho et al. (2006) the MSEP partition had shown itself evenly partitioned into random and mean components. Most of the error associated with the prediction for the model devised by Marcondes et al. (2010) was systematic, therefore, related to its inclination. The model devised by (Valadares Filho et al., 2006) was more likely to present a higher model efficiency and higher mean bias. The CCC and Cb were slightly higher for Valadares Filho et al. (2006) and the AIC slightly smaller for V06. Thus, it is 56.8 times more likely that model devised by Marcondes et al. (2010) explains better the variation in the amount of ether extract present in the empty body than the model proposed by Valadares Filho et al. (2006). Although, none of the models can be recommend to estimate the amount of EE in the empty body of F1 Nellore x Angus cattle.

3.3.3. Water: both models evaluated for the prediction of the water content in the empty body failed to reject the null hypothesis of a intercept equal to zero (P>0.05). When the null hypothesis tested was a slope of a unity the null hypothesis was rejected by both (*P*<0.05). Additionally, the simultaneous test for zero intercept and slope of a unity showed that none of the models failed to reject the null hypothesis. Both models presented a higher and similar precision (0.96) and differed a lot regarding the error of prediction (Table 7 and Figure 5). For both models roughly 80% of the prediction's error was associated with the mean. The model devised by Valadares Filho et al. (2006) was more likely to present a higher model efficiency and smaller mean bias. The CCC was slightly higher and the AIC slightly smaller for Valadares Filho et al. (2006). Therefore, it is 5.4 times more likely that model devised by Valadares Filho et al. (2006) explains better the variation in the amount of water present in the empty body than the model proposed by Marcondes et al. (2010). Although, none of the models can be recommend to estimate the amount of W in the empty body of F1 Nellore x Angus cattle.

3.3. Non-carcass components composition

For non-carcass components composition only one model was analyzed (Marcondes *et al.* 2010) (Table 8 and Fig. 6).

3.3.1. Blood and Hide: MM and W fail to reject the null hypothesis for a slope of zero and intercept of a unity (*P*>0.05). Although the model MM presented some weakness regarding its precision and reproducibility (r2=0.55 and CCC=0.67). The partition of the MSEP showed that about 5% of the error is explained by the mean and systematic biases, and the other 95% is explained by the random component. Furthermore, the model presented high accuracy (Cb=0.90). The model used to estimate the W content was very accurate and precise (0.99 and 0.98, respectively), with a good reproducibility index (0.98). Despite of the fact the evaluated model for CP had very good precision

and accuracy (0.95 and 0.91 respectively); it did fail to reject the null hypothesis, not allowing its recommendation to estimate CP contents in the blood and hide. The analyses for EE estimation showed relative average precision (r2=0.76), but low accuracy and therefore low reproducibility (Cb=0.28 and CCC=0.24) combined with the null hypothesis rejection. So the model could not be recommended to predict the amount of EE present in the blood and hide.

3.3.2. Head and Limbs: none of the predictions of the analyzed chemical components (CP, EE, MM, and W) were able to explain the observed data since they rejected the null hypothesis for both, slope of a unity and zero intercept (Table 8). Except for W that presented good precision (r2=0.80), all the others were poorly accurate and precise, and presented low reproducibility. At the error's partition, the main component explaining the error is the mean bias indicating the poor prediction ability. Therefore, it is not recommended to be used.

3.3.3. Organs and viscera: The CP and MM models failed to reject the null hypothesis of slope of a unity and zero intercept, thus could be used to estimate its chemical composition in organs and viscera. Both models presented high accuracy (0.97 and 0.89 for CP and MM respectively), and at the error's partition roughly 98% is explained by the random component. The main weakness would rely on their relative low precision and average reproducibility (Table 8). The EE model presented high accuracy and precision (0.94 and 0.97, respectively), and did not fail to reject the null hypothesis of an intercept of zero ($P>0.05$). Although, rejected the slope of a unity ($P<0.05$) indicating that a possible potential to be used but some re-parameterization might be necessary. Still, the main component of the error is the random (55.68%), but some improvement regarding the shifting of the errors from systematic and mean bias components to the random component is desirable. The EE model it is not recommended to be used.

The W model was highly precise (r^2=0.92), but rejected the null hypothesis of slope of a unity and zero intercept, not being able to explain the variation of the observed data. So, with the combination of lack of accuracy and rejection of the hypothesis, it is not recommended to be used in attempt to estimate the W content of the organs and viscera components.

4. Discussion:

4.1. Carcass physically separable composition: The database in which the equations were developed (Marcondes et al., 2012) represents the evolution of the previous Brazilian system dataset, once composed strictly by *Bos indicus* animals. Within the updated database, at least 50% of the animals were crossbred making it possible to account for some of the variation that those animals brought to the data, especially those related to the earlier maturity of animals and amount and proportion of tissues in the carcass and gain. Another difference relies on gender influence. The HH46 model was developed with the variation related to steers and heifers, and M12 with the presence of bulls, steers and heifers. The presence of bulls would eventually inflate the amount of the lean tissue and gain composition explaining the HH46's lean tissue underpredicion. The addition of the VF on the equations brings more accuracy and precision to it. Probably because, in Brazil, the KPH and kidneys are removed from carcass and all the implicit variation in this depot (i.e. undernutrition, sex) was heading to a different pool, here named internal fat, which despite of making part of the empty body it is not part of the carcass. Proof of that is the VF being discounted from the prediction of the total lean tissue amount (Table 3). Some extreme cases the KPH may compromise up to 6% of the carcass weight (Berg and Butterfield, 1976).

As fat is the most variable tissue in the body its manipulation will reflect on carcass composition whether by genetic or nutritional means, depending on controlling the

proportion of it. Under normal circumstances, weight at slaughter will determine the proportion of fat which increases along with BW(Berg and Butterfield, 1976). Differences between genders in weight of muscle relative to weight of bone are influenced by the criteria used to select them for slaughter than by direct sex-influenced differences. Thus, at an equal level of fatness, bulls will be superior to steers in muscle:bone ratios because they will be heavier, therefore forcing the amount of muscle in the carcass grow higher.

Animals that might have a higher amount of visceral fat due to any feed restriction and or re-feeding, would decrease the amount of lean tissue predicted by the model which may be a constraint for its generalized application, especially concerning grazing animals in tropical conditions, that frequently suffer with the lack of rain during the winter, making its compensation during the rainy season. Re-alimentation following weight loss tends to restore normal carcass composition. If the compensation period is long enough a normal state may be reached. However, at the same live weight the proportion of fat in carcasses of starved and re-alimented cattle would usually be less than those on uninterrupted growth (Berg and Butterfield, 1976).

In this dataset some of those animals were represented by the maintenance group, but yet, their influence it is not enough to cause any shift or scale location in the model since represents roughly 16% of the data set. Yet, maybe such difference is related to the growth patterns of the tissues that show the nature of a steady growth of the bones, but within a slow rate, comparing to muscle that grows relatively faster which would increase the ratio muscle:bone. The use of bones as a baseline instead of bones plus muscle seems to increase the sensitivity in a sense that permit to understand the allometric growth pattern of muscle related to bone. In other words, the angular coefficient of the bone's growth pattern shows that it takes a lot to alter or interfere in such prediction since the sensibility in which the bone deposition responds to

nutritional manipulation is not very high, therefore a severe and continuously starvation might have to take place in order to interfere in a model's ability to predict the natural phenomenon.

4.2. Carcass chemical composition:

The DP is also indirectly affected by the KPH amount and chemical profile since is altered by the differences in the dressing procedure in different countries. With VF, the estimates of Marcondes et al. (2010) presented a better goodness of fit compared to the previous models regarding the estimate of the amount of crude protein content in carcass. The models, V06 and HH46, were very similar even for variables that would affect the estimations, but the parameters were quite different in a sense that the first would account mainly for *Bos taurus* and the second would account mainly for *Bos indicus*. That indicates that the concept at the time of the model's development were the same and the re-parameterization was enough to account for the differences between breed, protein turnover, so forth and so on. With M10 models the crossbred animals were added and some variation in carcass protein content could be accounted. Especially those related to the heterosis and its effects on DF, VF, and the presence of non-emasculated animals, and muscle content in the carcass itself. Although the three models are indicated the M10 explained better the evaluated dataset.

So the model devised by Marcondes et al. (2010) accounted for some differences regarding the rate of the fattening phase among different breeds, and then performed more satisfactorily. It seems that the main one is the time of the onset of that phase.

Regarding the chemical composition of the different tissues, it has being reported a great variation within a depot depending in where it is located (Callow, 1962). The author reported between 25 and 90% of the subcutaneous fat tissue as chemical fat, while for intermuscular depot the range is between 30 and 83%, and at the KPH depot the chemical fat amount goes further as over 94%.

4.3. Empty body chemical composition:

Maturity, reflected by an increase in the proportion of fat, is accompanied by a decrease in the proportion of water and protein in the body. The range of fat proportion in the empty bodies of cattle can go from 2 up to 50%. Water varies from 80 to 40 and protein from 20 to 12%. So, the data suggests the range of fat contents were too high which did not allow the model to predict the fat chemical content in the empty body. The main variation for EE and water, which goes together in opposite directions, were due its slope, which means that the animals in the dataset had a higher rate of fattening, making a more conservative model underestimate the amount of fat and consequently overestimate the amount of water. The fatter the animal get the higher will be the amount of chemical fat in the body. That behavior could be explained by the higher efficiency of crossbred animal regarding its rate of growth and fattening compare to only *Bos indicus* animals. Furthermore, it has been shown that fat depots from thin animals contain more water and less fat than those from fatter animals (Berg and Butterfield, 1976), which agree in the BW of the dataset compared to the models.

Regarding its protein deposition the V06 model was very accurate and precise, probably because the animals in this data presented the same rate of gain but within a different composition of gain. Showing that the muscle grew at the same pattern as in the animals of V06, although the chemical maturity would be reached in a higher point of fattening, in other words, the animal were able to deposited more fat for a longer period of time, since the amount of chemical fat varies widely with the type of depot, and the age and fatness of the animal. The kidney fat depot has the highest amount of chemical fat (90%) and thus less water and protein than subcutaneous or intermuscular fat which contains approximately 70% of fat in a fattened steer (Berg and Butterfield, 1976).

4.4. Non-carcass chemical composition:

The equations used to estimate the chemical constitution of the blood and hide presented the best performance among all, yet were only useful for ashes and water determination. Probably due to a really small number of observations used to generate the models that did not account for the variations among tissues and nested external effects on them. Most of the models presented high intercept and just a small variation on the variables of influence showing only the uniformity of the animals that composed the dataset and the feeding and diet events, which does not show, yet, a pattern of composition in those parts. A way more had to be increased in the dataset before the equations shown good usefulness, such as a bigger range of animals, diet composition, compensatory growth, breeds, gender, and so forth and son on. Those equations assume that all chemical composition of the noncarcass is isometric with the growth pattern. The lack of a isometric behavior is exemplified in the equations used to estimate the heads and limbs composition and its lack of adjustment. Animals would differentiate if a severe restriction it is applied in the development of prioritary tissues (i.e. bones) which would alter the pattern of deposition and therefore required much more than only EBW by itself. The estimation of organs and viscera chemical content shows a weakness of a limited number of points and lack of variation of CP contents. Tissues like the liver or diaphragm, known as high protein content would not affect the prediction which is not likely showing only the present dataset was under similar feeding regime as the one used to develop the equations.

5. Conclusions

Regarding the prediction of the physically separable carcass composition the models devised by Marcondes et al. (2012) can be used to estimate the amount of muscle and fat contents in the carcass of F1 Nellore x Angus bulls and steers. None of the models are recommended to be used to estimate the amount of bones present in the carcass. For carcass chemical composition, the model devised by Marcondes et al. (2010) presented

as the best estimator for all components. Except for water and ether extract estimations through Hankins and Howe (1946) model, all other components can be estimated with the evaluated models. For empty body chemical fat content, neither EE nor W can be estimated using the models devised by Marcondes et al. (2010) or Valadares Filho et al. (2006). Though, crude protein content can be estimated with Valadares Filho et al. (2006). For non-carcass chemical composition the contents of ashes only can be recommended for blood and hide, and organs and viscera. Also the water content present in blood and hide can be estimated. None of the other non-carcass chemical components present in the non-carcass tissue can be estimated by the model devised by Marcondes et al. (2010).

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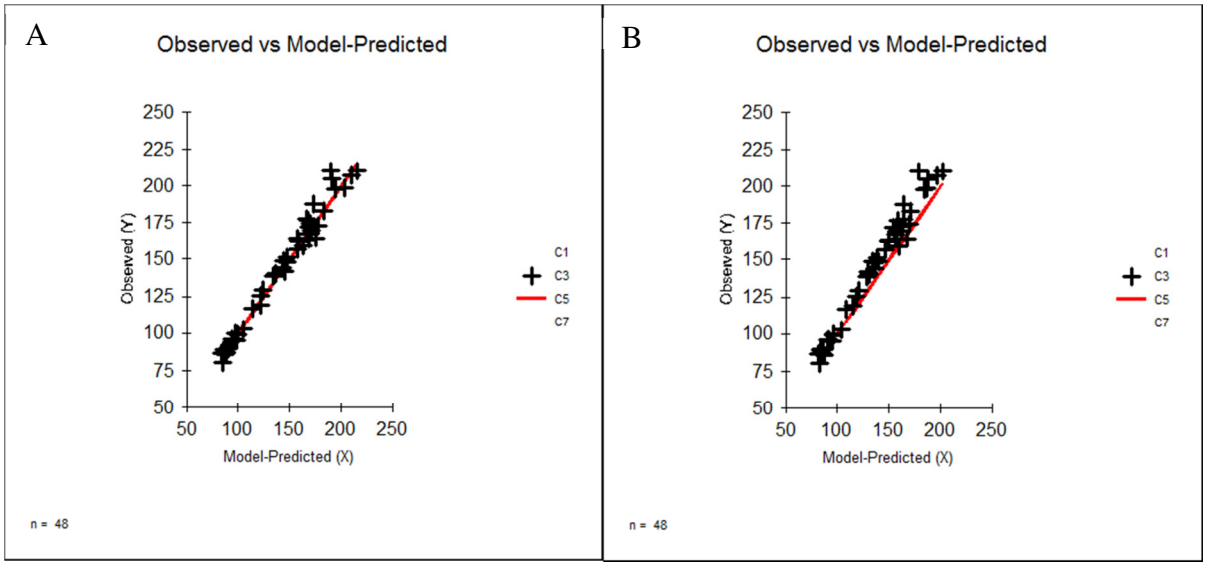

Figure 1 - Relationship among observed and model-predicted values for physically separable carcass muscle estimated by (A) Marcondes et al. (2012), and (B) Hankins and Howe (1946).

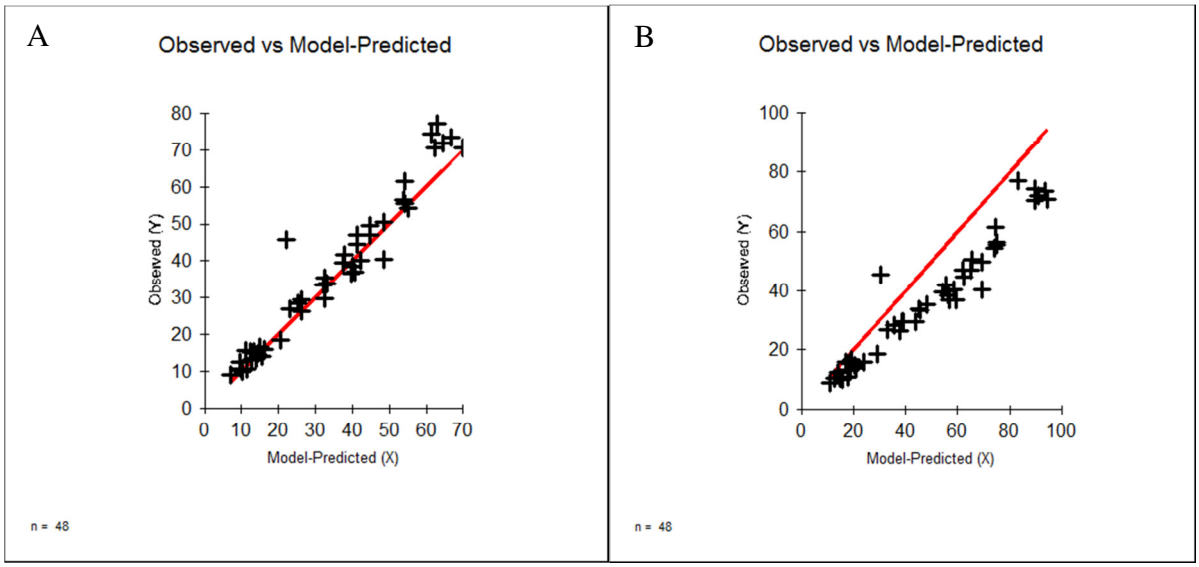

Figure 2 - Relationship among observed and model-predicted values for physically separable carcass fat estimated by (A) Marcondes et al. (2012), and (B) Hankins and Howe (1946).

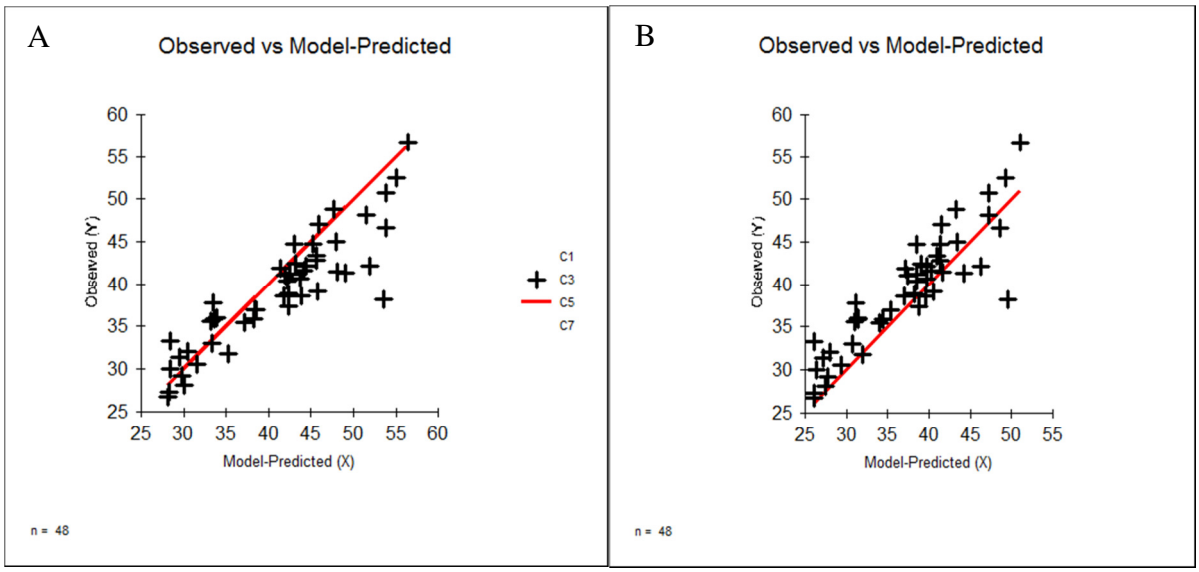

Figure 3 - Relationship among observed and model-predicted values for carcass bone estimated by (A) Marcondes et al. (2012), and (B) Hankins and Howe (1946).

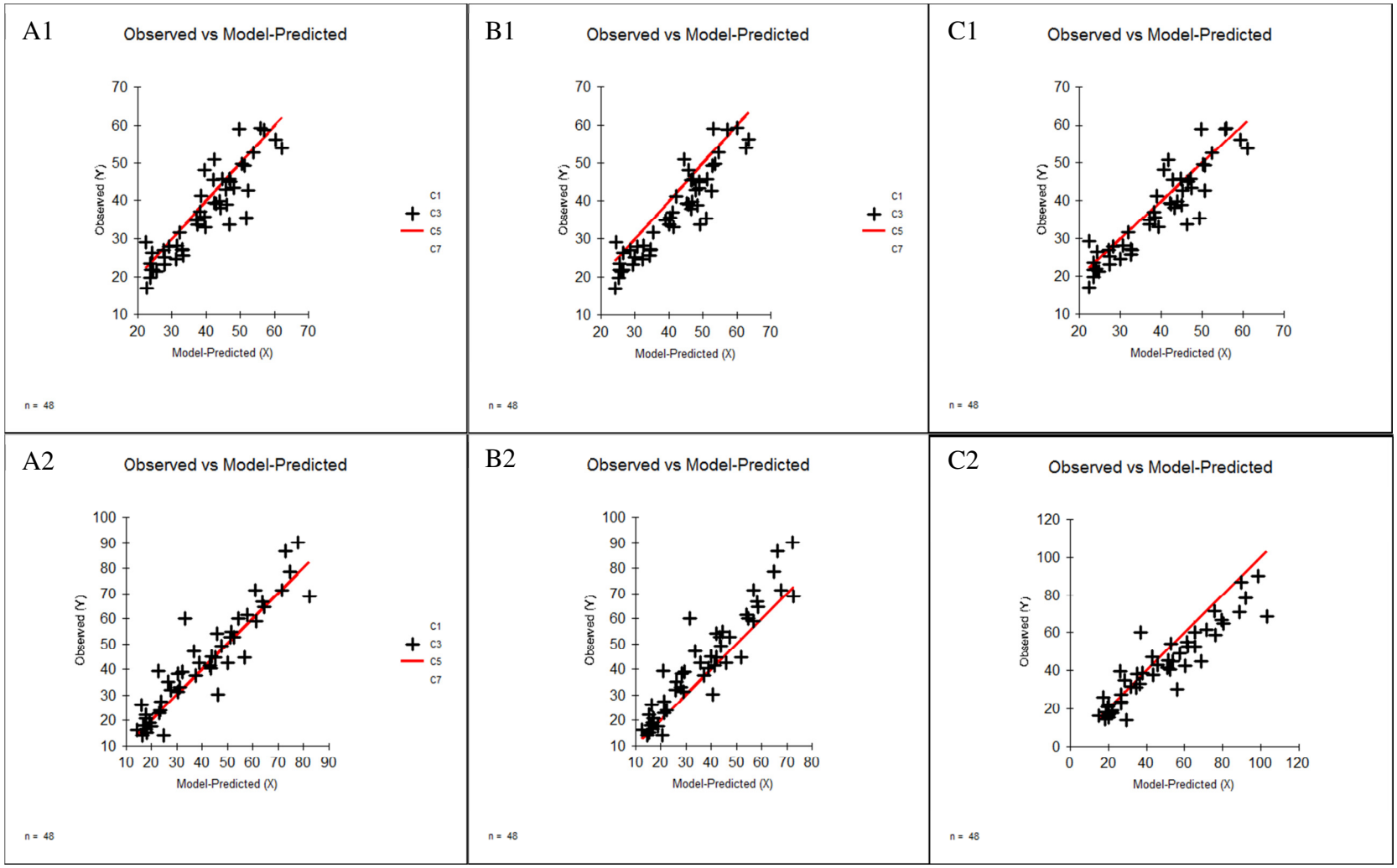

Figure 4 - Relationship among observed and model-predicted values for carcass chemical composition as models devised by (A) Valadares Filho et al. (2006); Marcondes et al. (2010) and (C) Hankins and Howe (1946) for (1) crude protein; (2) ether extract and (3) water. Continue…

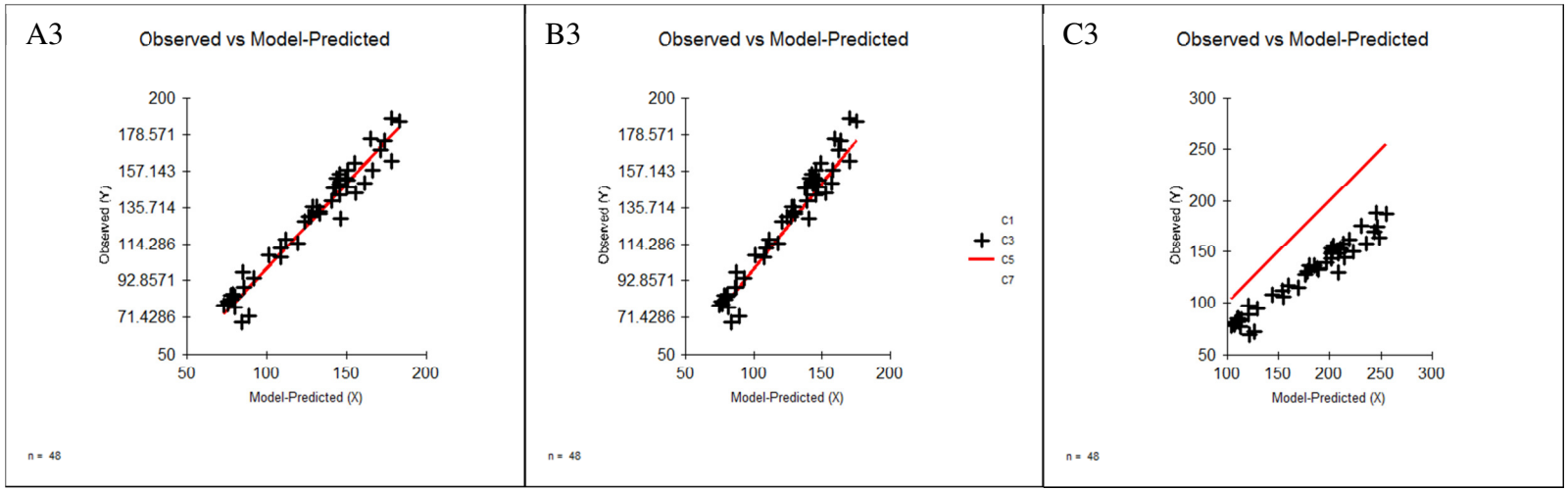

Figure 4 - Relationship among observed and model-predicted values for chemical carcass composition as models devised by (A) Valadares Filho et al. (2006); Marcondes et al. (2010) and (C) Hankins and Howe (1946) for (1) crude protein; (2) ether extract and (3) water.

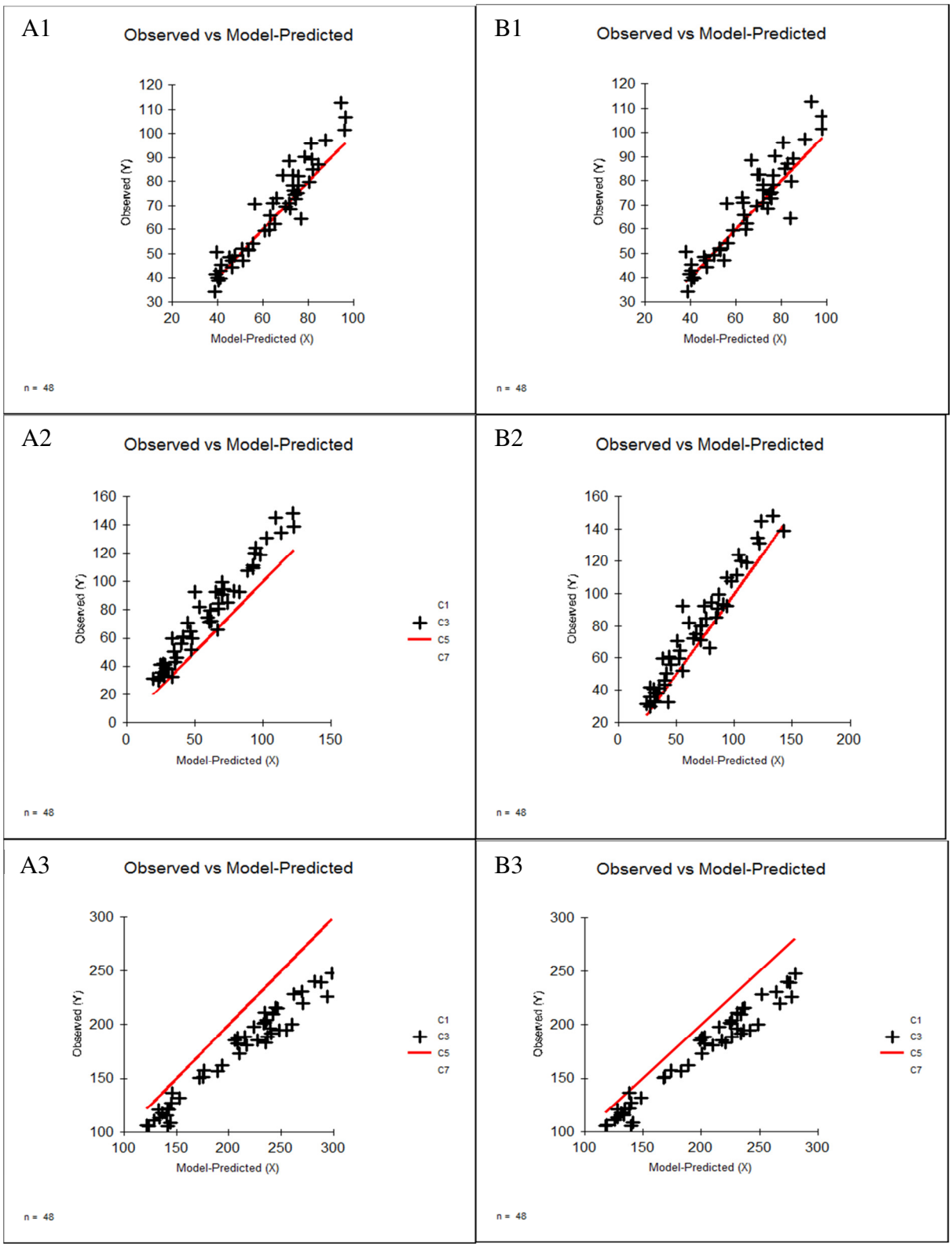

Figure 5 - Relationship among observed and model-predicted values for empty body carcass chemical composition estimated by Marcondes et al. (2010), A; and Valadares Filho et al. (2006), B, for 1: Crude protein; 2: Ether extract; 3: water.

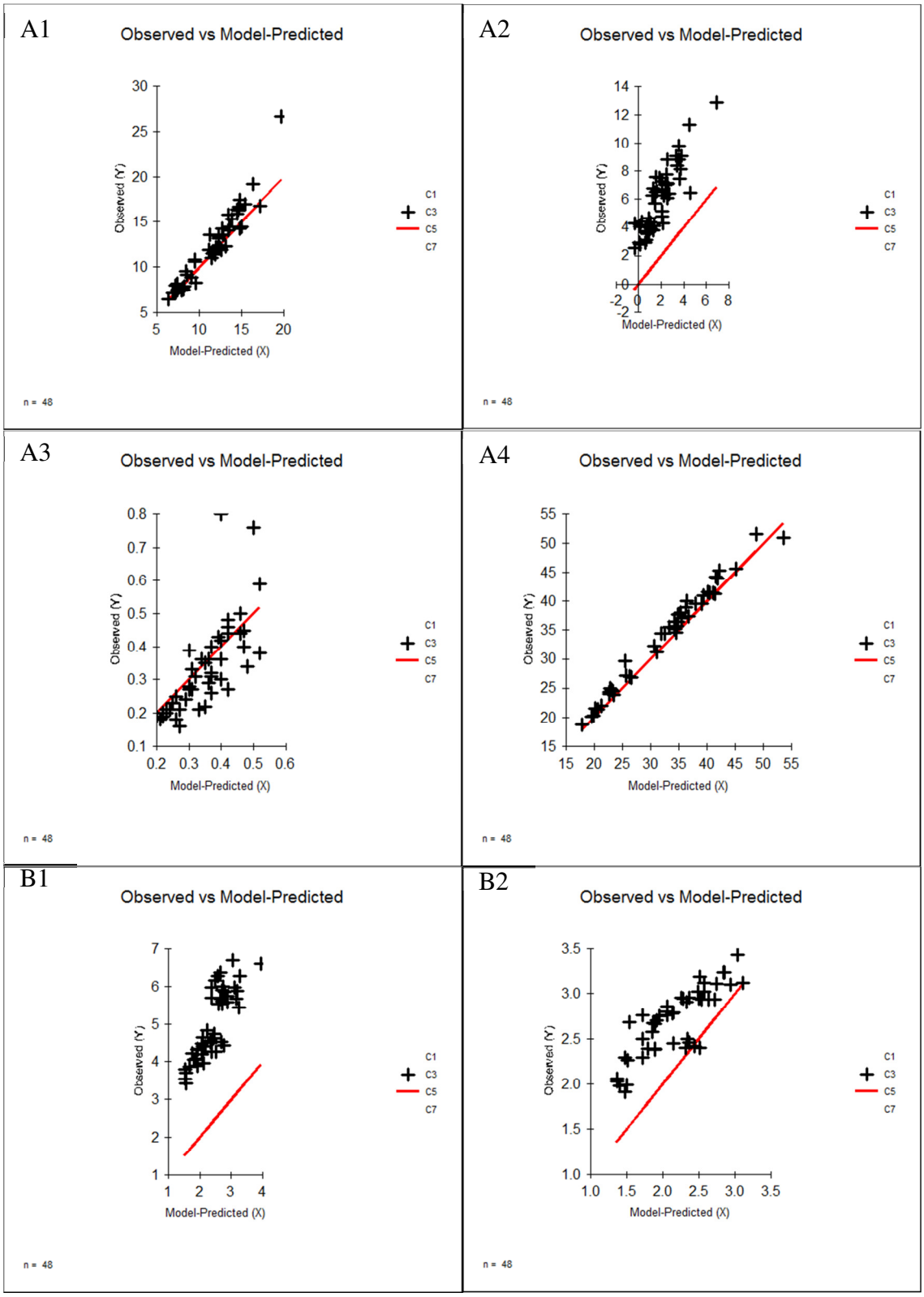

Figure 6 - Relationship among observed and model-predicted values for noncarcass chemical components estimated by Marcondes et al. (2010), A: blood and hide; B: Head and limbs; C: Organs and viscera; 1: Crude protein; 2: Ether extract; 3: ash; and 4: water. Continue…

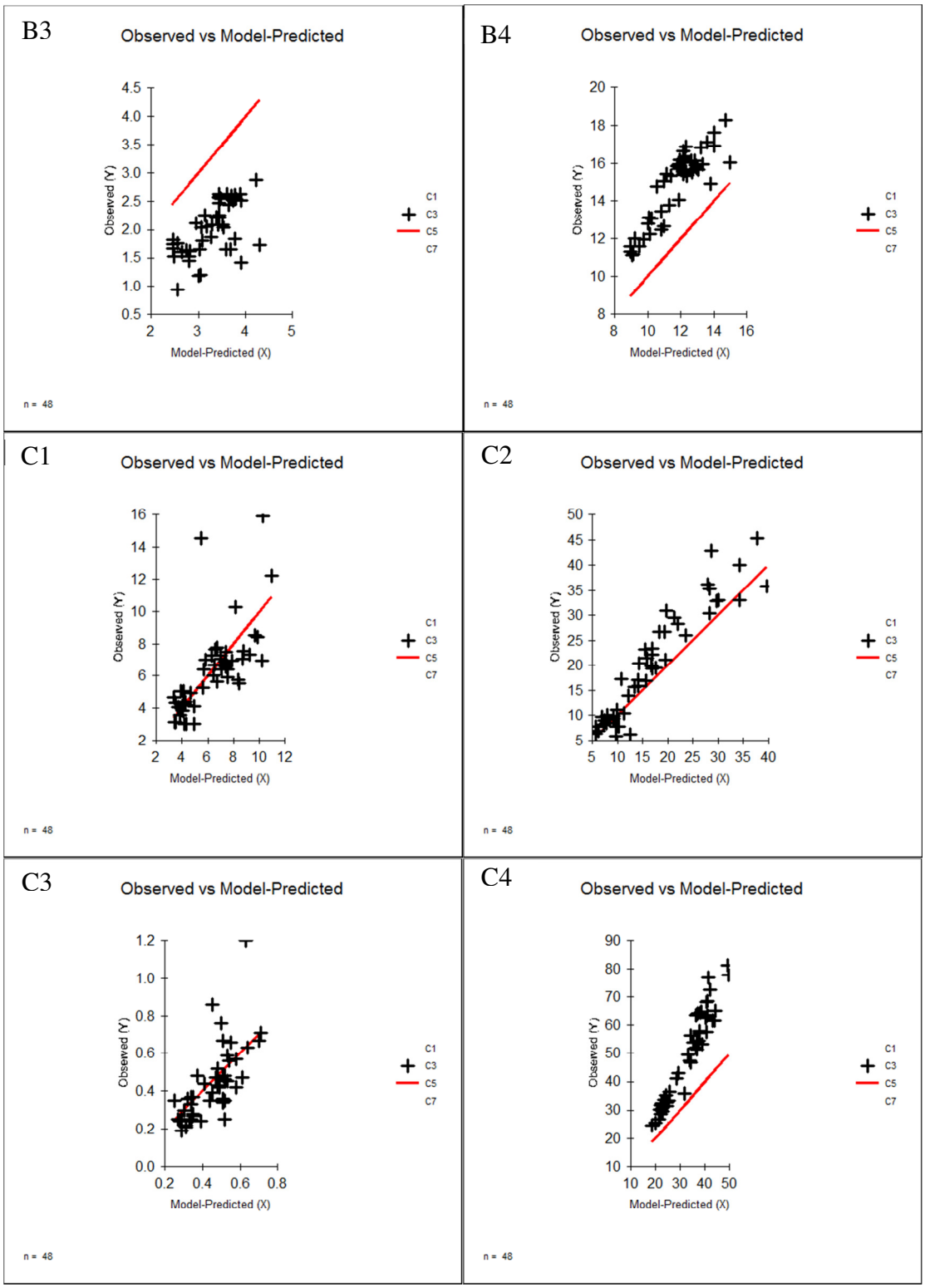

Figure 6 - Relationship among observed and model-predicted values for noncarcass chemical components estimated by Marcondes et al. (2010), A: blood and hide; B: Head and limbs; C: Organs and viscera; 1: Crude protein; 2: Ether extract; 3: ash; and 4: water.

Table 1 –Proportions of feed in concentrate and diet concentrate fraction composition in dry matter basis.

Ingredients	Concentrate	Diet
Proportion (g/kg DM)		
Corn Silage	-	600.00
Corn	833.50	333.40
Soybean Meal	108.30	43.30
Mineral premix	11.06	4.40
Urea:ammonium sulfate (9:1)	22.11	8.90
Salt	12.30	4.90
Limestone	12.80	5.10
Chemical composition		
Dry matter	885.00	537.30
Organic matter	938.00	944.94
Crude protein	170.50	105.84
Ether extract	32.30	29.08
Neutral Detergent fiber[a]	114.70	340.30
Non fiber carbohydrate[a]	655.90	469.70

[a] corrected for ash and protein contamination; [b] Assuming 260% CP in urea:ammonium sulfate mixture

Table 2 – Variables description used to estimate the physical and chemical carcass composition , chemical empty body composition and noncarcass components.

Variable	N	Mean	Std Dev	Minimum	Maximum
Empty body weight	48	349.43	98.26	199.41	541.42
Cold carcass weight	48	219.28	64.72	122.1	336.1
Organs and viscera (% EBW)	48	16.04	1.12	13.73	18.21
Dressing percentage (%)	48	56.74	2.28	51.57	61.25
Leather (%EBW)	48	9.21	0.81	7.84	11.29
Rib cut section ether extract (%)	48	23.29	7.14	12.39	39.56
Rib cut section crude protein (%)	48	18.14	2.33	12.87	25.51
Rib cut section water (%)	48	50.93	5.48	39.29	62.38
Rib cut section adipose tissue (%)	48	20.51	7.87	7.11	35.87
Rib cut section muscle tissue (%)	48	57.53	4.34	47.66	64.87
Rib cut section bone tissue (%)	48	21.96	4.20	15.86	28.20

Table 3 - Equations to estimate the physically separable and chemical carcass, and empty body chemical compositions.

Item	Equations
Carcass physical composition (Marcondes et al., 2012)	
Muscle	Mcar(%)= 54.42 + 0.26 x Mcor - 1.28 x VF
Fat	Fcar(%)= 0.69 + 0.46 x Fcor + 1.18 x VF
Bone	Bcar(%) = 7.91 + 0.56 x Bcor - 0.24 x VF
Carcass physical composition (Hankins and Howe, 1946)	
Muscle	Mcar(%)=15.56 + 0.81 x Mcor
Fat	Fcar(%)= 3.06 + 0.82 x Fcor
Bone	Bcar(%) = 4.30 + 0.61 x Bcor
Carcass chemical composition (Marcondes et al., 2010)	
Crude protein	CPcar(%)= 17.92 + 0.60 x CPcor - 0.17 x DP
Ether extract	EEcar(%)= 4.31 + 0.31 x EEcor + 1.37 x VF
Water	Wcar(%) = 48.74 + 0.28 x Wcor - 0.017 x EBW
Carcass chemical composition (Valadares Filho et al., 2006)	
Crude protein	CPcar(%)= 4.05 + 0.78 x CPcor
Ether extract	EEcar(%)= 4.96 + 0.54 x EEcor
Water	Wcar(%) = 34.97 + 0.45 x Wcor
Carcass chemical composition (Hankins and Howe, 1946)	
Crude protein	CPcar(%)= 5.98 + 0.66 x CPcor
Ether extract	EEcar(%)= 2.82 + 0.77 x EEcor
Water	Wcar(%) = 14.90 + 0.78 x Wcor
Empty body chemical composition (Valadares Filho et al., 2006)	
Crude protein	CPebw(%)= 4.96 + 0.76 x CPcor
Ether extract	EEebw(%)= 4.56 + 0.60 x EEcor
Water	Webw(%) = 31.42 + 0.51 x Wcor
Empty body chemical composition (Marcondes et al., 2010)	
Crude protein	CPebw(%)= 10.78 + 0.47 x CPcor - 0.21 x VF
Ether extract bulls	EEebw(%)= 2.75 + 0.33 x EEcor + 1.80 x VF
Ether extract steers	EEebw(%)= 1.84 + 0.33 x EEcor + 1.91 x VF
Water	Webw(%) = 38.31 + 0.33 x Wcor - 1.09 x VF + 0.50 x OV

Mcar: carcass muscle; Mcor: muscle in the 9-11th rib section; VF: visceral fat (renal, pelvic, cardiac and mesenteric fat deposts); Fcar: carcass fat; Fcor: fat in the 9-11th rib section; Bca: carcass bone; Bcor: bone in the 9-11th rib section; CPcar: carcass crude protein; CPcor: crude protein in the 9-11th rib section; DP: dressing percentage; EEcar: ether extract in the carcass; EEcor: ether extract in the 9-11th rib section; Wcar: carcass water: Wcor: water in the 9-11th rib section; OV: organs and viscera percentage; CPebw: empty body weigh crude protein; EEebw: empty body weght ether extract; Webw: empty body weight water.

Table 4 - Equations used to estimate the noncarcass components.

Item	Gender	Equantions
Blood and Hide		
Crude protein	S, B	$CP_{BL}(\%) = 24.895$
Ether extract	S	$EE_{BL}(\%) = -18.891 + 0.042 \times CCW + 1.480 \times H_{EBW}$
	B	$EE_{BL}(\%) = -14.383 + 0.019 \times CCW + 1.480 \times H_{EBW}$
Water	S, B	$W_{BL}(\%) = 59.243 + 2.468 \times B_{EBW}$
Ash	S	$A_{BL}(\%) = 2.622 - 0.026 \times DP - 0.036 \times H_{EBW}$
	B	$A_{BL}(\%) = 1.148 - 0.002 \times DP - 0.036 \times H_{EBW}$
Head and limbs		
	S	$CP_{HL}(\%) = 6.072 + 0.0155 \times EBW$
Crude protein	B	$CP_{HL}(\%) = 9.930 + 0.0014 \times EBW$
Ether extract	S, B	$EE_{HL}(\%) = 6.55 + 0.993 \times VF$
Water	S, B	$W_{HL}(\%) = 57.475 + 1.094 \times VF$
Ash	S, B	$A_{HL}(\%) = 15.121$
Organs and viscera		
Crude protein	S	$CP_{OV}(\%) = 10.656$
	B	$CP_{OV}(\%) = 12.015$
Ether extract	S	$EE_{OV}(\%) = 9.37 + 6.50 \times VF$
	B	$EE_{OV}(\%) = 9.37 + 5.00 \times VF$
Water	S, B	$W_{OV}(\%) = 77.217 - 5.212 \times VF$
Ash	S, B	$A_{OV}(\%) = 2.693 - 0.039 \times OV_{EBW} - 0.022 \times DP$

S: steers; B: bulls; CPbl: blood and hide crude protein; EEbl: blood and hide ether extract; CCW: cold carcass weight; Hebw: percentage of hide in the empty body weight; Wbl: blood and hide water; Bebw: percentage of blood in the empty body weight; Abl: blood and hide ashes; CPhl: head and limbs crude protein; EBW: empty body weight; EEhl: ether extract in the head and limbs; VF: visceral fat (renal, pelvic, cardiac and mesenteric fat depots); Whl: head and limbs water; Ahl: head and limbs ashes; CPov: organs and viscera crude protein; EEov: organs and viscera ether extract; Wov: organ and viscera water; Aov: organ and viscera ashes; OVebw: ratio of the organs and viscera to the empty body weight; DP: dressing percentage.

Table 5 - Mean and descriptive statistics of the relationship among observed and predicted values of physical carcass composition.

Item	Muscle			Adipose			Bone		
	OBS	HH46	M12	OBS	HH46	M12	OBS	HH46	M12
Mean	143.50	134.77	141.80	35.71	47.13	33.26	39.23	37.32	41.10
Standard deviation	40.11	35.67	38.67	20.39	25.92	18.57	6.68	6.68	8.10
Maximum	210.52	202.13	214.90	77.21	94.53	69.85	56.79	56.79	56.43
Minimum	79.89	81.80	84.07	8.97	10.86	7.08	26.74	26.74	28.17
REGRESSION ANALYSIS									
Intercept									
Estimate	-	-6.63	-2.14	-	-0.21	0.24	-	7.46	8.74
Sa	-	3.16	3.13	-	1.54	1.46	-	2.34	2.23
P-value[a]	-	0.04	0.50	-	0.89	0.87	-	0.00	0.00
Slope									
Estimate	-	1.11	1.03	-	0.76	1.07	-	0.85	0.74
Sb	-	0.02	0.02	-	0.03	0.04	-	0.06	0.05
P-value[b]	-	0.00	0.21	-	0.00	0.09	-	0.02	0.00
r^2	-	0.98	0.98	-	0.94	0.94	-	0.81	0.81
RMSE[c]	-	5.54	5.64	-	5.11	4.91	-	2.98	2.95
COMPARISON OF MODELS									
MSEP[d]	-	121.77	34.48	-	192.72	30.58	-	13.22	16.16
MB[e]	-	8.73	1.70	-	-11.42	2.45	-	1.91	-1.88
MEF[f]	-	0.92	0.98	-	0.53	0.93	-	0.70	0.63
CD[g]	-	1.19	1.07	-	0.52	1.19	-	0.84	0.65
Cb[h]	-	0.97	1.00	-	0.87	0.99	-	0.96	0.95
CCC[i]	-	0.96	0.99	-	0.84	0.96	-	0.86	0.86
AICc[j]	-	166.60	168.36	-	158.79	154.91	-	107.03	106.17

[a] $\beta_o=0$; [b] $\beta_1=1$; [c] RMSE is the root mean of the square error; [d] MSEP is the mean square error of the prediction; [e] MB is the mean bias; [f] MEF is the model efficiency statistic; [g] CD if the coefficient of model determination; [h] Cb is the bias correction factor; [i] CCC is the concordance correlation coefficient; [j] AICc is the corrected Akaike criterion information.

Table 6 - Mean and descriptive statistics of the relationship among observed and predicted values of chemical carcass composition.

Item	Crude Protein				Ether Extract				Water			
	OBS	V06	M10	HH46	OBS	V06	M10	HH46	OBS	V06	M10	HH46
Mean	142.12	133.71	140.72	144.88	34.43	45.83	32.30	37.00	39.15	37.44	41.19	39.30
Standard deviation	39.33	34.13	37.29	41.68	19.10	25.35	18.30	21.94	6.17	6.17	8.16	7.28
Maximum	210.46	186.62	203.40	210.52	71.96	94.53	69.85	77.21	56.79	56.79	56.43	52.54
Minimum	79.89	83.12	84.60	85.82	8.97	10.86	7.08	10.51	29.20	29.20	28.38	26.74
REGRESSION ANALYSIS												
Intercept												
Estimate	-	-0.74	-3.10	-1.24	-	3.29	2.65	6.37	-	4.51	-4.04	2.32
SD	-	2.75	2.51	2.57	-	2.58	2.48	2.49	-	4.11	4.35	4.28
P-value[a]		0.80	0.22	0.63		0.21	0.29	0.01		0.28	0.36	0.59
Slope												
Estimate	-	0.96	0.97	0.98	-	0.97	1.08	0.75	-	0.97	1.06	0.70
SD	-	0.07	0.06	0.06	-	0.06	0.06	0.05	-	0.03	0.03	0.02
P-value[b]		0.53	0.57	0.78		0.62	0.20	0.00		0.41	0.07	0.00
r^2	-	0.82	0.86	0.84	-	0.86	0.87	0.85	-	0.95	0.95	0.95
RMSE[c]	-	5.05	4.45	4.71	-	7.61	7.25	7.80	-	7.35	7.29	7.51
COMPARISON OF MODELS												
MSEP[d]		30.51	39.05	25.14		60.32	83.13	129.25		53.97	68.03	2750.43
MB[e]		-2.42	-4.47	-1.95		2.13	5.56	-5.75		1.19	3.66	-50.08
MEF[f]		0.77	0.70	0.81		0.85	0.79	0.67		0.95	0.94	-1.45
CD[g]		1.07	0.94	1.11		1.08	1.21	0.62		0.99	1.17	0.24
Cb[h]		0.98	0.93	0.98		0.99	0.95	0.95		1.00	0.99	0.54
CCC[i]		0.88	0.86	0.90		0.92	0.89	0.88		0.98	0.97	0.53
AICc[j]		157.65	145.51	151.08		197.03	192.44	199.48		193.71	192.95	195.82

[a] $\beta_o=0$; [b] $\beta_1=1$; [c] RMSE is the root mean of the square error; [d] MSEP is the mean square error of the prediction; [e] MB is the mean bias; [f] MEF is the model efficiency statistic; [g] CD if the coefficient of model determination; [h] Cb is the bias correction factor; [i] CCC is the concordance correlation coefficient; [j] AICc is the corrected Akaike criterion information.

Table 7 - Mean and descriptive statistics of the relationship among observed and predicted values of chemical empty body composition.

Item	Crude Protein			Ether extract			Water		
	OBS	M10	V06	OBS	M10	V06	OBS	M10	V06
Mean	67.70	64.49	64.84	77.06	60.26	68.05	173.86	206.35	198.72
Standard deviation	19.91	16.73	17.05	34.21	29.23	32.22	42.80	52.50	50.18
Maximum	112.56	96.26	98.12	148.20	122.79	142.52	247.72	298.36	280.83
Minimum	34.19	38.71	37.97	29.67	19.44	24.18	105.29	121.88	117.83
REGRESSION ANALYSIS									
Intercept									
Estimate	-	-5.59	-2.70	-	8.52	7.22	-	9.20	7.70
SD	-	3.47	4.25	-	2.71	3.01	-	5.23	5.08
P-valuea		0.11	0.53		0.00	0.02		0.08	0.14
Slope									
Estimate	-	1.14	1.09	-	1.14	1.03	-	0.80	0.84
SD	-	0.05	0.06	-	0.04	0.04	-	0.02	0.02
P-valueb		0.01	0.18		0.00	0.51		0.00	0.00
r^2	-	0.91	0.86	-	0.94	0.94	-	0.96	0.96
RMSE	-	5.97	7.41	-	8.13	8.84	-	8.84	8.53
MSEPd	-	49.61	62.87	-	361.36	156.81	-	1240.61	753.55
MBe	-	3.22	2.86	-	16.8	16.80	-	-32.49	-24.85
MEFf	-	0.87	0.84	-	0.69	0.86	-	0.31	0.58
CDg	-	1.37	1.33	-	1.02	1.04	-	0.48	0.58
Cbh	-	0.97	0.98	-	0.87	0.96	-	0.80	0.87
CCCi	-	0.93	0.91	-	0.84	0.93	-	0.78	0.85
AICcj	-	173.76	194.49	-	203.36	211.44	-	211.43	208.06

[a] $\beta_o=0$; [b] $\beta_1=1$; [c] RMSE is the root mean of the square error; [d] MSEP is the mean square error of the prediction; [e] MB is the mean bias; [f] MEF is the model efficiency statistic; [g] CD if the coefficient of model determination; [h] Cb is the bias correction factor; [i] CCC is the concordance correlation coefficient; [j] AICc is the corrected Akaike criterion information.

Table 8 - Mean and regression analysis between observed (Y) and predicted values (X) of non-carcass chemical composition.

	Blood and hide				Head and limbs				Organs and Viscera			
	CP	EE	MM	W	CP	EE	MM	W	CP	EE	MM	W
Y, kg	12.26	6.05	1.72	33.69	4.96	2.69	2.04	14.82	6.36	20.08	0.44	49.58
X, kg	11.57	1.92	0.35	32.30	2.40	2.16	3.30	11.75	6.40	17.00	0.45	33.20
r^2	0.91	0.76	0.55	0.98	0.69	0.67	0.35	0.80	0.46	0.97	0.45	0.92
CCC[a]	0.91	0.24	0.67	0.98	0.11	0.46	0.13	0.34	0.67	0.88	0.61	0.43
Cb[b]	0.95	0.28	0.90	0.99	0.13	0.55	0.22	0.38	0.97	0.94	0.89	0.45
REGRESSION ANALYSIS												
Intercept												
Estimate	-1.84	3.34	-0.07	1.35	1.50	1.28	0.05	2.00	0.82	0.62	-0.07	-10.97
SD	0.67	0.28	0.05	0.66	0.34	0.15	0.39	0.97	0.91	1.17	0.08	2.64
P-value[c]	0.01	0.00	0.19	0.05	0.00	0.00	0.89	0.04	0.37	0.60	0.43	0.00
Inclination												
Estimate	1.22	1.41	1.17	1.00	1.44	0.65	0.60	1.09	0.87	1.15	1.11	1.82
SD	0.06	0.12	0.15	0.02	0.14	0.07	0.12	0.08	0.14	0.06	0.18	0.08
P-value[d]	0.00	0.00	0.28	0.95	0.00	0.00	0.00	0.27	0.33	0.02	0.53	0.00
MSEP[e] (%)												
MB[f]	20.62	91.35	2.51	60.09	95.48	79.60	90.02	92.66	0.04	37.50	1.02	80.27
Syst. Bias	19.74	1.88	2.42	0.00	2.17	7.77	1.99	0.20	2.09	6.82	0.87	14.07
Random Error	59.64	6.77	95.07	39.91	2.35	12.63	7.99	7.14	97.87	55.68	98.11	5.67
RMSEP[g]												
kg	1.52	4.32	0.48	1.80	2.62	0.59	1.33	3.19	1.95	5.00	0.14	18.29
%	12.39	71.42	27.95	5.34	52.77	21.89	64.86	21.53	30.66	24.92	32.40	36.89

[a] CCC is the concordance correlation coefficient; [b] Cb is the bias correction factor; [c] $H_o = \beta o = 0$; [d] $H_o = \beta_1 = 1$; [e] MSEP is the mean square error of the prediction; [f] MB is the mean bias; [g] RMSE is the root mean of the square error.

Chapter IV

Evaluation of predictive equations developed to assess body composition in beef cattle using biometric measurements[1]

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Evaluation of predictive equations developed to assess body composition in beef cattle through the use of biometric measurements

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ABSTRACT

This study was conducted in attempt to evaluate current devised models to estimate the body and empty body physically separable fat, and chemical composition through biometric (BM) and 9-11th rib section measurements taken in 40 F1 Nellore x Angus bulls (B) and steers (S). The animals used had 12.5±0.51 mo of age, and average shrunk BW (BW) 233±23.47, and 238±24.6 kg for B and S respectively. Animals were fed 60% of corn silage and 40% concentrate. Eight animals were slaughtered at the beginning of the trial and the remaining animals were randomly assigned in a factorial 2 (genders) x 3 (slaughter weights) arrangement. The remaining animals were slaughtered when the average BW of de group reached 380 (6B and 5S), 440 (6B and 5S), and 500 kg (5B and 5S). Before the slaughter, the animals were lead through a squeeze chute in which BM were taken, including hook bone width (HBW), pin bone width (PBW), abdomen width (AW), body length (BL), rump height (RH), height at withers (HW), pelvic girdle length (PGL), rib depth (RD), girth circumference (GC), rump depth (RuD), body diagonal length (BDL), and thorax width (TW). Additionally, post mortem measurements were included: total body surface (TBS), body volume (BV), subcutaneous fat (SF), internal fat (InF), intermuscular fat (ImF), carcass physical fat (CF), empty body physical fat (EBF), carcass chemical fat (CFch), empty body chemical fat (EBFch), fat thickness in the 12th rib (FT), and 9 – 11th rib section fat (HHF). The values estimated with prediction equations were compared to the observed values and among models. Among all evaluated equations to predict the body composition and its paths to do so, only equations [7] and [8], for body volume prediction, and [27] and [32], for empty body physically separable fat prediction can be

devised to be used while estimating their contents using F1 Nellore x Angus bulls and steers.

Key Words: carcass composition, carcass prediction, empty body composition, empty body prediction, modeling evaluation.

1. Introduction:

As most of all techniques used to estimate body composition of bovines some difficulties have been reported regarding the measurements taken in live animals, which might be associated within correct identification and location of the reference points, anatomical distortions due to position, posture and muscle tone; and errors at the moment of taking the measurements (Fisher, 1975). One feasible measurement to be obtained is BW; therefore it has been widely reported in animal's growth rates determinations, and also as predictor of body composition (Lawrence and Fowler, 2002). Some other measurements had been used in attempt to increase the precision of the prediction equations while using BW as an independent variable (De Paula et al., 2013; Fernandes et al., 2010a). In addition, body fat has been shown as one of the most variable components in the body or carcass and hence, the most difficult to predict (Bonilha et al., 2011; Jones et al., 1978; Owens et al., 1995).

One of the main advantages in using live animals measurements would be the possibility to follow the changes that may occur in composition in experimental animals without the necessity of slaughter. However, it has been reported that body measurements added only 2 to 4 percent to slaughter weight alone in accounting for differences in edible product (Berg and Butterfield, 1976). Regardless the difficulties, research wise, an accurate estimate is very important since mistaken values could easily lead to sophisms and therefore wrong recommendations. Furthermore, a new use of the information provided by biometric measurements point out that this technique could be used more as a temporary path than actually a routine either in farm and research trials.

The objectives with this study were to evaluate the current devised models used to assess the total body surface, volume, body and empty body, physically separable and chemical fat composition through biometric and 9-11th rib section measurements.

2. Material and Methods:

Humane animal care and handling procedures of the Federal University of Viçosa (Brazil) were followed in this research.

The dataset utilized in this trial was obtained at the Federal University of Viçosa, Brazil, between December of 2009 and August of 2010. Laboratory analyses were performed at the Ruminant Nutrition Laboratory located at Department of Animal Science, Federal University of Viçosa, Brazil.

2.1. Location, animals, and diet composition: Forty eight F1 Nellore x Angus bulls (**B**) and steers (**S**), with initial age of 12.5±0.51 mo, and shrunk BW (**SBW**) of 233.03±23.47, and 238±24.6 kg for B and S, respectively were utilized. The trial was conducted in a 2 x 3 factorial arrangement of treatments (two genders and three slaughter weights). The animals were randomly assigned into four slaughter-weight based groups: baseline, 380, 440 and 500. The baseline group was slaughtered at the beginning of the trial (4B and 4S). The other groups were slaughtered when the group of animals reached an average BW of 380 (6B and 5S), 440 (6B and 5S), and 500 kg (5B and 5S). The animals were housed in individual pens with concrete floors, provided with feeders and concrete bunks, with total area of 30 m^2, and 8 m^2 of sheltered area. The diet (Table 1) was formulated according to (Valadares Filho et al., 2006) to contain 11% CP. Animals were fed 60% corn silage and 40% concentrate, containing corn, soybean meal, urea, ammonium sulfate, sodium chloride, limestone, and mineral mix. The animals were fed twice daily (at 6h00 and 16h00) as a total mixed ration, and the intake adjusted to maintain orts in a ratio of 5 to 10% of offered as fed basis diet. Water was permanently available.

2.2. Biometric measures: The biometric measurements (**BM**) were taken at the precedent day of each slaughter, along with weighing (Table 2), to obtain the full BW (**FBW**). The BM were performed by the same technician during the whole trial. Animals were properly adapted to a squeeze chute before the experiment had started. While in there, each animal had been erectly positioned and had the BM taken. The BM were adapted from Fischer (1975), Lawrence and Fowler (2002), (Fernandes et al., 2010a), and (De Paula et al., 2013). To be able to accomplish all measurements, a large caliper (Hipometro type Bengala with two bar, Walmur, Porto Alegre, Brazil) and a graduated plastic flexible tape were used. Measurements included were hook bone width (**HBW**) as the distance between the 2 ventral points of the tuber coxae (large calipers); pin bone width (**PBW**) as the distance between the 2 ventral tuberosity of the tuber ischia (large calipers); abdomen width (**AW**) measured as the widest horizontal width of the abdomen (paunch) at right angles to the body axis (large calipers); body length, which had to be converted for each recommendation, $\mathbf{BL_{fernandes}}$ (Fernandes et al., 2010a) and $\mathbf{BL_{DePaula}}$ (De Paula et al., 2013), and primarily identified as the distance between the dorsal point of the scapulae and the ventral point of the tuber coxae (tape) as devised by (Fernandes et al., 2010a), and $BL_{depaula}$ as, roughly, the summation of $BL_{fernandes}$'s, pelvic girdle length and scapulae width (**SW**); rump height (**RH**) as measured from the ventral point of the tuber coxae, vertically to the ground (large calipers); height at withers (**HW**) measured from the highest point over the scapulae, vertically to the ground (large calipers); pelvic girdle length (**PGL**) as the distance between the ventral point of the tuber coxae and the ventral tuberosity of the tuber ischii (large calipers); rib depth (**RD**) measured vertically from the highest point over the scapulae to the end point of the rib, at the sternum (large calipers); girth circumference (**GC**) taken as the smallest circumference just posterior to the anterior legs, in the vertical plane (tape); rump depth (**RuD**) measured as the vertical distance

between the ventral point of the tuber coxae and the ventral line (large calipers); body diagonal length (**BDL**) measured as the distance between the ventral point of the tuber coxae and the cranial point of shoulder (tape); and thorax width (**TW**) the widest horizontal width across shoulder region, at the back (large calipers).

2.3. Slaughter and Dissections

All experiments followed the same slaughter procedure. The animals were fasted for 16 h period and then desensitized with a non-penetrating stunner and killed by exsanguination at the jugular vein using conventional humane procedures. The gastro-intestinal tract (**GIT**) was cleaned and weighed with other organs to measure empty BW (**EBW**). Carcasses were weighed (hot carcass weight) and chilled (1 to 4 ^{o}C) for 18 h and then re-weighed to obtain the chilled carcass weight (CCW). The Rib_{9-11} section was removed from the left carcass and subsequently dissected into bone, fat, and lean tissues. The rest of the left half carcass was completely dissected into bone, fat, and lean tissues and the Rib_{9-11} section was summed, at the end, to obtain the full carcass composition. Samples of bone, fat, and lean tissues from the carcass, head, limbs, hide, blood, and organs and viscera were taken to determine carcass and body chemical compositions. The mesenteric fat was physically removed from the GIT and weighed with kidney, pelvic, and heart fat to compose the visceral fat. Tendons were weighed with the lean tissue, while connective tissues were added to the fat pool. After weighing each component, lean and fat tissues were separately ground, subsampled, and mixed together to obtain their original physical proportion. Carcass bones were separated into vertebral, ribs, and long bones. They were sawn into small pieces (5 to 5 cm) and proportionally sub-sampled to compose the total carcass bone sample. The Rib_{9-11} bones were also sawn into small pieces (5 to 5 cm) and sampled. The head and feet were sampled from two animals per group and then separated into hide, bone, and soft tissues, which represented the slaughtered group composition of those samples.

The hide was weighed and its composition was considered equal to the hide sampled from the body. Soft tissues were ground and bones were sawn into small pieces (5 to 5 cm), and sub-sampled. Viscera and organs were ground together and sub-sampled. Blood was sampled during the exsanguination. The hide was sampled (25 to 25 cm) from the left rump of each animal and ground.

Except for blood samples, which were dried at 60 ^{o}C for 72 h, all samples were preliminary freeze dried and partially defatted by washing with petroleum ether, as described by Fernandes et al. (2010). The amount of fat lost during this procedure was computed by weight differences. Then, all samples were ground using a ball mill and analyzed for moisture (method 934.01; AOAC, 1990), protein (method 920.87; (AOAC, 1990), ether extract (EE; method 920.85; AOAC, 1990), and ash (method 924.05; AOAC, 1990) in order to determine the chemical composition of the $Rib_{9\text{-}11}$ section, carcass, and empty body. The final EE was corrected by adding the fat being lost during the partial defatting process.

2.5. Equations evaluated

Equations developed by (Fernandes et al., 2010a) and De Paula et al. (2013) were used to predict body area, body volume; subcutaneous, carcass, and empty body physically separable fat depots; carcass and empty body chemical fat depots; and to evaluate its robustness while using an independent dataset.

2.6. Statistical analyses:

The body's surface, volume, and physical and chemical, as well carcass physical and chemical composition, estimated by the equations developed by Fernandes et al. (2010) and De Paula et al. (2013) were tested against the observed values using the following regression:

$Y = \beta_0 + \beta_1 \times X$,

Where x = predicted values; y = observed values; β_0 and β_1 are the intercept and slope, respectively.

The regression was evaluated according to the null hypothesis that states β_0 is equal to zero and β_1 is equal to one, and the alternative hypothesis that is not H_0. A nonrejection of the null hypothesis means that the model explained accurately the variation that had occurred in the dataset. The precision was assessed by the evaluation of the coefficient of correlation of the linear regression of Y on X, which assumes the value closer to 1 is the best estimative for the purpose.

Furthermore the standard deviation (**SD**) and Mean squared error of prediction (**MSEP**) were evaluated to account for the distance between the prediction and its true value, in which a smaller value is better. The Mean bias (**MB**), described by (Cochran and Cox, 1957), that represents the average inaccuracy of the model (Kohn et al., 1998), was evaluated for attesting the zero proximity which, in other words, would represent a more accurate estimative of the model-predicted values. The Modeling efficiency factor (**MEF**) which represents the proportion of the variation explained by the line Y = X, was used as an indicator of goodness of fit (Mayer and Butler, 1993). Values closer to 1 are better and lower than zero means that the model-predicted values are worse than the observed mean (Loague and Green, 1991). The Coefficient of model determination (**CD**) was used to assess the variance of the predicted data, in which a value closer to 1 represents the best estimator of the observed data. The Bias correction factor (**Cb**), a component of the Concordance correlation coefficient (**CCC**), indicates the deviation of the model from the regression line in relation to a slope of a unity. The CCC (Lin, 1989) represents the reproducibility index and may account simultaneously for accuracy and precision. For both analyses of fitting errors a value closer to 1 is desirable. Finally, the Corrected Akaike's Information Criterion (**AICc**), a measure of estimated information loss, was evaluated, in which a smaller value would represent a

better goodness of fit of the statistical model. All calculations were obtained using the Model Evaluation System (http://nutritionmodels.tamu.edu/mes.htm, last accessed April 22, 2013; Tedeschi, 2006) and discussions based on (Tedeschi, 2006).

3. Results:

3.1. Total body surface:

The Eq. [1] to [4] in Table 3 were devised in attempt to estimate the total body surface of bovines. The models presented high precision, r^2 between 0.79 and 0.91, and very low accuracy summed with a low reproducibility index. Regarding their test for the null hypothesis of zero intercept and slope of a unity, which would determinate whether or not the model is applicable to explain the present data set; none of the models could explain the variation and not being recommended for its use to estimate the total body surface of F1 Nellore x Angus.

3.2. Body volume:

The Equations [5] to [9] were used to estimate the body volume of F1 Nellore x Angus animals. All equations presented a high precision (0.87; 0.98; 0.94; 0.98; 0.95, respectively), and excellent accuracy (0.92; 0.87; 1.00; 1.00; 0.97). Therefore, excellent reproducibility index (0.86; 0.86; 0.94; 0.99; 0.94). The MSEP partition showed that the main component of the error was random for the models [7], [8], [9], and for models [5] was the systematic component. Also the models [5] and [9] presented problems regarding its intercept and slope while tested for a intercept zero and slope of a unity, since rejected the null hypothesis ($P<0.05$) and not being able to be recommended to estimate the body volume of the animals in this data set. The model [6] also presented problems regarding its slope which is verified by its associated error been mainly explained by the mean. Although its intercept did fail to reject the null hypothesis of intercept equals to zero. The models [7] and [8] also failed to reject the null hypothesis of a zero intercept and a slope of one, making it both being able to be

recommended to estimate the body volume of F1 Nellore x Angus animals. The model [8] was slightly better concerning the variation that could be explained by the plotted observed on model-predicted values (r^2), therefore slightly more precise. The CCC indicated better reproducibility [8] and a slightly higher accuracy for [7]. The MEF shad shown similar and high efficiency for both models when compared to its respective r^2, confirming their good ability of prediction; yet, model [8] was closer to 1. Model [7] presented smaller AIC compared to model [8]. Despite of the fact that both models can be devised to estimate the body volume of F1 Nellore x Angus bulls and steers, it is more than 10000 times more likely, that model [8] is more appropriate than model [7].

3.3. Subcutaneous fat:

The Eqs. [10] to [15] were used to estimate the subcutaneous fat depot of F1 Nellore x Angus bulls and steers. Eq. [11], [12], and [14] presented high precision (0.80; 0.83 and 0.80, respectively) but a lack of accuracy (0.23; 0.18 and 0.56, respectively), therefore a low reproducibility index (0.20; 0.16 and 0.50). Equations [10] and [13] presented satisfactory precision (0.78) although only Eq. [10] was accurate (0.82), and therefore presented a relatively good reproducibility index (0.72). The model [15] presented itself as poorly accurate (0.32) and not interesting regarding its precision. Yet, the errors partition showed that only in Eq. [10] the random component affects the most the MSEP, while in the others the main influencer of the equations' error of prediction was the MB pointing out a problem within the models. While testing the null hypothesis of an intercept of zero and slope of a unity none of the tested models were considerate adequate since did not fail to reject the null hypothesis, thus not been recommended to estimate the amount of subcutaneous fat of F1 Nellore x Angus bulls and steers.

3.4. Internal fat:

The Eqs. [16] and [17] were used to estimate the internal fat depots of F1 Nellore x Angus animals. The models were satisfactory precise (0.83 and 0.74, respectively) although poorly accurate which impaired the reproducibility index (0.43 and 0.41). Yet, the errors partition showed the main influencer of the equations error of prediction was the MB pointing out a problem within the models. For attesting models' adequacy, the null hypothesis test of a null intercept and a slope of a unity showed that none of the proposed models can be recommended to estimate the amount of internal fat of F1 Nellore x Angus bulls and steers.

3.5. Carcass physical fat:

The Equations [18] to [26] were used to estimate the carcass physically separable fat depot of F1 Nellore x Angus animals. All the equations presented satisfactory precision (0.88; 0.95; 0.93; 0.70; 0.88; 0.96; 0.90; 0.92; 0.68, respectively). The accuracy of the models were high for Eq. [18], [19], [20], [21], [23], [24], and [25] (0.76; 0.92; 0.98; 0.81; 0.92; 0.99; 0.96, respectively), and medium for the models [22] and [26] (0.56 and 0.45). Therefore the reproducibility index followed the same pattern. The MSEP partition showed that the error is roughly evenly partitioned for the components mean, systematic and random, for Eq. [18], [23], and [26]. The MB is affecting the most Eq. [19] and [21] and the random component is affecting the most Eq. [20], [25] and [24]. Meanwhile, the model [22] presented evenly partitioned the error's responsibility for MB and systematic components showing the model's weakness of prediction. While testing the null hypothesis of a null slope and an intercept equals to zero, all models presented problems ($P<0.05$) with its intercept (Eq. [21]), slope (Eq.[19], [20], and [25]), or both (Eq. [18], [22], [23], [24], and [26]), not being able to be recommended to estimate the amount of physically separable carcass fat in F1 Nellore x Angus bulls and steers.

3.6. Empty body physical fat:

The Equations [27] to [36] were used to estimate the empty body physical fat depot of F1 Nellore x Angus bulls and steers. Except for Eq. [30] and [36] that presented average towards high precision (0.69 and 0.77, respectively), all the other evaluated models (Eq. [27], [28], [29], [31], [32], [33], [44], and [35]) presented high precision (0.99; 0.99; 0.93; 0.88; 0.99; 0.99; 0.90; 0.92). Regarding the models' accuracy, except for the model [31]; which along with Eq. [30] and [36], presented average values (Cb of 0.54; 0.73 and 0.52, for [31]; [30] and [36] respectively); the high precise models (Eq. [27], [28], [29], [32], [33], [34], and [35]) had the same high fitted behavior presenting good approximations of the empty body's physical fat with the observed data (Cb of 1.00; 0.97; 0.92; 1.00; 0.96; 0.99; 0.91, respectively), and good possibility of being reproduced overtime (CCC of 0.99; 0.97; 0.89; 0.99; 0.96; 0.94; 0.87). The MSEP partition showed that the component of the error that it is affecting the most the models' capability of prediction is the MB for Eq. [28], [29], [30], [31], [33], and [35]; systematic component for Eq. [36] and the random component for Eq. [27], [32], and [34]. The test of the models' parameters for its approximation with the identity line, showed that some models presented problems ($P<0.05$) with its intercept (Eq. [30]), slope (Eq. [28], [29]), or both (Eq. [31], [33], [34], and [36]), not being able to be recommended to estimate the amount of empty body physical fat in F1 Nellore x Angus bulls and steers. The models [27] and [32] failed to reject the null hypothesis ($P>0.05$), thus being able to be recommended as a good predictor of the dependent variable. Model [32] was better concerning the variation that could be explained by the linear regression of Y on X (r^2), therefore more precise (0.987 against 0.864). The CCC indicated a way better reproducibility (0.993 against 0.562) and higher accuracy for [32] since its related component, Cb, was higher (0.999 against 0.604). The higher MEF value observed for [32], while compared to its respective r^2, indicated a higher

efficiency of prediction as well a closed value to one (0.986 against 0.279). Also model [32] presented smaller AIC compared to model [27]. Despite of the fact that both models can be devised to estimate the empty body physically separable fat of F1 Nellore x Angus bulls and steers, it is more than 10000 times likely that model [32] is more appropriate than model [27].

3.7. Carcass chemical fat:

The Equations [37] to [46] were used to estimate the carcass chemical fat depot of F1 Nellore x Angus animals. Except for Eq. [46] that presented very low precision (0.08), and [40] that presented average precision (0.62), all the other evaluated models (Eq. [37], [38], [39], [41], [42], [43], [44], and [45]) presented high precision (0.82; 0.83; 0.82; 0.82; 0.85; 0.77; 0.78; 0.84, respectively). The accuracy was assessed by the values of Cb which indicated levels going from average to high (0.52; 0.74; 0.86; 0.59; 0.58; 0.76; 0.92; 0.96; 0.80; and 0.77 for Eq. [37], [38], [39], [40], [41], [42], [43], [44], [45], and [46]). Then, the reproducibility index was not quite satisfactory for the models [37], [38], [40], [41], and [46] since presented average low to value, going as low as 0.24 for Eq. [46] to 0.67 for Eq. [38]. The rest of the other models presented good CCC going from 0.70 (Eq. [42]) to 0.85 (Eq. [44]). The MSEP partition showed that the component of the error that it is affecting the most the models' capability of prediction is the MB for Eq. [37], [38], [39], [40], [41], [42], and [45]; systematic component for Eq. [43] and the random component for Eq. [44], and [46]. The test of the models' parameters which adopted as the null hypothesis an intercept of zero and a slope of a unity, showed that all models presented problems ($P<0.05$) with its intercept (Eq. [39], [40], and [46]), slope (Eq. [37], [42], and [45]), or both (Eq. [38], [41], [43], and [44]), not being able to be recommended to estimate the amount of carcass chemical fat in F1 Nellore x Angus bulls and steers.

3.8. Empty body chemical fat:

The Equations [47] to [55] were used to estimate the empty body chemical fat composition of F1 Nellore x Angus bulls and steers. Except for Eq. [55] that presented very low precision (0.08), all the other evaluated models (Eq. [47], [48], [49], [50], [51], [52], [53], and [54]) presented high precision (0.88; 0.97; 0.91; 0.80; 0.88; 0.97; 0.85; and 0.91, respectively). Regarding the models' accuracy, Eq. [47], [49], [50], [51], [54], and [55] presented average values (Cb of 0.45; 0.70; 0.71; 0.46; 0.67; and 0.64, respectively); and models [48], [52], and [53] presented quite accurate fit behavior presenting good approximations of the empty body's physical fat while using these observed dataset (Cb of 0.93; 0.97;and 0.93, respectively). The index for reproducibility showed that the models [48], [52], and [53] had the best estimates among all tested (CCC of 0.93; 0.95; 0.86). The MSEP partition showed that the component of the error that it is affecting the most the models' capability of prediction is the MB for Eq. [47], [48], [49], [51], [52], and [54]; and the random component for Eq. [55]. The test of the models' parameters for a the plotted observed on model predicted values for the null hypothesis of an intercept of zero and a slope of a unity showed that all models presented problems ($P<0.05$) either with its intercept (Eq. [52] and [55]), slope (Eq.[47] and [54]), or both (Eq. [48], [49], [50], [51] and [53]), thus not being able to be recommended to estimate the amount of empty body chemical fat content in F1 Nellore x Angus bulls and steers.

4. Discussion:

Fat by itself provides a different problem since it is the most variable and also malleable tissue of the body. Selection has changed the proportion of fat in different depots overtime increasing the difficulties of prediction.

4.1. Total body surface:

The main difference between Eqs. [1] and [3] relies on which is considerate the shape of a bovine's body. The assumption of Fernandes et al. (2010) that the frustum would explain it better does not seem accurate. When predicting the TBS using the frustum, the estimates presented an overestimation of 163%, and 69% for heavier and lighter animal respectively, while compared with the observed TBS. Animals that had suffered from feed restriction the overprediction goes as high as 31% in average. It seems that the distortion caused by the frustum makes the carcass bigger than actually it is, thus overestimating its area. The frustum shape it does exists, though represents a carcass while hanging on the hooks, and as much more time hanging and combined with heavier the carcasses, the prediction of the TBS will be even more distorted. In the devised models by De Paula et al. (2013), the shape of the body is accounted as the animal is standing and, it seems that the cylinder fit better the observed data, diminishing its overprediction to 152%, which is very similar to the parameter of 1.57 devised by De Paula et al. (2013). The next step would be to determine the dimension of the cylinders for different genders, breeds and nutritional plans. While the BM along with SBW, were used to predict the TBS, also some improvement was observed. For the frustum the body length affected the most, the prediction which corroborates with the hypothesis that gravity was influencing the estimation while using the frustum. For the models devised by De Paula et al. (2013) the HW was the main BM influencing the TBS. the meaning of that is the animals were the same gender, bulls, and grew at the similar relative rate, which made the proportions of the front part with similar pattern and the withers the main influence the animal's body.

4.2. Body volume:

Regarding the BV estimation and its lack of accurate prediction by the Eq. [5], [6], and [9], some considerations might be needed for the animals that can be used as an input

on model evaluation. Eq. [5] brings all problems discussed above for overestimation due to its distortion of the real shape of the animal, thus indeed overestimates the BV prediction. Eq. [9] uses only SBW as an independent variable but some problems regarding its slope shows that the coefficient angular is more accentuate than should be within an implicit meaning that the animals' predicted with this model have a higher BV and when maintenance animals are evaluate together brings an inconsistency of different composition of gain (tissue composition in the body). Also shows that in average the animals used by Fernandes et al. (2010) were heavier at the slaughter, then using maintenance animals the equation would push its prediction forward. If the same data set was tested without the maintenance animals, it would failure to reject the null hypothesis of a slope of a unity. The Eq. [7] and [8], could be used for F1 Nellore x Angus bulls and steers even with the maintenance group in this data set. Corroborating with the hypothesis the cylinder is the best shape to estimate the TBS, the independent variable entered in the prediction equation. The Eq. [9] used among all the higher use of BM in its independent variable hall, and caries the same problem concerning the maintenance group. Probably because as the animals grow it changes its shape and maintenance animal have somehow a lack of development not growing at the same pattern, but still growing. An actually grow at the maintenance level would be smaller than the model's prediction pointed. While the dataset is analyzed without the maintenance group the Eq. [9] also can be used as predictor.

4.3. Subcutaneous fat:

The ratio of subcutaneous fat and intermuscular fat differs among breeds, which could mean that a certain depth of backfat would indicate different amounts of total fat for different breeds. For this dataset around 17% of the body's fat depot was subcutaneous. For De Paula et al. (2013) that ratio is around 15% and for Fernandes et al. (2010) is 19.5%.

Those small differences resulted in a lack of adjustment of the proposed equation. Thus, it is not recommended to estimate the amount of subcutaneous fat present in the carcass of F1 Nellore x Angus. Both authors used animals under grazing conditions while developing the equations. Eventually the dry and rainy seasons, higher maintenance for physical activity or pronounced compensatory growth may have high influenced the body composition of those animals. Another inconvenient is that a linear and uniform deposition is assumed for SF which it does not occur in a real system. The SF cover the muscle like in the shin region is considerate to have the same cover of fat than over the brisket region or *Longissimus dorsi*. Eq [10] also assumes that 4% of the body weight gain, independently of compensation or maturity is SF which is not necessarily true, and had contributes to its lack of adjustment. Among all the equations evaluated, Eq. [15] seems to have a significant biological meaning since ponders for maturity and region where the SF is predominantly effective within the use of the BM of HW and BL respectively. Despite of that, primarily data showed some differences in the proportions of SF related to the CF. For De Paula et al. (2013) that ratio of SF and CF was around 21% and for Fernandes et al. (2010) is 34%, which is in agreement with the present dataset (32%).

4.4. Internal fat:

It was observed a high underprediction by the models (Figure 4) concerning the estimation of the internal fat depots. The Eq. [16] and [17] (Table 4) showed values 34 to 21% inferior to the observed data. The biggest discrepancy was observed in steers which presented a lot more of fat retained as internal depot. It is believed that the difference in metabolizable energy intake during the trials which is nested with the feedlot and pasture feeding conditions, was responsible for the higher deposition for Nellore x Angus since the average daily gain was higher and at the partition of the tissues during the deposition more energy was available to other than preferential

depots. It was hypothesized (Eq.[16], Table 4) that, at the slaughter, 3.4% of the SBW would be internal fat, though that was not proven correct since the model rejected the null hypothesis.

4.5. Carcass physical fat:

The equations used to assess carcass physical fat used SBW, SF, HHF, AW, RD or GC as independent variables. While using only SBW to estimate CF, the assumption that between 7.9 to 10.8% of the SBW would be physical fat in the carcass was not confirmed by the lack of fit of both equations. In fact SBW has been selected to be used in all equations to predict CF since presents a quite constant ratio related to BW, or dressing percentage, which varies from 50 to 65%. Some improvement of prediction has been reported by the authors while SF is added, though none of the equation used to estimate SF worked and the ones that use SF as independent variable are underestimating the amount of fat in the carcass. HHF also has been reported to improve the prediction while used along SBW. Indeed, backfat thickness measured over the *Longissimus dorsi* muscle has proven to be useful predictor of total percentage of fat in the carcass (Berg and Butterfield, 1976). The BM of RD and GC used in Eq. [26] had influenced the prediction in a sense that contributes to a big part of the BW, especially for bulls, which were the conditions of the animals used to develop the models. That would be because non-emasculated animals tend to grow its forequarter at a higher rate than its hindquarter.

4.6. Empty body physical fat:

The difficulties in estimate the EBF are associated to several factors such nutritional plan, or whether the animals are under feedlot or grazing conditions. Within grazing, a rainy or dry period would affect the gut fill and by consequence the empty body weight.(Goodchild, 1985), working with grazing animals, verified that the ratio

between heart girth and EBW, and therefore indirectly the BW, is greater in the dry season than in the wet season.

None of the BMs were good in accounting for the variation present in the EBF. However, the general performance of the models was better, since Eqs. [27] and [32] were able to correctly estimate the real content of EBF in the body of the animals. The biological meaning rely on the responsibility of SBW and CF. Around 14.2% of the SBW would be a share of the physical fat on empty body, and also, the amount of fat in the EBF was verified as 44.5% greater than CF content, which roughly means that around 70% of the EBF is CF and the other 30% is related to other depots as non-carcass and KPH fats.

4.7. Carcass chemical fat:

The equations used to assess carcass chemical fat used SBW, SF, HHF, AW and RD independent variables. While using only SBW to estimate CFch, the assumption that around 9.3 to 9.4% of the SBW would be carcass chemical fat was not confirmed by the lack of fit of both equations. In fact SBW has been selected to be used in all equations to predict CFch since presents a quite constant ratio related to BW, or dressing percentage. It is more likely that amount of fat goes higher as twice this value within an even higher discounted, or negative intercept, which would represent a fatter carcass and a fatter GIT (Fonseca 2013, unpublished). Some improvement of prediction had been reported by the authors (Fernandes et al., 2010; De Paula et al. 2013) when SF is added, though none of the equation used to estimate SF worked and the ones that use SF as independent variable were underestimating the amount of chemical fat in the carcass. Also HHF also has been reported as a good predictor while used alone (Lanna et al., 1995; Marcondes et al., 2010; Paulino, 2002; Paulino et al., 2005) or along with SBW which would improve the prediction. Although the higher amount of chemical fat present is this dataset had its observed value underestimated, and while HHF was

used to explain the CFch, the models presented as a smaller contribution than actually it does. The BMs, AW and RD, had influenced the most the prediction of CFch according Fernandes et al. (2010) and De Paula et al. (2013). Probably because they represent the higher pattern of growth of bulls, which composed the authors' data, of the forequarter in detriment of the hindquarter, especially in are an by the dimensions hereby analyzed the *Bos indicus* data set presented a higher surface and therefore would explain it better for the parts of the body that most grew. The same pattern of growth was not observed for F1 Nellore x Angus bulls and steers animals, and therefore the model's ability of prediction was impaired.

4.8. Empty body chemical fat:

One of the reasons that could justify the lack of fit of the models is the gender effect. All models were developed using bulls while the present data set was composed by bulls and steers. The presence of steers might contribute to a higher amount of EE present in the EBW which is verified by the underestimation of almost all models regarding the EE content. Analysis of EE in EBW showed sex effect on rate of deposition (Marcondes, 2010), which could cause part of the differences regarding model prediction. Also some authors (Marcondes et al., 2010) have obtained a better estimation of the EBFch by adding VF and OV on the prediction equation and stated that those would be a better metabolic standard. However, neither De Paula et al. (2013) nor Fernandes et al. (2010) have selected those variables as possible explanation of the amount of chemical fat present in the EBFch. Another source of variation is the nutritional plane of the animals. The grazing animals used in the model's development could be expressing the interactions of normal and compensatory growth, and diet since almost a year in between the beginning of the trial and the slaughter of the animals had passed, than rainy, dry and its season transitions had come to an end along with the results. The VF and OV would reflect that especially in a short period of time before all

the tissues had been replenished (Ferrell et al., 1978; Williams et al., 1983). Despite of the fact that some researchers had pointed out the possibility of using the 9-11th Rib section to estimate the EBFch (Lanna et al., 1995), the models hereby evaluated did not met the criteria or its acceptability, and probability the main reason is a *Bos indicus* equation being evaluated for the crossbred *Bos indicus* x Bos *Taurus*. The BM did not increase the goodness of fit of the EBFch prediction.

5. Conclusion

Among all evaluated equations used to predict the body composition of beef cattle using biometrics measurements, only [7] and [8], for body volume, and [27] and [32], for empty body physically separable fat predictions performed satisfactorily and can be devised to to estimate their contents in F1 Nellore x Angus bulls and steers. Furthermore, more equations might be needed for different breeds, genders and planes of nutrition.

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Table 1 - Proportions of feed in concentrate and diet concentrate fraction composition in dry matter basis.

Ingredients	Concentrate	Diet
Proportion (g/kg DM)		
Corn Silage	-	600.00
Corn	833.50	333.40
Soybean Meal	108.30	43.30
Mineral premix	11.06	4.40
Urea:ammonium sulfate (9:1)	22.11	8.90
Salt	12.30	4.90
Limestone	12.80	5.10
Chemical composition		
Dry matter	885.00	537.30
Organic matter	938.00	944.94
Crude protein	170.50	105.84
Ether extract	32.30	29.08
Neutral Detergent fiber[a]	114.70	340.30
Non fiber carbohydrate	655.89	469.70

[a] corrected for ash and protein contamination; [b] Assuming 260% CP in urea:ammonium sulfate mixture

Table 2 – Descriptive Statistics of the data omitting maintenance group.

Variable	N	Mean	Maximum	Minimum	Std Dev
Age at slaughter, mo	48	16.56	19	12	2.45
Full body weight, kg	48	390.49	603	225	106.32
Shrunk body weight, kg	48	384.07	588.5	223.5	105.44
Empty body weight, kg	48	349.43	541.42	199.41	98.26
Fat thickness, cm	46	4.33	11.58	0.4	3.35
KPH, kg	48	5.07	14.47	0.91	3.19
Internal fat. Kg	48	17.28	37.61	4.05	9.5
Separable fat, kg					
Subcutaneous	48	5.77	15.64	0.4	3.86
Intermuscular	48	12.46	27.33	3.63	6.66
9-11th Rib section	48	3.57	6.23	1.84	1.15
Muscle in 9-11th Rib section	48	2.01	3.44	1.07	0.56
Fat in 9-11th Rib section	48	0.81	1.82	0.18	0.51
Bones in 9-11th Rib section	48	0.74	1.01	0.49	0.13
Volume, m^3	48	0.36	0.55	0.21	0.1
Body density, kg/m^3	48	1079.18	1155.23	882.01	38.95
Chemical fat, kg					
Carcass	48	42.53	90.22	14.02	20.1
Empty body	48	77.06	148.2	29.67	34.21
Biometrical measurements, cm					
HBW	48	43.08	52	33	4.83
PBW	48	28.71	37.4	22	3.92
AW	48	52.95	68	38.5	7.32
BL	48	89.47	108	51.5	16.68
RH	48	130.03	139	120	4.35
HW	48	123.11	138	15.5	16.65
PGL	48	44.97	55	36	4.31
RD	48	65.33	82	53	7.11
GC	48	170.03	199	136	17.25
RuD	48	47.81	55.5	40.5	3.9
SW	48	33.71	43	23	4.41
BDL	48	97.72	111	85	6.59
TW	48	47.93	448	27	59.36
$BL_{fernandes}$	48	55.76	73	24	13.44
$BL_{DePaula}$	48	134.44	159.5	89	20.3

HBW: hook bone width; PBW: pin bone width; AW: abdomen width; BL: body length; RH: rump height; HW: height at withers; PGL: pelvic girdle length; RD: rib depth; GC: girth circumference; RuD: rump depth; SW: scapulae width; BDL: body diagonal length; TW: thorax width; BLNEL: body length as De Paula et al. (2013); TBS: total body surface.

Table 3 - Regression equations for predicting total body surface (TBS) and body volume (BV) 1 as described by Henrique et al (2010) and De Paula et al. (2013).

#	Equations [2]	Statistics		
		n	RMSE	r^2
	Total body surface, m^2			
[1]	$TBS = -1.170(\pm 0.27^{***}) \times 5.20(\pm 0.256^{***}) \times TBS_{frustum}$	39	0.290	0.918
[2]	$TBS = 9.23 \times 10^{-3}(\pm 7.01^{***} \times 10^{-4}) \times SBW + 0.022(\pm 3.755 \times 10^{-3}{}^{***}) \times BL_{fernandes}$	39	0.307	0.995
[3]	$TBS = 1.570(\pm 0.009^{***}) \times TBS_{cylinder}$	25	0.129	0.999
[4]	$TBS = 0.007(\pm 5.08 \times 10^{-4}{}^{***}) \times SBW + 0.013(\pm 1.5 \times 10^{-3}{}^{***}) \times HW$	26	0.134	0.999
	Body volume, m^3			
[5]	$BV = 2.70\ (\pm 0.029^{*}) \times BV_{frustum}$	34	0.017	0.996
[6]	$BV = 8.06 \times 10^{-4}\ (\pm 2.51^{***}) \times SBW$	35	0.005	0.999
[7]	$BV = 0.036(\pm 0.016^{*}) + 1.028(\pm 0.049^{***}) \times BV_{cylinder}$	28	0.016	0.942
[8]	$BV = -0.011(\pm 0.004^{*}) + 9.8 \times 10^{-4}(\pm 1.84 \times 10^{-5}{}^{***}) \times SBW$	27	0.003	0.997
[9]	$BV = -0.092(\pm 0.030^{**}) + 9.002 \times 10^{-4}(\pm 2.55 \times 10^{-5}{}^{***}) \times SBW + 0.001(\pm 4.37 \times 10^{-4}{}^{*}) \times HBW + 4.783 \times 10^{-4}(\pm 2.11 \times 10^{-4}{}^{*}) \times RH$	28	0.004	0.997

[1] TBS is the observed total body surface, m^2; SBW is the shrunk BW, kg; HW is height at withers, cm; HBW is hook bone width, cm; RH is rump height; and BV is body volume, m^3;$BL_{fernandes}$ is summation of pelvic girdle length and scapulae width . Values within parentheses are SE of the parameter estimate, and *, **, and *** indicate $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively. Intercepts that were not different from zero were removed from the final equation; when the intercept was utilized, the r^2 for Eqs [1] and [3] were 0.9331 and 0.9461, respectively. RMSE is root mean square error.

[2] $TBS_{cylinder} = BLS_{cylinder} + Sbt$; $BLS_{cylinder} = 2\pi \times RB \times BL / 10^4$; $BV_{cylinder} = \pi \times RB^2 \times BL / 10^6$; $RB = GC / 2\pi$; $Sbt = 2 \times (\pi \times RB^2) / 10^4$; where $BLS_{cylinder}$ is lateral surface area, m^2; RB is radius of the body, cm; Sbt is base and top (parallel planes) surface area, m^2; $\pi = 3.1416$; and BL is body length, cm.

[3] $TBS_{frustum} = [\pi \times (RTx + RRp) \times ((BL_{fernandes})^2 + (RTx - RRp)2)^{0.5}]/10000$.

[4] $BV_{frustum} = [\pi \times BL_{fernandes} \times (RTx^2 + RTx \times RRp + RRp^2)]/3 \times 10^{-6}$, where RTx is the radius of the thorax, cm; RRp is the radius of rump, cm and TBL is the total body length.

Table 4 - Regression equations developed to predict subcutaneous, internal, carcass and empty body physical fat as described by Henrique et al (2010) and De Paula et al. (2013).

#	Equations	Statistic		
		n	RMSE	r^2
	Subcutaneous fat, kg			
[10]	SF = -5.76(±0.990***) + 0.04(±3.06***×10^{-3}) × SBW	38	1.65	0.827
[11]	SF = 2.15(±0.514***) + 0.513(±0.046***) × SFp	38	1.89	0.773
[12]	SF = -10.1(±2.41***) + 0.022(±4.21***×10^{-3})× SBW+12.1 (±3.07***) × FT + 0.159(±0.066*) × AW	38	1.22	0.911
[13]	SF = -2.779(±0.553***) + 0.022(±0.0016***) × SBW	41	1.01	0.830
[14]	SF = 3.348(±0.528***) + 0.283(±0.048***) × SFp	25	1.25	0.579
[15]	SF = 0.03(±0.003***) × SBW - 0.099(±0.03**) × BL + 0.052(±0.021*) × HW	39	0.94	0.967
	Internal fat, kg			
[16]	InF = -2.121(±0.716**) + 0.034(±0.002***) × SBW	44	1.32	0.866
[17]	InF = 0.0405(±0.003***) × SBW – 0.159(±0.0428***) × PBW	43	1.26	0.984
	Carcass physical fat, kg			
[18]	CF = -13.9(±2.02**) + 0.108(±0.006***) × SBW	37	3.22	0.897
[19]	CF = -3.96(±1.21**) + 0.040(±0.006***) × SBW + 1.62(±0.146***) × SF	37	1.44	0.980
[20]	CF = -9.8(±1.81***) + 0.073(±0.009***) ×SBW + 19.0(±4.0***)× HHF	37	2.53	0.938
[21]	CF = -31.13(±4.86***) + 0.078(±0.009***) ×SBW + 0.523(±0.137***)× AW	38	2.71	0.931
[22]	CF = -5.434(±1.889**) + 0.079(±0.005***) × SBW	44	3.47	0.830
[23]	CF = 0.0425(±0.004***) × SBW + 1.382(±0.240***) × SF	44	2.84	0.984
[24]	CF = 4.0645(±1.075***) + 39.052(±2.255***) × HHF	44	2.99	0.874
[25]	CF = 0.029(±0.005***) × SBW + 25.941(±3.499***) × HHF	43	2.41	0.988
[26]	CF = 0.076(±0.008***) × SBW – 0.783(±0.248**) × RD + 0.265(±0.098*) × GC	43	2.98	0.981

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	Empty body physical fat, kg			
[27]	EBF = -16.8 (±2.68***) + 0.142 (±0.008***) × SBW	36	4.17	0.897
[28]	EBF = 0.011(±0.002***) × SBW+1.22 (±0.024***) × CF	35	0.689	0.999
[29]	EBF = -11.4(±2.38***) +0.096(±0.012***) × SBW + 24.5(±5.16***) × HHF	36	3.26	0.940
[30]	EBF = 39.0(±6.05***) + 0.102(±0.011***) ×SBW + 0.682(±0.169***)× AW	36	3.31	0.938
[31]	EBF = -7.555(±2.242**) + 0.113(±0.006***) × SBW	44	4.12	0.878
[32]	EBF = 1.445(±0.0103***) × CF	43	1.51	0.998
[33]	EBF = 0.017(±0.003***) × SBW + 1.184(±0.050***) × CF	42	1.18	0.999
[34]	EBF = 6.202(±1.197***) + 55.764(±2.569***) × HHF	42	3.28	0.920
[35]	EBF = 0.047(±0.006***) × SBW + 33.055(±4.099***) × HHF	43	2.82	0.992
[36]	EBF = 0.128(±0.009***) × SBW – 0.203(±0.053***) × RD	44	3.99	0.985

[1] SF is subcutaneous fat, kg; SBW is the shrunk BW, kg; BL is body length, cm; HW is height at withers, cm; PBW is Pin bone width, cm; RD is rib depth, cm; GC is girth circumference, cm; INTF (internal fat) = KPH + fat visceral; CF is carcass fat; HHF is section HH fat, kg; EBF is empty body fat, kg; RMSE is root mean square error. Values within parentheses are SE of the parameter estimate, and *, **, and *** indicate $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively. Intercepts that were not different from zero were removed from the final equation; when the intercept was utilized, the r^2 for Eqs. [3], [5], [7], [9], [10], [15], and [17] were 0.8463, 0.8952, 0.8888, 0.9173, 0.8501, 0.9390, and 0.8906, respectively. SFp (subcutaneous fat predict, kg) = TBS × FT × 912 / 100, where BS is body surface, m^2 and FT is fat thickness, cm.

Table 5 - Regression equations to predict the carcass and empty body chemical fat as described by Henrique et al (2010) and De Paula et al. (2013).

#	Equations	Statistic		
		N	RMSE	r^2
	Carcass chemical fat, kg			
[37]	CFch = -9.28(±1.97***) + 0.093(±0.006***) × SBW	37	3.23	0.871
[38]	CFch = 0.029(±0.004**) × SBW + 1.58(±0.174***) × SF	37	2.25	0.990
[39]	CFch = -4.63(±1.55**) + 0.051(±0.008***) ×SBW + 22.7(±1.8***)× HHF	37	2.22	0.941
[40]	CFch = -22.1(±5.73***) + 0.074(±0.010***) ×SBW + 0.373(±0.158***)× AW	37	3.04	0.889
[41]	CFch = -7.170(±1.418***) + 0.094(±0.004***) × SBW	44	2.61	0.925
[42]	CFch = -5.659(±1.448***) + 0.081(±0.006***) × SBW + 0.589(±0.225***) × SF	44	2.44	0.934
[43]	CFch = 7.259(±1.411***) + 3.611(±0.269***) × SF	41	4.19	0.818
[44]	CFch = 4.817(±1.179***) + 45.741(±2.512***) × HHF	43	3.24	0.887
[45]	CFch = -4.678(±1.459**) + 0.069(±0.008***) × SBW + 13.379 (±3.899**) × HHF	44	2.33	0.940
[46]	CFch = 17.239(±7.419*) + 0.131(±0.011***) × SBW – 0.604(±0.181**) × RD	44	2.34	0.940
	Empty body chemical fat, kg			
[47]	EBFch = -18.9(±2.81***) + 0.162(±0.009***) × SBW	35	4.41	0.913
[48]	EBFch = 1.56(±0.012***) × CFch	34	1.41	0.998
[49]	EBFch = -12.3(±2.50***) + 0.106(±0.013***) × SBW + 28.7 (±5.68**) × HHF	35	3.34	0.952
[50]	EBFch = 0.199(±0.010***) × SBW – 1.43(±0.229***) × PBW + 0.453(±0.154**) × AW	35	3.47	0.991
[51]	EBFch = -10.517(±2.343***) + 0.149(±0.007***) × SBW	44	4.31	0.920
[52]	EBFch = 1.6133(±0.00***) × CFch	43	1.86	0.998
[53]	EBFch = 8.565(±1.928***) + 72.717(±4.109***) × HHF	43	5.30	0.881
[54]	EBFch = -6.633(±2.448**) + 0.111(±0.013***) × SBW + 20.854(±6.541**) × HHF	44	3.90	0.934
[55]	EBFch = 28.165(±12.386*) + 0.208(±0.019***) × SBW – 0.957(±0.302**) × RD	44	3.91	0.934

[1] CFch is the carcass chemical fat, kg; SBW is the shrunk BW, kg; SF is subcutaneous fat, kg; HHF is section HH fat, kg; RD is rib depth, cm; EBFch is the empty body chemical fat, kg; RMSE is root mean square error. Values within parentheses are SE of the parameter estimate, and *, **, and *** indicate $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively. Intercepts that were not different from zero were removed from the final equation; when the intercept was utilized, the r^2 for Eq. [8] was 0.9855.

Table 6 - Mean (kg) and descriptive statistics of the relationship among observed and predicted values of total body surface (TBS) and body volume (BV).

Variable	TBS	[1]	[2]	[3]	[4]	BV	[5]	[6]	[7]	[8]	[9]
Mean	1.98	5.38	4.77	5.09	4.29	0.36	0.37	0.31	0.36	0.37	0.34
Standard Deviation	0.28	2.17	1.20	1.10	0.86	0.10	0.15	0.09	0.10	0.10	0.12
Maximum	2.53	1.78	2.65	2.96	1.78	0.552	0.14	0.18	0.18	0.21	0.11
Minimum	1.47	8.1	6.83	6.76	5.91	0.206	0.61	0.47	0.53	0.57	0.55
r^2	-	0.79	0.91	0.84	0.88	-	0.87	0.98	0.94	0.98	0.95
CCC[a]	-	0.07	0.07	0.05	0.07	-	0.86	0.86	0.94	0.99	0.94
Cb[b]	-	0.07	0.07	0.06	0.08	-	0.92	0.87	1.00	1.00	0.97
REGRESSION ANALYSIS											
Intercept											
a	-	1.36	0.93	0.80	0.67	-	0.12	-0.01	0.02	0.00	0.08
SD	-	0.05	0.05	0.08	0.07	-	0.01	0.01	0.02	0.01	0.01
P-value[c]	-	0.00	0.00	0.00	0.00	-	0.00	0.27	0.38	0.62	0.00
Slope											
B	-	0.11	0.22	0.23	0.30	-	0.63	1.18	0.93	0.97	0.80
SE	-	0.01	0.01	0.01	0.02	-	0.03	0.02	0.05	0.02	0.03
P-value[d]	-	0.00	0.00	0.00	0.00	-	0.00	0.00	0.20	0.06	0.00
MSEP[e] (%)											
MB[f]	-	76.12	89.99	93.12	93.71	-	4.65	85.63	3.83	33.62	13.27
Systematic Bias	-	23.78	9.93	6.77	6.14	-	67.74	8.61	3.39	4.96	37.81
Random Error	-	0.10	0.08	0.12	0.16	-	27.61	5.76	92.78	61.42	48.92
RMSEP[g]											
kg	-	3.90	2.95	3.23	2.39	-	0.07	0.05	0.04	0.02	0.04
%	-	72.45	61.73	63.36	55.67	-	18.07	16.78	9.80	4.27	11.77

[a]CCC is the concordance correlation coefficient; [b]Cb is the bias correction factor; [c]β_o=0; [d] β_1=1; [e] MSEP is the mean square error of the prediction; [f] MB is the mean bias; [g]RMSEP is the root mean of the square error of prediction.

Table 7 - Mean (kg) and descriptive statistics among observed and predicted values of subcutaneous fat (SF) and internal fat (InF).

Variable	SF	[10]	[11]	[12]	[13]	[14]	[15]	InF	[16]	[17]
Mean	11.30	9.60	43.94	53.78	5.67	22.08	4.62	17.28	10.94	11.67
Standard Deviation	7.60	4.22	37.08	47.45	2.32	16.62	2.28	9.50	3.58	3.36
Maximum	30.73	3.18	2.15	-5.18	2.14	3.35	-2.05	37.61	5.48	5.46
Minimum	0.78	17.78	135.43	152.49	10.17	63.1	9.68	4.05	17.89	18.9
r^2	-	0.78	0.80	0.83	0.78	0.80	0.55	-	0.83	0.74
CCC[a]	-	0.72	0.20	0.16	0.33	0.50	0.24	-	0.43	0.41
Cb[b]	-	0.82	0.23	0.18	0.37	0.56	0.32	-	0.48	0.48
REGRESSION ANALYSIS										
Intercept										
a	-	-4.00	3.23	3.43	-5.13	2.25	-0.26	-	-9.21	-11.27
SD	-	1.30	0.77	0.69	1.38	0.82	1.67	-	1.82	2.55
P-value[c]	-	0.00	0.00	0.00	0.00	0.01	0.88	-	0.00	0.00
Slope										
B	-	1.59	0.18	0.15	2.90	0.41	2.50	-	2.42	2.45
SE	-	0.12	0.01	0.01	0.23	0.03	0.33	-	0.16	0.21
P-value[d]	-	0.00	0.00	0.00	0.00	0.00	0.00	-	0.00	0.00
MSEP[e] (%)										
MB[f]	-	13.45	53.98	52.76	50.28	52.44	55.24	-	50.14	40.92
Systematic Bias	-	28.66	45.46	46.97	30.09	42.53	14.21	-	31.70	30.03
Random Error	-	57.89	0.57	0.27	19.63	5.04	30.55	-	18.16	29.06
RMSEP[g]										
kg	-	4.62	44.43	58.48	7.94	14.89	8.99	-	8.96	8.77
%	-	48.13	101.11	108.75	139.91	67.45	194.84	-	81.89	75.10

[a]CCC is the concordance correlation coefficient; [b]Cb is the bias correction factor; [c]β_o=0; [d] β_1=1; [e] MSEP is the mean square error of the prediction; [f] MB is the mean bias; [g]RMSEP is the root mean of the square error of prediction.

Table 8 - Mean (kg) and descriptive statistics of the relationship among observed and predicted carcass physical fat (CFp).

Variable	CFp	[18]	[19]	[20]	[21]	[22]	[23]	[24]	[25]	[26]
Mean	35.71	27.58	28.90	32.63	22.77	24.91	30.58	33.64	30.78	24.33
Std. Deviation	20.39	11.39	17.11	18.02	17.90	8.33	14.92	22.06	17.48	6.51
Maximum	77.21	10.24	4.98	6.52	-13.7	12.22	9.5	4.06	6.48	12.17
Minimum	8.97	49.66	64.54	64.31	48.25	41.06	60.45	75.14	62.46	40.3
r^2	-	0.88	0.95	0.93	0.70	0.88	0.96	0.90	0.92	0.68
CCC[a]	-	0.71	0.90	0.95	0.68	0.53	0.90	0.94	0.92	0.37
Cb[b]	-	0.76	0.92	0.98	0.81	0.56	0.92	0.99	0.96	0.45
REGRESSION ANALYSIS										
Intercept										
a	-	-10.67	2.07	0.04	13.83	-21.55	-5.19	6.20	1.25	-27.25
SD	-	2.70	1.26	1.60	2.60	3.25	1.40	1.72	1.70	6.54
P-value[c]	-	0.00	0.11	0.98	0.00	0.00	0.00	0.00	0.47	0.00
Slope										
B	-	1.68	1.16	1.09	0.96	2.30	1.34	0.88	1.12	2.59
SE	-	0.09	0.04	0.04	0.09	0.12	0.04	0.04	0.05	0.26
P-value[d]	-	0.00	0.00	0.03	0.67	0.00	0.00	0.01	0.02	0.00
MSEP[e] (%)										
MB[f]	-	38.18	63.83	24.24	58.64	41.77	38.53	8.30	40.04	35.68
Systematic Bias	-	34.05	10.63	7.07	0.17	41.02	36.37	13.81	7.06	28.82
Random Error	-	27.77	25.54	68.69	41.19	17.21	25.10	77.89	52.90	35.51
RMSEP[g]										
kg	-	13.16	8.53	6.27	16.90	16.72	8.27	7.20	7.79	19.06
%	-	47.72	29.50	19.20	74.20	67.11	27.03	21.41	25.30	78.37

[a]CCC is the concordance correlation coefficient; [b]Cb is the bias correction factor; [c]β_o=0; [d] β_1=1; [e] MSEP is the mean square error of the prediction; [f] MB is the mean bias; [g]RMSEP is the root mean of the square error of prediction.

Table 9 - Mean (kg) and descriptive statistics of the relationship among observed and predicted empty body physical fat (EBFp).

Variable	EBFp	[27]	[28]	[29]	[30]	[31]	[32]	[33]	[34]	[35]	[36]
Mean	52.99	37.74	0.48	44.03	109.40	35.85	51.60	47.24	48.43	43.08	34.89
Std. Deviation	29.54	14.97	0.27	23.43	23.37	11.91	29.47	24.94	31.50	23.27	9.83
Maximum	113.7	14.94	0.12	10.06	61.8	17.7	12.96	14.05	6.2	10.5	16.04
Minimum	13.02	66.77	1.04	85.19	142.68	58.95	111.57	96.84	107.69	85.09	55.8
r^2	-	0.99	0.99	0.93	0.69	0.88	0.99	0.99	0.90	0.92	0.77
CCC[a]	-	0.99	0.97	0.89	0.61	0.51	0.99	0.96	0.94	0.87	0.46
Cb[b]	-	1.00	0.97	0.92	0.73	0.54	1.00	0.96	0.99	0.91	0.52
REGRESSION ANALYSIS											
Intercept											
a	-	1.53	-1.10	-0.71	19.89	-30.74	1.53	-2.69	9.90	0.39	-40.27
SD	-	0.91	0.92	2.35	4.01	4.63	0.91	0.94	2.52	2.51	7.61
P-value[c]	-	0.10	0.24	0.76	0.00	0.00	0.10	0.01	0.00	0.88	0.00
Slope											
B	-	1.00	1.13	1.22	1.05	2.34	1.00	1.18	0.89	1.22	2.46
SE	-	0.02	0.02	0.05	0.10	0.12	0.02	0.02	0.04	0.05	0.19
P-value[d]	-	0.86	0.00	0.00	0.60	0.00	0.86	0.00	0.02	0.00	0.00
MSEP[e] (%)											
MB[f]	-	17.33	57.18	49.82	64.01	46.06	17.33	54.03	17.59	52.14	34.81
Systematic Bias	-	0.06	24.24	16.08	0.22	38.86	0.06	31.73	10.00	13.74	36.05
Random Error	-	82.61	18.58	34.09	35.77	15.08	82.61	14.24	72.41	34.13	29.14
RMSEP[g]											
kg	-	3.33	6.87	12.70	26.99	25.26	3.33	7.82	10.87	13.72	25.48
%	-	8.83	1433.86	28.85	24.67	70.47	6.46	16.56	22.45	31.85	73.02

[a]CCC is the concordance correlation coefficient; [b]Cb is the bias correction factor; [c]β_o=0; [d] β_1=1; [e] MSEP is the mean square error of the prediction; [f] MB is the mean bias; [g]RMSEP is the root mean of the square error of prediction.

Table 10 - Mean (kg) and descriptive statistics of the relationship among observed and predicted values of carcass chemical fat (CFch).

Variable	CFch	[37]	[38]	[39]	[40]	[41]	[42]	[43]	[44]	[45]	[46]
Mean	42.53	51.60	48.81	48.43	43.08	37.96	31.81	46.26	39.46	31.96	34.23
Std. Deviation	20.10	29.47	25.83	31.50	23.27	10.61	13.00	29.60	25.84	14.50	11.77
Maximum	90.22	12.96	14.45	6.2	10.5	17.84	12.44	7.26	4.82	10.74	14.1
Minimum	14.02	111.57	100.24	107.69	85.09	60.51	56.74	118.23	88.07	57.74	59.03
r^2	-	0.82	0.83	0.82	0.62	0.82	0.85	0.77	0.78	0.84	0.08
CCC[a]	-	0.47	0.67	0.79	0.47	0.53	0.70	0.81	0.85	0.74	0.24
Cb[b]	-	0.52	0.74	0.86	0.59	0.58	0.76	0.92	0.96	0.80	0.77
REGRESSION ANALYSIS											
Intercept											
a	-	-6.67	6.48	9.60	16.78	-10.74	-2.86	14.95	15.32	1.86	24.30
SD	-	3.56	2.63	2.52	3.40	3.82	3.01	2.62	2.49	2.84	8.65
P-value[c]	-	0.07	0.02	0.00	0.00	0.01	0.35	0.00	0.00	0.52	0.01
Slope											
B	-	1.86	1.24	1.02	1.10	1.84	1.43	0.60	0.69	1.27	0.53
SE	-	0.13	0.08	0.07	0.12	0.13	0.09	0.05	0.05	0.08	0.24
P-value[d]	-	0.00	0.00	0.72	0.42	0.00	0.00	0.00	0.00	0.00	0.06
MSEP[e] (%)											
MB[f]	-	65.05	70.34	61.32	71.26	57.37	56.40	5.69	6.02	59.09	15.14
Systematic Bias	-	17.53	4.87	0.11	5.94	31.51	14.79	57.25	40.11	8.08	6.50
Random Error	-	17.42	24.79	38.58	22.81	11.12	28.82	37.06	53.87	32.83	78.36
RMSEP[g]											
kg	-	19.95	16.15	13.26	22.66	17.95	14.27	15.63	12.53	13.76	21.34
%	-	38.66	33.08	27.38	52.60	47.29	44.86	33.78	31.75	43.06	62.36

[a]CCC is the concordance correlation coefficient; [b]Cb is the bias correction factor; [c]β_o=0; [d] β_1=1; [e] MSEP is the mean square error of the prediction; [f] MB is the mean bias; [g]RMSEP is the root mean of the square error of prediction.

Table 11 - Mean (kg) and descriptive statistics of the relationship among observed and predicted values of empty body chemical fat (EBFch).

Variable	EBFch	[47]	[48]	[49]	[50]	[51]	[52]	[53]	[54]	[55]
Mean	77.06	43.32	66.35	50.15	62.26	46.71	68.61	63.63	51.79	52.25
Std. Deviation	34.21	17.08	31.35	26.79	17.83	15.71	32.42	41.07	22.95	18.66
Maximum	148.2	17.31	21.87	11.39	30.01	22.78	22.62	8.57	18.18	23.29
Minimum	29.67	76.44	140.74	97.3	101.68	77.17	145.55	140.91	92.68	94.52
r^2	-	0.88	0.97	0.91	0.80	0.88	0.97	0.85	0.91	0.08
CCC[a]	-	0.42	0.93	0.67	0.64	0.43	0.95	0.86	0.64	0.20
Cb[b]	-	0.45	0.95	0.70	0.71	0.46	0.97	0.93	0.67	0.64
REGRESSION ANALYSIS										
Intercept										
a	-	-4.66	5.79	15.99	-30.35	-18.74	5.79	27.97	3.27	45.62
SD	-	4.61	2.07	3.22	8.00	5.31	2.07	3.49	3.66	14.97
P-value[c]	-	0.32	0.01	0.00	0.00	0.00	0.01	0.00	0.38	0.00
Slope										
B	-	1.89	1.07	1.22	1.73	2.05	1.04	0.77	1.42	0.57
SE	-	0.10	0.03	0.06	0.12	0.11	0.03	0.05	0.06	0.26
P-value[d]	-	0.00	0.01	0.00	0.00	0.00	0.17	0.00	0.00	0.10
MSEP[e] (%)										
MB[f]	-	76.29	73.75	84.07	36.39	69.92	65.80	41.98	76.87	30.21
Systematic Bias	-	15.04	3.40	3.87	27.20	20.26	1.42	20.10	11.20	4.02
Random Error	-	8.67	22.85	12.06	36.41	9.82	32.78	37.92	11.93	65.77
RMSEP[g]										
kg	-	38.62	12.47	29.35	24.53	36.29	10.41	20.72	28.82	39.68
%	-	89.16	18.79	58.53	39.40	77.69	15.17	32.56	55.64	75.94

[a]CCC is the concordance correlation coefficient; [b]Cb is the bias correction factor; [c]β_o=0; [d] β_1=1; [e] MSEP is the mean square error of the prediction; [f] MB is the mean bias; [g]RMSEP is the root mean of the square error of prediction.

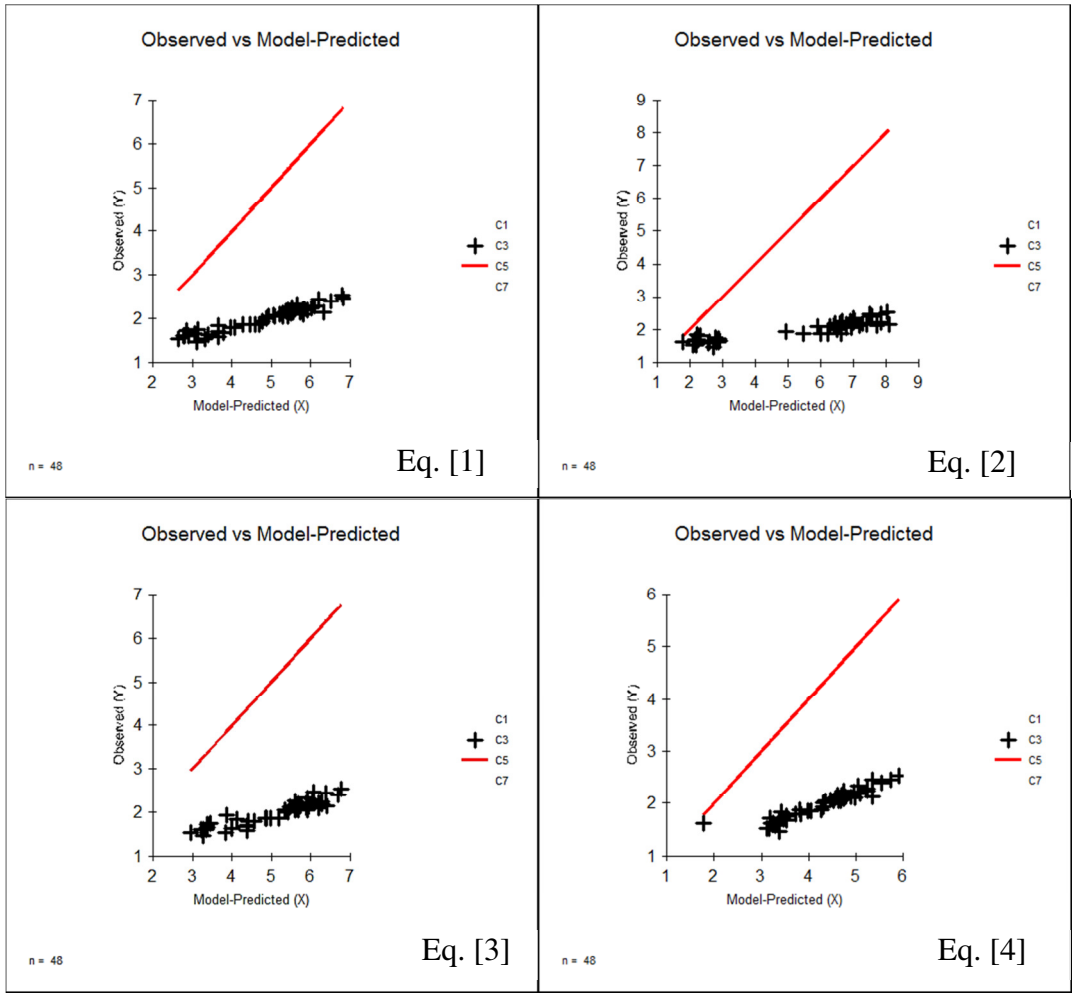

Figure 1 - Relationship among observed and model-predicted values for body surface (m^2) as devised by Fernandes et al. (2010), Eqs. [1] and [2]; and De Paula et al. (2013), Eqs. [3] and [4].

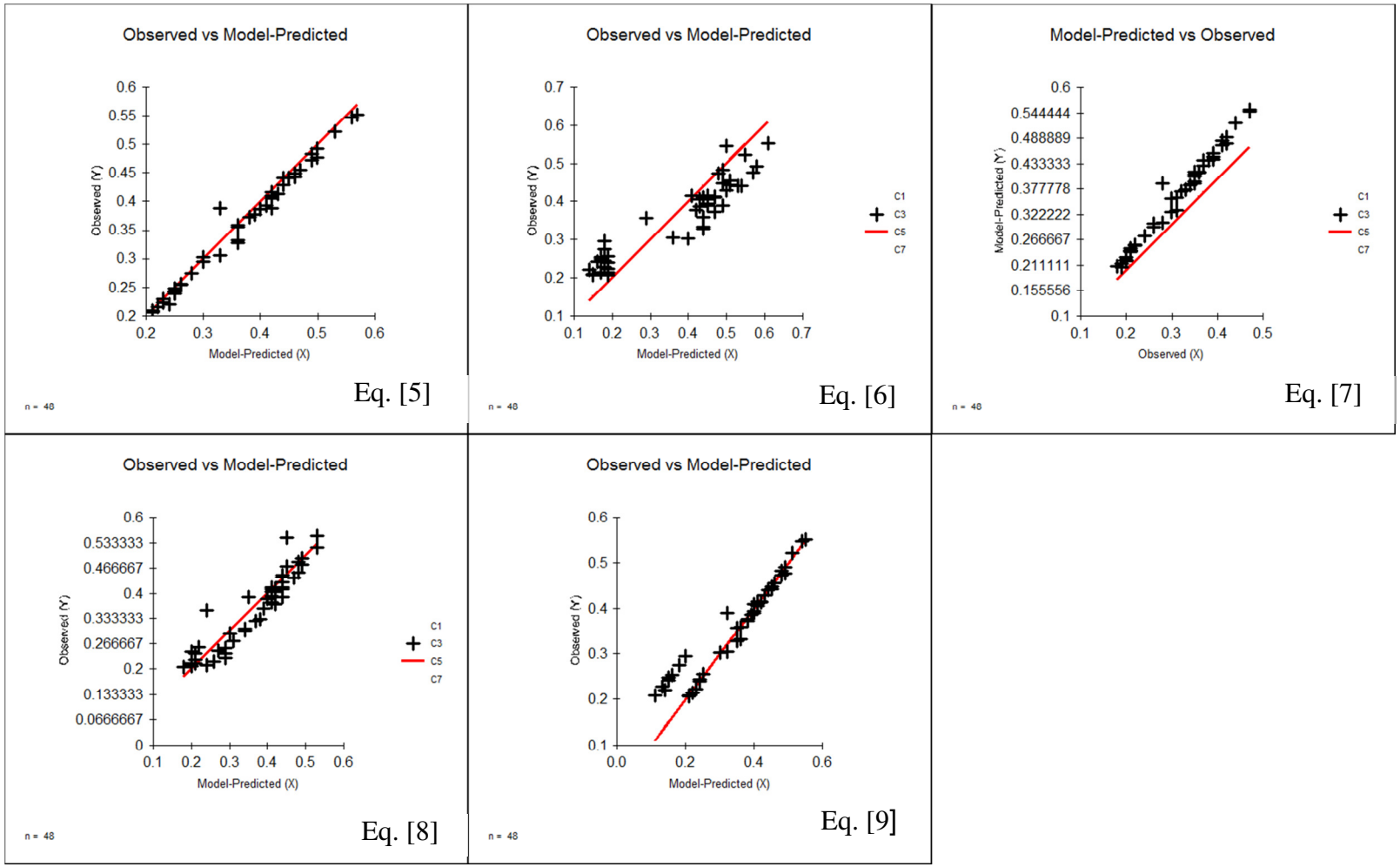

Figure 2 - Relationship among observed and model-predicted values for body volume (m^3) as devised by Fernandes et al. (2010), Eqs. [5] and [6]; and De Paula et al. (2013), Eqs. [7], [8], and [9].

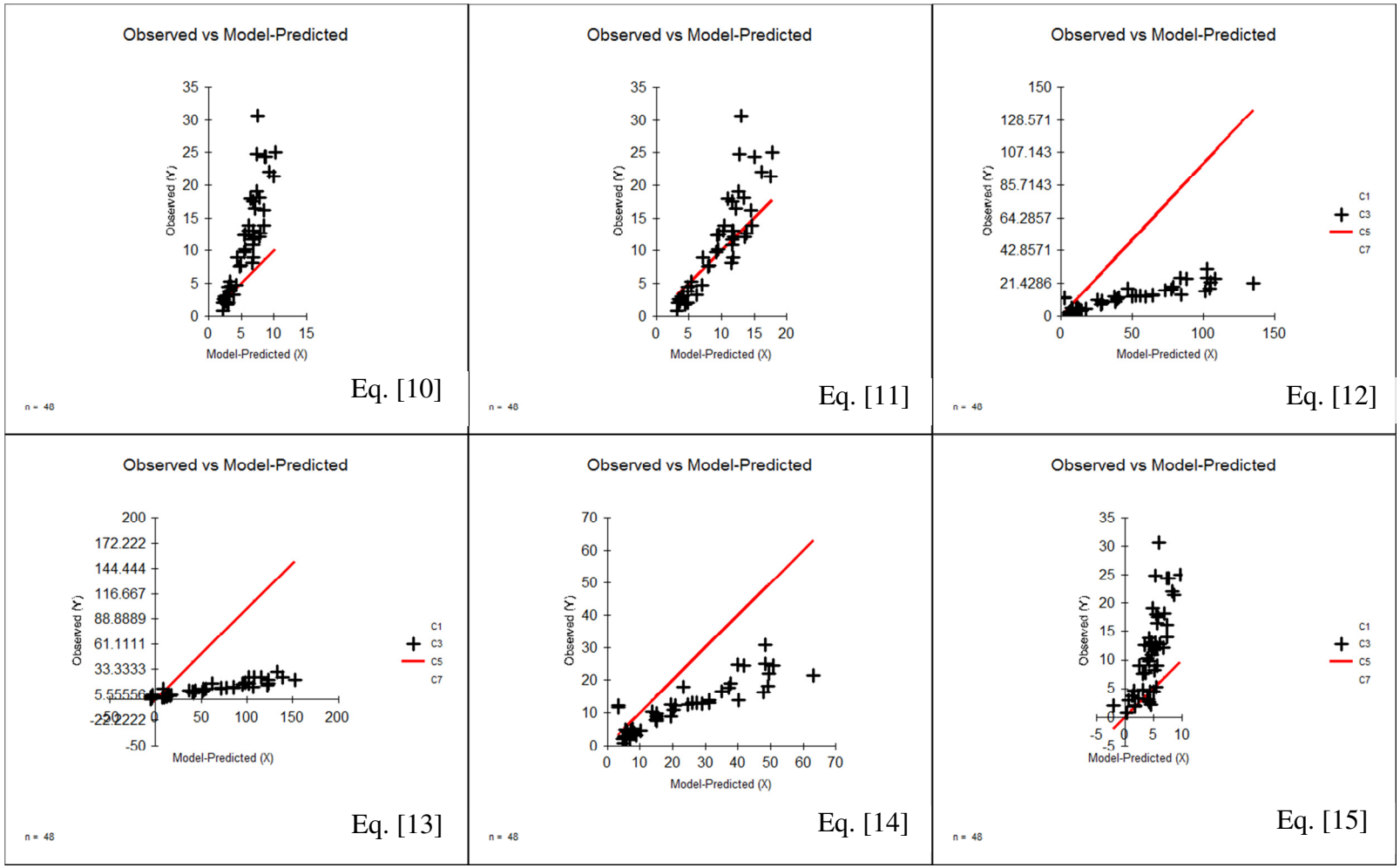

Figure 3 - Relationship among observed and model-predicted values for subcutaneous fat (kg) as devised by Fernandes et al. (2010), Eqs. [10], [11], and [12], and De Paula et al. (2013), Eqs. [13], [14], and [15].

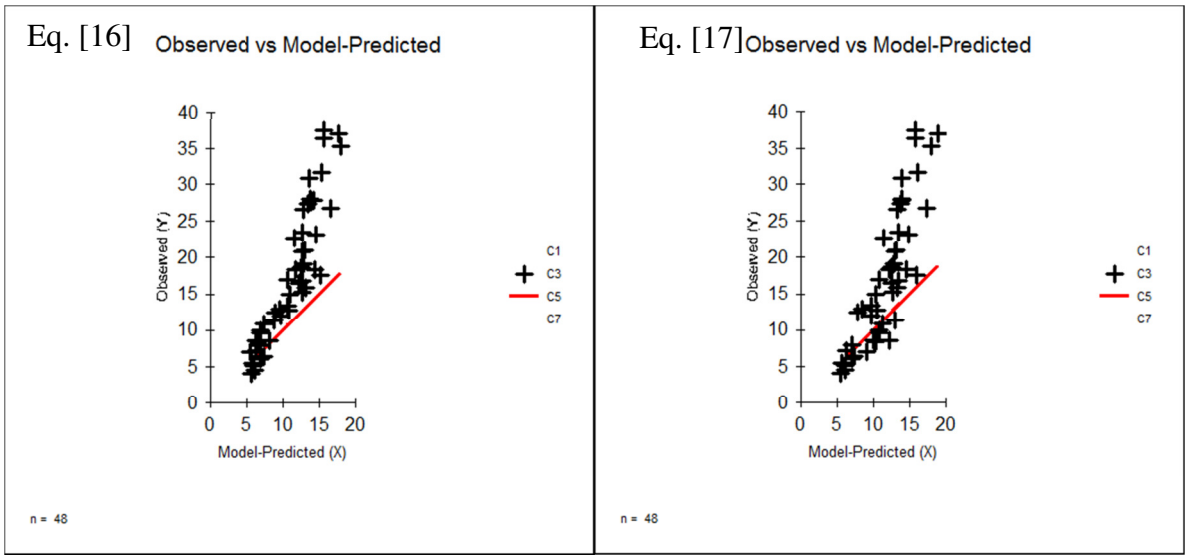

Figure 4 - Relationship among observed and model-predicted values for internal fat (kg) as devised by De Paula et al. (2013), Eqs. [16] and [17].

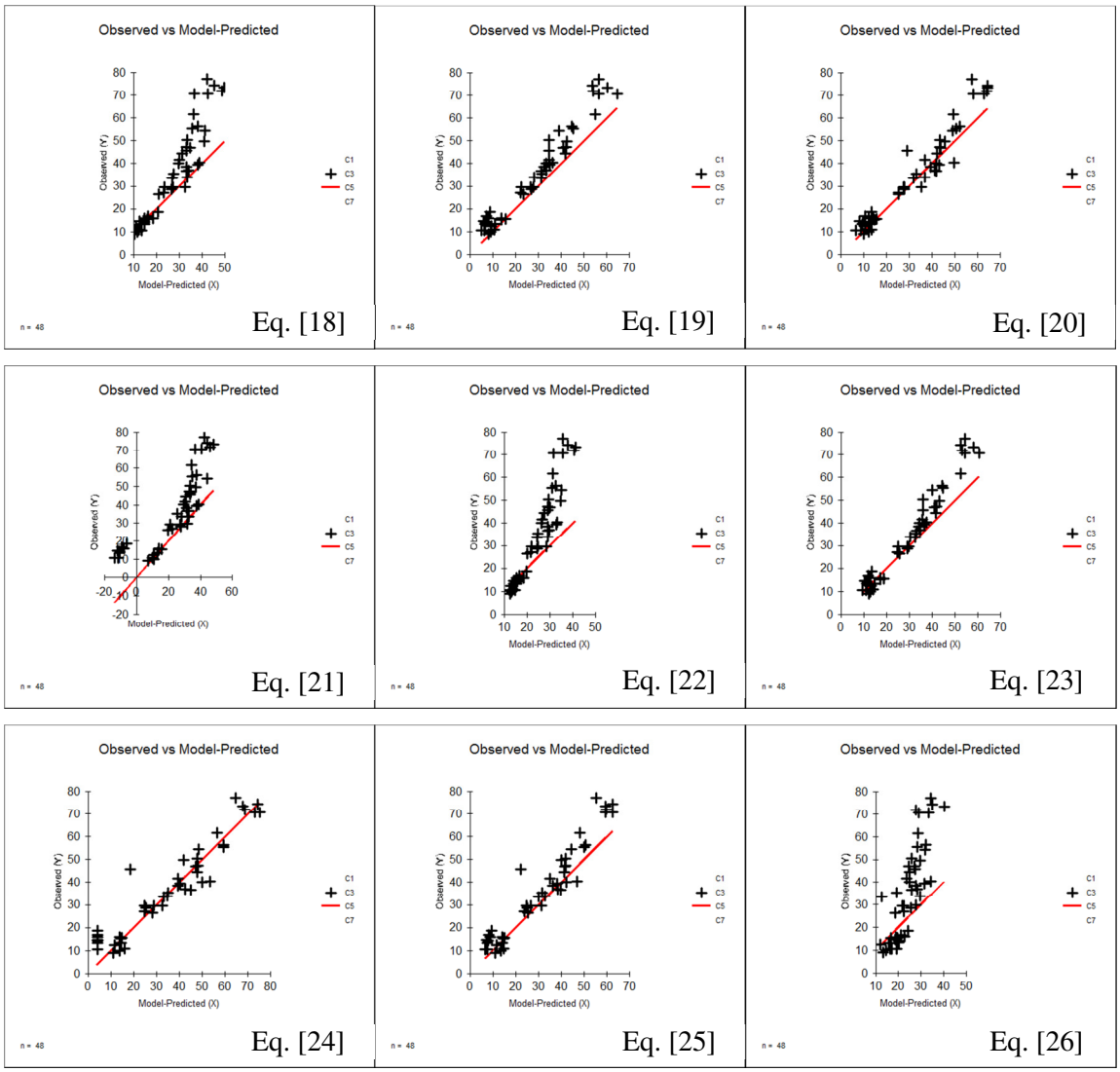

Figure 5 - Relationship among observed and model-predicted values for physically separable carcass fat (kg) as devised by Fernandes et al. (2010), [18], [19], [20], and [21]; and De Paula et al. (2013), Eqs. [22], [23], [24], [25], and [26].

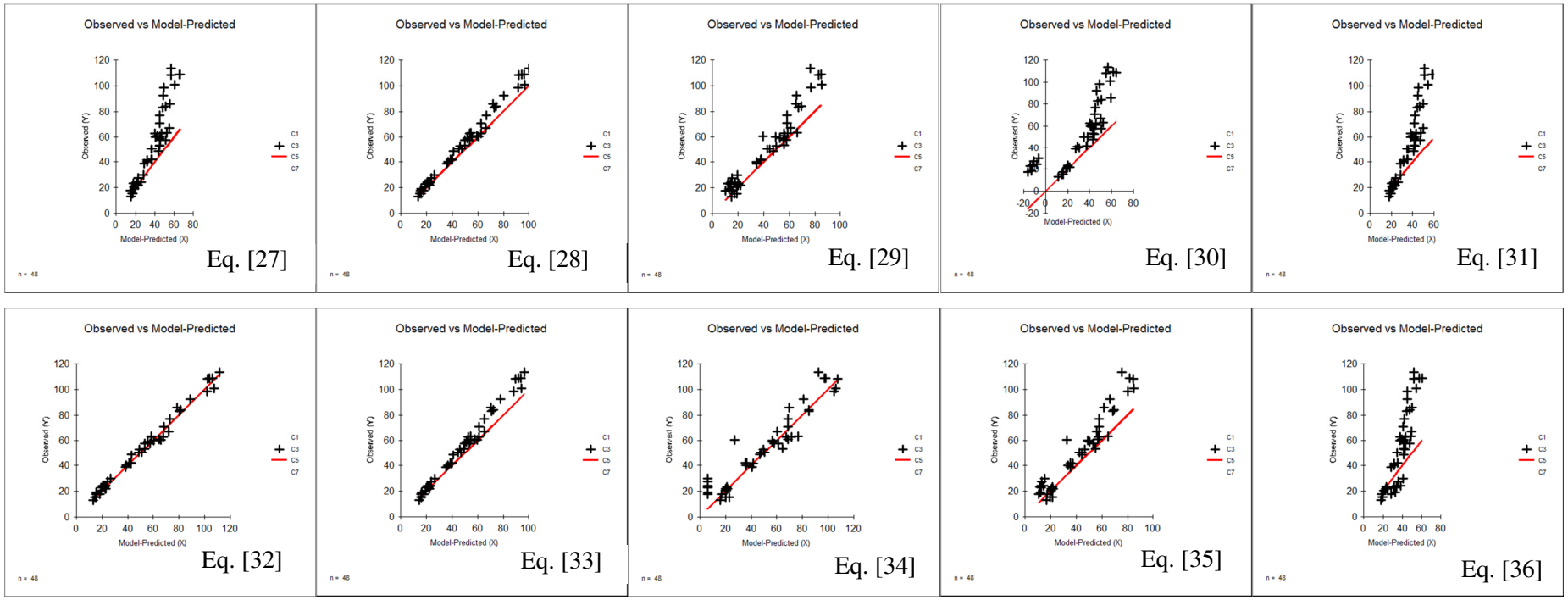

Figure 6 - Relationship among observed and model-predicted values for physically separable empty body fat (kg) as devised by Fernandes et al. (2010), Eqs. [27], [28], [29], and [30]; and De Paula et al. (2013), Eqs. [31], [32], [33], [34], [35] and [36].

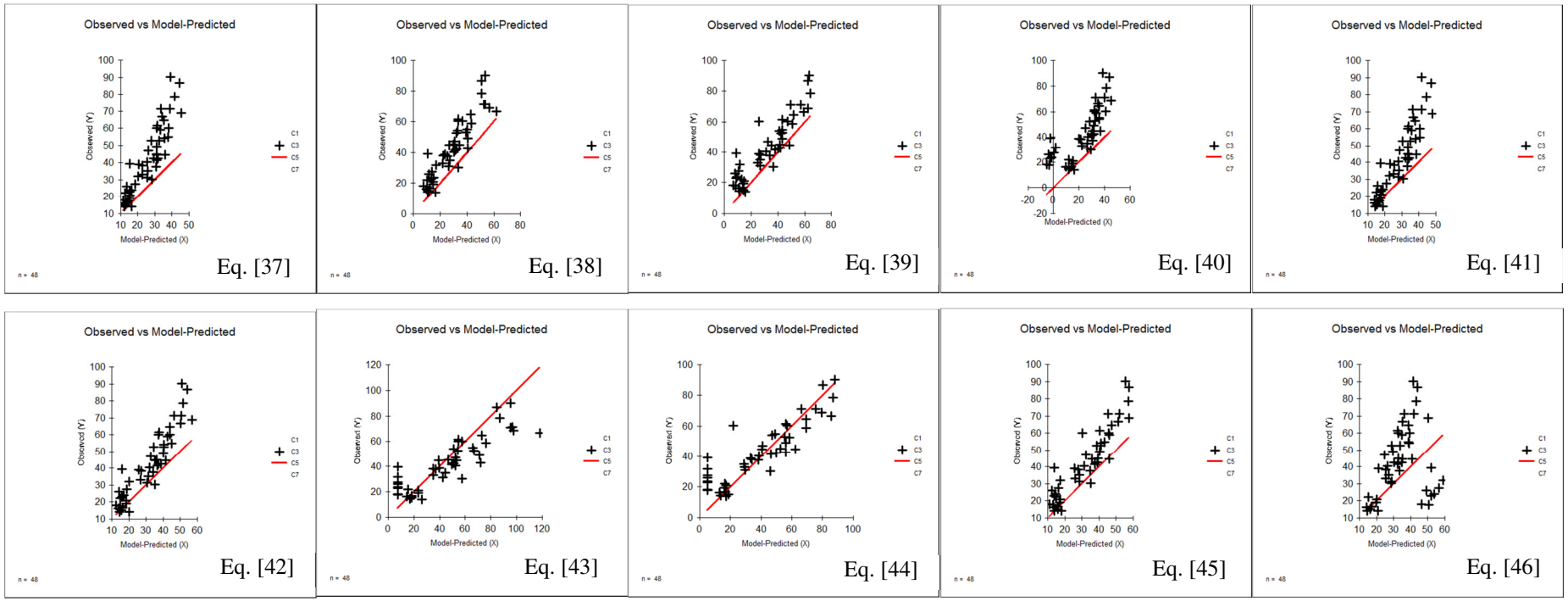

Figure 7 - Relationship among observed and model-predicted values for carcass chemical fat (kg) as devised by Fernandes et al. (2010), Eqs. [37], [38], [39], and [40]; and De Paula et al. (2013), Eqs. [41], [42], [43], [44], [45] and [46].

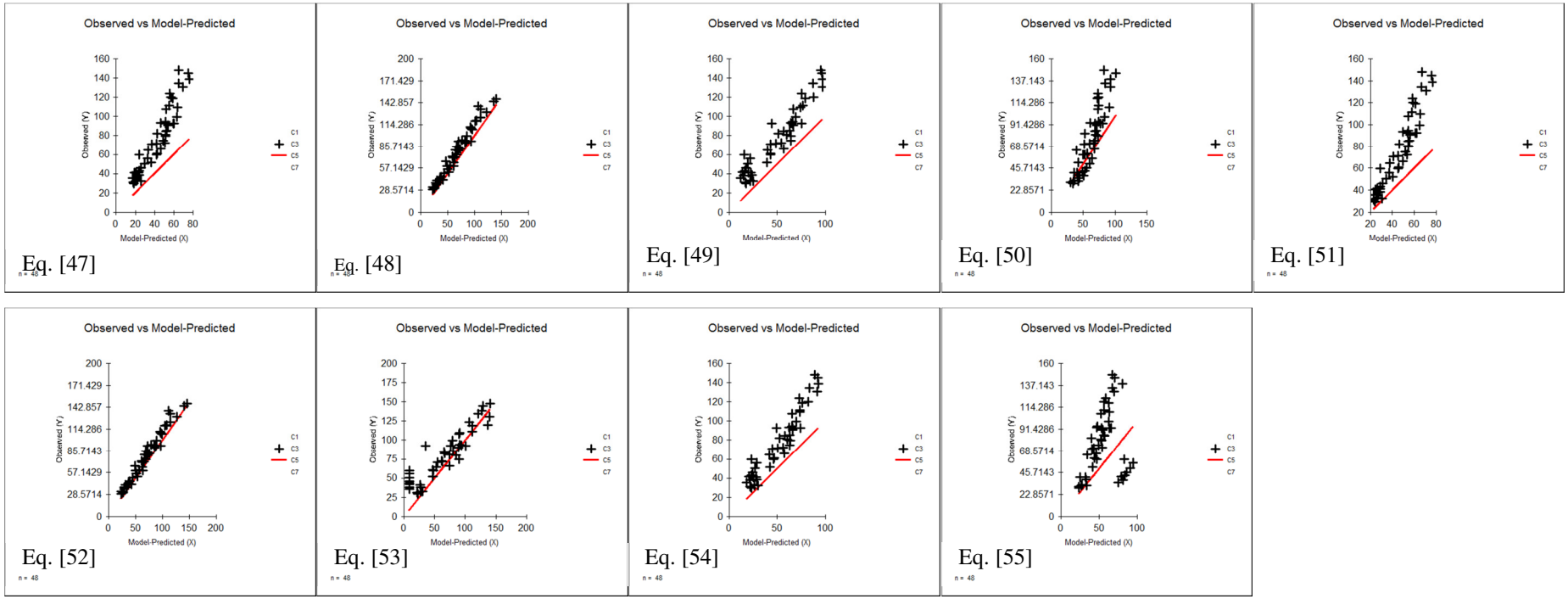

Figure 8 - Relationship among observed and model-predicted values for empty body chemical fat (kg) as devised by Fernandes et al. (2010), Eqs. [47], [48], [49], and [50]; and De Paula et al. (2013), Eqs. [51], [52], [53], [54], [55] and [56].

Chapter V

Biometric measurements: a tool to assess body fat composition in beef cattle[1]

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ABSTRACT: This study was conducted in attempt to assess the body and empty body fat physical and chemical composition through biometric (BM) and postmortem measurements taken in 40 F1 Nellore x Angus bulls (B) and steers (S). The animals used had 12.5±0.51 mo of age, and average shrunk BW (BW) 233±23.5, and 238±24.6 kg for B and S respectively. Animals were fed 60:40 ratio of corn silage:concentrate. Eight animals were slaughtered at the beginning of the trial and the remaining animals were randomly assigned in a factorial 2 (genders) x 3 (slaughter weights) arrangement. The remaining animals were slaughtered when the average BW of de group reached 380 (6B and 5S), 440 (6B and 5S), and 500 kg (5B and 5S). Before the slaughter, the animals were lead through a squeeze chute in which BM were taken, including hook bone width (HBW), pin bone width (PBW), abdomen width (AW), body length (BL), rump height (RH), height at withers (HW), pelvic girdle length (PGL), rib depth (RD), girth circumference (GC), rump depth (RuD), body diagonal length (BDL), and thorax width (TW). Additionally, post mortem measurements were included: total body surface (TBS), body volume (BV), subcutaneous fat (SF), internal fat (InF), intermuscular fat (ImF), carcass physical fat (CF), empty body physical fat (EBF), carcass chemical fat (CFch), empty body chemical fat (EBFch), fat thickness in the 12^{th} rib (FT), and 9 – 11^{th} rib section fat (HHF). The equations were developed using a stepwise procedure to select the variables that should enter in the model. The r^2 and root mean square error (RMSE) were used to account for precision and accuracy. For TBS r^2 ranged from 0.852 to 0.946 and RMSE from 0.06 to 0.100 kg; for BV r^2 ranged from 0.942 to 0.998 and RMSE from 0.004 to 0.022 kg; for SF r^2 ranged from 0.767 to 0.997 and RMSE from 2.70 to 3.24 kg kg; for InF r^2 ranged from 0.816 to 0.900 and RMSE from 3.04 to 4.12 kg; for CF r^2 ranged from 0.830 to 0.988 and RMSE from 3.44 to 8.39 kg; for EBF r^2 ranged from 0.861 to 0.998 and RMSE from 2.98 to 10.98 kg; for CFch r^2 ranged from 0.825 to 0.985 and RMSE from 5.96 to 8.46 kg; and for EBFch r^2

ranged from 0.862 to 0.992 and RMSE from 5.54 to 12.19 kg. Our results indicated that there BM could be used to either increase the goodness of fit or as alternative to predict the different fat depots of confined F1 Nellore x Angus bulls and steers.

Key Words: carcass composition, carcass prediction, empty body composition, empty body prediction, modeling

INTRODUCTION

As every empirical process to assess body chemical and physical composition of cattle through the use of information obtained in vivo, some difficulties associated within Techniques and measurements still limit their applicability. One feasible measurement to be obtained is BW; therefore it has been widely reported in animal's growth rates determinations, and also as predictor of body composition (Lawrence and Fowler, 2002). Some other measurements had been used in attempt to increase the precision of the prediction equations while using BW as an independent variable (Brody, 1964; De Paula et al., 2013; Fernandes et al., 2010a). In addition, body fat has been shown as one of the most variable components in the body or carcass and hence, the most difficult to predict (Jone et al., 1978; Owens, 1995; Bonilha et al., 2011).

Changes in body composition should be taken into account while analyzing the development of body physical and chemical composition. Some equations had been developed (Byers, 1979; Clark et al., 1976; Crouse and dikeman, 1974; Hankins and Howe, 1946; Hooper, 1944; Kraybill et al., 1952; Powell and Huffman, 1973) to do so and are still being used despite of the likelihood to have limited application nowadays due to important changes in the potential growth of the animal. If potential growth is affected nutrient requirements might be affected towards the same direction. Thus alternative methods that can estimate body composition without sacrificing the entire

carcass are important because they save time, labor (Marcondes, 2010) and improve the predictability of the questions asked by either research or industry.

The objectives within this study were (1.) to develop prediction equations for carcass and body fat compositions using BM, (2.) to determine the relationships between BM and carcass and empty body fat compositions of crossbred animals under feedlot conditions, and (3.) to analyze the distribution of fat depots in the body.

MATERIALS AND METHODS

Humane animal care and handling procedures of the Federal University of Viçosa (Brazil) were followed in this research.

Location, animals, and diet composition. The data were obtained at the Federal University of Viçosa, Brazil, between December of 2009 and August of 2010. Forty F1 Nellore x Angus bulls (B) and steers (S), with initial age of 12.5±0.51 mo, and shrunk BW (**SBW**) of 233±23.5, and 238±24.6 kg for B and S, respectively were utilized. The trial was conducted in a 2 x 3 factorial arrangement of treatments (two genders and three slaughter weights). The animals were randomly assigned into four slaughter-weight based groups: baseline, 380, 440 and 500. The baseline group was slaughtered at the beginning of the trial (4B and 4S). The other groups were slaughtered when the group of animals reached an average BW of 380 (6B and 5S), 440 (6B and 5S), and 500 kg (5B and 5S). The animals were housed in individual pens covered with concrete floors, and provided with feeders and concrete bunks placed in a total area of 30 m^2, of which 8 m^2 were sheltered. The diet was formulated according to Valadares Filho et al. (2006) to contain 11% CP. Animals were fed 60% corn silage and 40% concentrate, containing corn, soybean meal, urea, ammonium sulfate, sodium chloride, limestone, and mineral mix. The animals were fed twice daily (at 600 and 1600) as a total mixed ration, and the intake adjusted to maintain orts in a ratio of 5 to 10% of the offered as fed diet. Water was permanently available.

Biometric measures. The BMs were taken the precedent day of each slaughter, along with weighing, to obtain the full BW (**FBW**). The same technician was responsible for all BMs taken during trial. Animals were properly adapted to the squeeze chute before the experiment had started. Once in the squeeze chute, each animal was erectly positioned and the BMs were taken using specific anatomical locations as baseline points for its determination. The positions of each measurement point were determined by hand palpation as recommended by (Fisher, 1975). The BMs were adapted from Fischer (1975), (Lawrence and Fowler, 2002), (Fernandes et al., 2010a), and (De Paula et al., 2013); and taken with the aid of a large caliper (Hipometro type Bengala with two bar, Walmur, Porto Alegre, Brazil) and a graduated plastic flexible tape. Measurements included were hook bone width (**HBW**) as the distance between the 2 ventral points of the tuber coxae (large calipers); pin bone width (**PBW**) as the distance between the 2 ventral tuberosity of the tuber ischia (large calipers); abdomen width (**AW**) measured as the widest horizontal width of the abdomen (paunch) at right angles to the body axis (large calipers); body length (**BL**) as the distance between the dorsal point of the scapulae and the ventral point of the tuber coxae (tape); rump height (**RH**) as measured from the ventral point of the tuber coxae, vertically to the ground (large calipers); height at withers (**HW**) measured from the highest point over the scapulae, vertically to the ground (large calipers); pelvic girdle length (**PGL**) as the distance between the ventral point of the tuber coxae and the ventral tuberosity of the tuber ischii (large calipers); rib depth (**RD**) measured vertically from the highest point over the scapulae to the end point of the rib, at the sternum (large calipers); girth circumference (**GC**) taken as the smallest circumference just posterior to the anterior legs, in the vertical plane (tape); rump depth (**RuD**) measured as the vertical distance between the ventral point of the tuber coxae and the ventral line (large calipers); body diagonal length (**BDL**) measured as the distance between the ventral

point of the tuber coxae and the cranial point of shoulder (tape); and thorax width (**TW**) the widest horizontal width across shoulder region, at the back (large calipers).

Slaughter. The animals were fasted for 16h before the slaughter to account for the Shrunk BW. Animals were stunned with a non-penetrating compressed air pistol and killed by bleeding using conventional humane procedures. Blood was weighed and sampled (about 340 g) for posterior laboratory analysis. All the body constituents were cleaned and weighed: internal organs (lungs, heart, kidneys, trachea, liver, reproductive tract, and spleen), digestive tract (rumen, reticulum, omasum, abomasum, and small and large intestines), KPH, visceral fat, tongue, tail, hide, head, limbs, and carcass. Empty BW (**EBW**) was computed with the summation of all body constituents. Viscera and organs were ground together immediately after slaughter, sub-sampled, and frozen. Similarly, hide, head, and limbs (1 anterior and 1 posterior) were sampled and frozen, freeze dried and stored for subsequent laboratorial analyses. Internal physical fat (**InF**) was calculated by the summation of KPH and the visceral fat.

Volume and total body surface. The body volume (**BV**) was measured using a cylindrical, iron-made, barrel filled with tapped water. At the moment that each animal was stunned, it had the body lifted and submerged into the barrel with the head remaining outside the water. A translucent hose within a measure tape attached inside was tightly and vertically connected to the outside of the barrel and used as communicating vessels which allowed the measurement of the water displacement by the animal's body immersion into the barrel. Then, the BV was computed using the distance of the water displaced and the radius of the water tank. The total body surface (**TBS**) was determined by adapting the method described by Brody and Elting (1926), and as recently described by Fernandes et al. (2010) and De Paula et al. (2013), as follows: the TBS was measured immediately after slaughter and the removal of the hide, which was completely extended over a 2 x 2 cm gridded banner, 3 x 3 m

dimension, in which the coordinates (X, Y) of the hide borders were taken and the area was computed using regular integration process. Additionally, for comparison purposes, a second method was used to determine TBS which consisted of marking a 20 x 20 cm on the hide of the live animal located on the top and back left region of the body, respecting a ratio of 1:2 of shaded to non-shaded hide area as described by Fernandes et al. (2010). The reason for the ratio should be related to possible variability in the hide's thickness. After the animal was killed, the marked area was extracted from the properly removed hide and the TBS was calculated by extrapolating the ratio of area:weight of the marked sample (400 cm^2) and the full hide.

Dissections. The individual carcasses were separated into two identical longitudinal halves. The half carcasses were weighed hot and chilled at -1° C. After 24-h chill, the carcasses were re-weighed to obtain the chilled carcass weight before the dissections. A section of the rib was obtained by sawing the area between the 9^{th} and 11^{th} rib from the left carcass as described by (Hankins and Howe, 1946), and then dissected into bone, muscle, and fat (**HHF**), and properly weighed. The fat thickness (**FT**) was obtained at the 12^{th} rib in the same left half carcass. The rest of the left half carcass was dissected and weighed as subcutaneous fat (**SF**), intermuscular fat, muscle, and bone; and then summed with the 9^{th}-11^{th} rib section weight and composition to account for the full left half carcass. All components were weighed and sampled to determine chemical composition. The intermuscular fat and SF were summed to represent the total carcass physical fat (**CF**). The EBF was calculated by summing InF and CF weights.

Laboratory analyses. Except for blood samples, which were dried at 60°C for 72 h, all other samples were freeze dried for 72 to 96 h and partially defatted by washing them with petroleum ether in a Soxhlet extractor apparatus for approximately 6 h (Fernandes et al., 2010). The fat extracted was computed by weight difference. All

samples were ground using a ball mill (TE350, Tecnal, Piracicaba, Brazil) and analyzed for ether extract and DM. The remaining fat was extracted in a XT15 extractor (Ankom, Macedon - NY, 14502) using XT4 filter bags as suggested by (AOCS, 2009) utilizing petroleum ether. The total chemical fat content was assessed by the summation of the two extractions, partial (Soxhlet) and definitive (XT15). The amount of carcass chemical fat (**CFch**) and the empty body chemical fat (**EBFch**) were estimated by multiplying each component weight by its fat content.

Model Development

Prediction of TBS and BV. The technique used to develop theoretical equations to predict TBS and BV was adapted from (Thompson et al., 1983) as cited by (De Paula et al., 2013), which considered that the animal's body has the shape of a cylinder and two parallel planes (base and top), beginning at the thorax and ending posterior junction of the buttocks. The TBS were computed as the surface and volume of the cylinder, respectively as shown in Eqs. [1] to [5]. Equation [1] is the sum of the lateral body surface (Eq. [2]) and the surface of the top and base of the cylinder (Eq. [3]). The radius of the body was calculated with the GC as shown in Eq. [4] and used to compute the BV as shown in Eq. [5].

$$TBS = LBS + Sbt \quad [1]$$

$$LBS = \frac{2\pi \times RB \times BL}{10^4} \quad [2]$$

$$Sbt = 2 \times \frac{(\pi \times RB^2)}{10^4} \quad [3]$$

$$RB = \frac{GC}{2\pi} \quad [4]$$

$$BV = \frac{\pi \times RB^2 \times BL}{10^6} \quad [5]$$

Where *TBS* is the total body surface, m^2; *LBS* it the lateral body surface, m^2; *BV* is the body volume, m^3; *RB* is the radius of the body, cm; *Sbt* is the base and top (parallel planes) surface area, m^2; $\pi = 3.1416$; and *BL* is the body length.

The predicted values of TBS or BV were regressed on the observed TBS or BV to adjust for body parts the TBS and BV equations were not able to take into account. In addition, other empirical equations to predict TBS and BV were developed using SBW and BM.

Predictions of fat depots: subcutaneous, carcass, and body. Equations were developed using information either obtained in vivo (e.g. SBW) or post mortem. The equations development was done in steps. In each step, variables associated with the deposition of SF, InF, CF, and EBF were included in the statistical model. These variables were included in the model either to adjust the variation not explained by SBW alone or to give an alternative source of estimation when difficulties in taken the measurements are limiting information availability. First, several equations were developed for all dependent variables using SBW as the only predictor (Eq. [7], [10] in Table 3; Eq. [12], [17], [21], [26] in Table 4; Eq. [32], [40] in table 5). Next, each fat depot was analyzed in its ability to be predicted whether by HHF inclusion or through BMs. When investigated the possibility of using the BMs, if so, that was combined within SBW in attempt to increase the equations power of prediction. SF predicted (**SFp**) could, theoretically, be obtained by the multiplication of the TBS by the FT and body density (Bieber et al., 1961); as devised by De Paula et al. (2013). The SFp was then first used to predict SF (Eq. [13] in Table 4). Then the HHF was used as the only independent variable to estimate SF (Eq. [14] in Table 4). Along was tested the ability to predict SF using only BMs (Eq. [15] in Table 4), and finally BM and SBW were used together in attempt to increase both predictions while done alone (Eq. [16] in Table 4). The InF models were also adjusted to use HHF along with BMs (Eq. [18] in Table 4), BMs by itself (Eq. [19] in Table 4) or SBW along BMs (Eq. [20] in Table 4). The CF was assessed by use of HHF along with SBW (Eq. [22] in Table 4) or BMs (Eq. [23] in Table 4), BMs by itself (Eq. [24] in Table 4) or SBW along with SF (Eq.

[25] in Table 4). The EBF models were adjusted to use either CFp (Eq. [27] in Table 4) or HHF (Eq. [28] in Table 4) alone, or the combination of HHF and SBW (Eq. [29] in Table 4). Furthermore, another 2 models were developed to estimate EBF which took into account the BMs by itself (Eq. [30] in Table 4) or SBW along BMs (Eq. [31] in Table 4). The CFch models were adjusted to be used either with single predictors SF (Eq. [33] in Table 5) and HHF (Eq. [34] in Table 5), or with the combination of predictors: BMs (Eq. [35] in Table 5), SBW and SF (Eq. [36] in Table 5); SBW along HHF (Eq. [37] in Table 5); HHF along with BMs (Eq. [38] in Table 5); and SF along BMs (Eq. [39] in Table 4). Finally, the EBFch models were also adjusted to be used either with single predictors CFch (Eq. [41] in Table 5) and HHF (Eq. [42] in Table 5), or with the combination of predictors: SBW and SF (Eq. [43] in Table 5); SBW along HHF (Eq. [44] in Table 5); BMs (Eq. [45] in Table 5); SBW along with and BMs (Eq. [46] in Table 4) and HHF along with BMs (Eq. [47] in Table 5).

Statistical Analyses and Model Evaluation

Statistical analyses. Statistical analyses were performed using SAS (SAS Inst. Inc., Cary, NC). Descriptive statistics were obtained with PROC MEANS and Pearson correlation coefficients among variables were obtained with PROC CORR to decide which variables could be used to explain variation of fat depots. Linear regressions were developed to estimate TBS, BV, physical SF and InF, and physical and chemical CF and EBF with PROC REG. The STEPWISE and Mallow's Cp options were used in PROC REG to determine significant ($P < 0.05$) variables to be included in the statistical models. Outliers were tested by plotting the studentized residual against the statistical model-predicted values. Data points were removed if the studentized residual was outside the range of −2.5 to 2.5. All interactions among variables and their quadratic effects were evaluated and removed from the statistical model if they were

not significant at $P < 0.10$.The goodness-of-fit of the regression was assessed by the root of the mean square error (**RMSE**) and the r^2.

Model evaluation. The comparison of observed and predicted TBS, BV, and SF were realized using the concordance correlation coefficient (CCC) and the root of the mean square error of the prediction (RMSEP) as discussed by (Tedeschi, 2006). The accuracy for these comparisons was obtained by comparing the Cb statistic as reported by (Lin, 1989).

RESULTS AND DISCUSSION

Descriptive Statistics and Correlation Analyses

Table 1 presents the descriptive statistics of these present dataset. The animals were contemporaries and came from the same heard bringing a high homogeneity to the groups at the time of the random distribution. The animals were about 12 months old at the beginning of the trial and reached up to 19 months old at the last slaughter group (500 kg). Due to experimental design the range of weights was from 230 to 600 kg, similar to Fernandes et al. (2010) and heavier than De Paula et al. (2013). The average ratio between EBW and SBW was 0.909, not too distant from what has been reported, 0.891 by (NRC, 2000), 0.896 by (Valadares Filho et al., 2006) and (Valadares Filho et al., 2010). That is probably due to small fill influence (Berg and Butterfield, 1976) from a regular diet (60% roughage) and the young animals slaughtered as baseline group at the beginning of the trial. The average carcass yield or dressing percentage (DP) was 56.74% which is similar to observed values reported in the literature (Berg and Butterfield, 1976; Marcondes, 2007; Paulino, 2006). The reason lies on the dressing procedure itself since if KPH, which is removed in Brazil, is added at the end of the calculations it will increase the DP in up to 2.5% with values going high as 61.25%. The empty body fat content in the empty body of the animals were high as twice the amount reported for grazing animals, as well for the chemical contents. The distribution

within depots was similar to those reported in the literature (Fernandes et al., 2010; De Paula et al., 2013). The amounts in kg of fat a lot higher than those for grazing animals but while the proportion is compared the behavior patterns seems to maintain.

The correlations between BM and physical and chemical characteristics were significant ($P<0.01$), as well for BV and TBS (Table 2). The high correlations could be interpreted as the proximity of the allometric growth of the body. In other words, represent whether the measurements are increasing at the same moment. That could be a good indicator of the possibility of using BMs to predict growth rates in cattle. Corroborating with the Literature HHF presented very high correlations among analyzed variables indicating its importance on the prediction equations. Among BMs HBW, RD, GC, AW and TW presented the highest correlations indicating its importance in explaining the body composition, especially within SBW as exemplified by GC, 9-11th Rib section (RD) and hindquarter length (AW, and HBW) . Among all, only HW did not present high correlations with the variables analyzed which was attributed to a small variation in height, characteristic of Angus and Angus descendant animals which grow more horizontally that vertically.

Equations to Predict TBS and BV

Equations developed to predict TBS and BV are listed in Table 3. The TBS and BV developed with Eqs. [6] and [9], respectively, were based on the hypothesis that the body of an animal has the shape of a cylinder.

Predicting TBS. Eq. [6] was efficient in predicting the observed TBS, although presented a significant intercept. The Eq. [6] suggests that if a variation in TBS occurs, about 33.95% of it will reflect as variation in the cylinder's surface. Also about 35 to 70% of the body surface will be accounted as head and limbs and the rest of the variation will reflects in the cylinder area. De Paula et al. (2013) stated that about 57% of the cylinder's area would be heads and limbs. Table 3 suggested an average high

precision (r^2 of 0.85), high accuracy (Cb of 0.997), therefore a high reproducibility index (CCC of 0.921). Despite of the model's underestimation, the MSEP partitions show that almost 100% of the error is random and a small RMSE with only about 4.93% of the variation related to the observed mean this underestimation. Eq. [7], working only with SBW as independent variable, did increase the precision (r^2 of 0.924) of the estimate and decrease the RMSE which represented about only 3.5% of the observed mean values. Eq. [8] combined BMs (TW) with SBW in attempt to increase the power of prediction. An overprediction was observed, though the model presented itself as highly accurate (Cb of 1) and with an increased precision (r^2 of 0.95). The partition of the errors showed a smaller RMSE and a reduction in its ratio compared with the average observed values. Thus, the results indicated the use of Eq. [8] might be a better predictor of TBS than the assumption that the body has shape of a frustum or a cylinder as previously suggested by Fernandes et al. (2010) and De Paula et al. (2013). It has been observed in the literature that the combination of SBW and BMs have successfully increased the goodness of fit of those equations (Brody and Elting, 1926; De Paula et al., 2013; Fernandes et al., 2010a; Pani et al., 1976)

Predicting BV. The Eq. [9] in Table 3 was developed to predict BV by assuming the animal's body has a shape of a cylinder. The Eq. [9] in Table 3 was able to explain approximately 94% of the variation of the observed BV with a small RMSE of 0.0228 m^3, in which the error's partition had shown over 96% as random component responsibility and only about 8.78% of the observed mean as the ratio of RMSEP and Y. Despite of that the model [9] underpredicted the estimation of BV, presented high accuracy (Cb of 1.00) and high reproducibility index (CCC of 0.94). Interesting to observe that while BMs were combined with HHF (Eq. [11] in Table 3), the prediction presented similar precision and accuracy showing that Eq.[11] could be used as an alternative rather than substitute. When SBW was taken into account alone (Eq. [10] in

Table 3) an increase of precision was observed (r^2 of 0.998), followed by a higher accuracy and reproducibility index (1.00 and 0.99 respectively) bringing the RMSEP down to a fraction of 3.6% of the observed mean values. It does appear that there is a strong relationship between BV with SBW which may be linked to small variations in body density; regardless of the fat content it seems that there is a pattern of tissue distribution of these animals, especially within trials.

It seems that SBW is the best variable to explain variation in BW and could be used alone to predict the BV. It is possible though to use BMs along with HHF or the TBS of the cylinder, although it does not increase the goodness of fit of the models.

Equations to Predict Subcutaneous Fat, Internal Fat, and Carcass and Empty Body Fats

Equations developed to predict TBS and BV are listed in Table 3. The TBS and BV developed with Eqs. [6] and [9], respectively, were based on the hypothesis that the body of an animal has the shape of a cylinder.

Predicting subcutaneous fat. A large portion of the variability of SF (Eq. [12] in Table 4) was accounted for by SBW (r^2 = 0.812). Fernandes et al. (2010) and De Paula et al. (2013) also reported a high precision (0.827 and 0.839 respectively) in predicting SF when SBW was the only predictor of SF. As SBW increased, SF increased by 58 g SF/kg SBW in our study while Fernandes et al. (2010) reported a relationship of 40 g/kg and De Paula et al. (2013) reported a relationship of 22 g SF/kg SBW. This difference is likely related to animal variation and nutritional planes (Wright and Russel, 1984) and gender (Berg and Butterfield, 1976). The precision in predicting SF using the theoretical equation (Eq. [13] in Table 4) was high intermediate (r^2 = 0.77 and RMSE = 3.24 kg). Around 86% of the error was random, although a high fraction of the error, about 26.7% of the RMSEP, lay on the ratio between it and the average mean of the observed values. Despite of the the model was accurate (Cb of

0.97) and presented a good reproducibility index (CCC of 0.85). Among with this two equations Eq. [15] (Table 4), which used only BM for the predictions, presented similar precision (r^2 of 0.83 and RMSE = 2.70 kg), accuracy (Cb of 0.98) and reproducibility index (CCC of 0.83). Those allied with the fact that main component of the error is random and about 30% of the RMSEP, lay on the ratio between it and the average mean of the observed values, and indicate the similar goodness of fit of these three models. An improvement could be observed when SBW was used along with BDL (Eq. [16] in Table 4); as well when HHF was used as a single predictor (Eq. [14] in Table 4). Both equations presented a reduced RMSE (2.7 and 2.84 kg for Eq. [14] and Eq. [16], respectively) maintaining the same proportion (Eq. [16] in Table 4) or slightly less (Eq. [14]) of random component, and RMSEP proportion to the average observed mean. Eq. [14] presented an even better accuracy (Cb = 1.00) and reproducibility index (CCC = 0.93) when compared to Eq. [16] (Cb = 0.97 and CCC = 0.83).

In general SF is quite difficult to predict since it has a lot of implicit variation in its amount of deposition and partition of it. Variations in the distribution of SF of age, e. g. young animals seem to be difficult to predict because of the small amount of this tissue; plane of nutrition, tissue mobilization followed by compensatory growth, gender, hormone activity and so forth and so on . It seems that the amount of tissue mobilized in a starvation situation is the same for the different depots because what it matters at the time is the amount of energy generated by tissue catabolism. Although it varies while analyzing its proportions since some tissues are more representative than others in the carcass or empty body.

Predicting internal fat. Equations [17] to [20] in Table 4 were developed to estimate the internal fat content in the animal's body, which comprised the visceral fat plus KPH. The Eq. [17], Table 4, was based only on SBW and had an r^2 of 0.82 and RMSE of 4.12 kg. The Eq. [20], Table 4, included HBW and BL to explain the

variation in the InF not account for by SBW alone. Indeed, the inclusion of the BMs improved the precision of the prediction (r^2 of 0.89 and RMSE of 3.27 kg). Then an alternative Eq. [19] was fitted in attempt to estimate the InF only through BM (HBW and AW). The equation presented similar precision (r^2 of 0.82) and slightly smaller RMSE (3.27 kg), with about 20.67% of the value of observed average mean being RMSEP. Also Eq. [19] presented high accuracy (Cb of 0.996) and reproducibility index (CCC of 0.91). (Holloway et al., 1990) reported that ultrasonic measurement at the rib was important to predict the percentage of body fat in the viscera and the measurement over the rump was important to predict the percentage of body fat in the KPH. Therefore the BMs selected by the stepwise corroborated with the assumption.

Predicting carcass fat. Equations to predict CF are shown in Table 4 (Eq. [21] to [25]. All equations had high r^2 values ranging from 0.83 to 0.99. The portion of the variability of the CF that was accounted for by SBW was 0.83, given then a possibility of increment in predictability (Eq. [21]). This equation had shown that for each kg incremented in the BW, about 173g would be deposited as carcass fat. For the sake of proportioned an alternative option of prediction, an equation using HHF (Eq. [22] in Table 4) was fitted since the cutting of the 9-11th Rib section been quite common in research procedures (Bonilha et al., 2011; Tedeschi et al., 2004) and it is a feasible measurement to be obtained . It was observed an increase of the model's precision (r^2 = 0.984) along with its accuracy (1.00 compared to the former 0.99) and reproducibility index (0.96 against to the former 0.91). The RMSE, represented mainly by the random component was around 13.8% of the observed average CF (Eq. [22] in Table 4). Then an equation that combined HHF and AW (Eq. [23] in Table 4), was adjusted and it maintained similar high standards of goodness of fit (r2 = 0.988, Cb = 0.999, CCC = 0.956, RMSE = 3.64 kg representing the same 14% of the average observed CF amount). Also an equation combining only BMs was fitted (Eq. [24] in Table 4) and the

results were similar to Eq. [21] with an r^2 of 0.87, an RSME of 8.40 kg, and a nearly identical Cb of 0.99 and CCC of 0.91. The last equation adjusted to predict CF was using again SBW but along with SF to increase the prediction (Eq. [25] in Table 4). The equation assumes that SBW affects CF in a rate of 7.6% of its value. A possible constraint in using this equation would be the difficulty in predict accurately the amount of SF due to a lot of possible factor influencing its pattern of deposition make tis last equation more indicated while SF is actually measured. Although, Eq. [25] (Table 4) presented one of the best goodness of fit among the equations developed to predict CF. A r^2 of 0.98 and RMSE of 3.78 kg, which represents only about 9% of the average observed value of CF. Furthermore, the model was highly accurate (Cb of 1.00) and presented a high reproducibility index (CCC of 0.98) . This suggested that the SF can be a good predictor of the variation in CF and can be used to explain the variation not accounted for by SBW alone. (Holloway et al., 1990) reported that GC is an important BM variable to explain variation in the distribution of fat, being related to all depots, except percentage of total EBF in soft tissue. Fernandes et al. (2010) also reported a better prediction of CF when BMs were included in the model, specifically AW. De Paula et al. (2013), found that RD and GC were affecting the most the CF prediction. Our results suggest that both RD and AW can be used while combined with HHF or HBW, respectively (Eqs. [23] and [24] in Table 4). Therefore, these results suggested that BM obtained in the live animal might be useful in the prediction of CF.

Predicting empty body fat. Equations developed to predict EBF are shown in Table 4 (Eq. [26] to [31]). Similar to the equations developed to predict CF, all the equations to predict EBF had a high r^2 (> 0.85%), probably because carcass itself represented, in average, 62.7% of the EBW and CF corresponded, in average, to 68% of the EBF. The Eq. [26] in Table 4 used only SBW as the estimator of EBF and it accounted for approximately 86% of the variation of EBF. Therefore, SBW is also the

single important variable for estimating EBF. This equation estimated an increase of 269 g of EBF for each kg of SBW. De Paula et al. (2013) observed an amount of 113 g/ kg of increased SBW, while Fernandes et al. (2010) observed 142 g/kg of the same ratio. Such information confirms the marked existent difference between different planes of nutrition and among breeds regarding the fat deposition and content in the animal's body. The difference between 269 g of EBF per kg of SBW estimate by Eq. [26] (Table 4) and the 173 g of CF per kg of SBW (Eq. [21]) should be close to the 87 g of InF per kg of SBW as shown in Eq. [17] (Table 4), discounted the standard errors of the parameters. The actual estimation is 96 g InF/kg of SBW.

The inclusion of CFp to predict EBF (Eq. [27] in Table 4) significantly increased the precision (r^2 = 0.998 and RMSE = 2.98). It is interesting that each kg increased in the EBF means that about 68% of it is responsibility if an increased in the CF which corroborates exactly with the proportion of the EBF explained by CF. Eq. [27] was highly accurate (Cb of 1.00) and presented a high reproducibility index (CC of 0.99).

The next step followed the same idea of CF's prediction by adding HHF as a possible predictor, which was done either alone (Eq. [28] in Table 4) or along with SBW (Eq. [29] in Table 4). That actually did increase the ability to explain the variation observed on the present dataset (r^2 of 0.974 for Eq. [29] against r^2 of 0.861 for Eq. [26]). Both equations presented a very high accuracy (Cb > 0.998) and a high reproducibility index (CCC > 0.95). Also the amount of fat that varies at the HH depot is roughly 56 times, in average, the amount that would vary ate the EBF level. The observed values are (Table 1) also suggest that approx. 70% of empty body fat was deposited as EBFC and 30% as InF. These values are similar to those reported by (Ferrell and Jenkins, 1984), Fernandes et al. (2010), and De Paula et al. (2013).

The ability of prediction of the BMs was first investigated accounting its participation while alone (Eq. [30] in Table 4) or along SBW (Eq. [30] in Table 4). Eq. [30] presented an average high r^2 of 0.848 with a RMSE of 10.86 kg, which corresponds to a 20% amount of observed average value for EBF. Though the model was highly accurate (Cb = 0.987) and presented high reproducibility index (CCC = 0.91). Finally, Eq. [31], confirmed the increment in the goodness of fit of the Eqs. [26] and [30] that used either SBW or BMs alone, respectively. Its high precision (r^2 of 0.972), and combined: high accuracy (Cb of 0.997) and high reproducibility index (CCC of 0.924), summed to the fact that the equation did fail to reject the simultaneous test for the null hypothesis of an intercept of zero and slope of one, have supported its goodness of fit.

Development of Equations to Predict Chemical Fat in the Carcass and in the Empty Body

Predicting carcass chemical fat. Equations developed to predict CFch are shown in Table 5 (Eq. [32] to [39]). Similar to the previous equations, the SBW seemed to be the main variables in predicting CFch. In general, all equations developed to predict CFch had high r^2. The same steps were maintained in developing the equations. First of all, an equation that used only SBW (Eq. [32] in Table 5) was adjusted, bringing similar precision to those equations that used only SBW to estimate fat in the other body depots (r^2 of 0.83 and RMSE of 7.87). The Eq. [32] also presented high accuracy (Cb = 0.999), high reproducibility index (CCC=0.889). Eq. [32] says that about 176 g/kg of SBW is CFch , if you consider the average DP observed of 57%, it can be estimated an amount of 101 g/kg of SBW coming from carcass, which is in agreement with the 112g/kg on Eq. [36]. For the average SBW of 407 kg hereby observed, the amount of CFch estimated would be 41 kg which is close to the observed value of 45 kg. In a hypothetical scenario, if the three groups maintained the DP, the

weight difference of 60 kg (380, 440 and 500) between them, would indicate that those animals, in average, would alter around 6kg of chemical fat in the carcass or roughly 11 kg of CFch in the SBW for each group. The model estimate for those animals the amount of CFch would be of 40.43, 51.02 and 61.60 which would match with the observed amount of CFch of 39.70, 53.00 and 66.00. The main difference was for the 500 kg group that actually presented higher DP. The importance would be that the observed difference of CFch between groups would was actually 13kg.

The following step was to adjust equations that would use only SF (Eq. [33] in Table 5), HHF (Eq. [34] in Table 5), or BMs (Eq. [35] in Table 5) as independent variable to predict CFch. The three equations presented a high precision (r^2 of 0.825, 0.829 and 0.866, respectively) and a small RMSE (7.87, 8.46 and 6.66), representing up to 20% of the observed mean (Eq. [33] in Table 5). The equations were highly accurate (Cb > 0.992) and presented a high reproducibility index (CCC > 0.90). Furthermore, all the equations failed to reject the simultaneous test ofr the null hypothesis of zero intercept and slope a unity. In attempt to improve precision of Eq. [33], Eq. [36] was adjusted, and although could be an alternative for CFch estimation due to its high accuracy (0.994) and reproducibility index (0.928), it did not improve the precision of the estimates. Though, when SBW was combined with HHF (Eq. [37] in Table 5), it did increase the precision to about a r^2 of 0.983 maintaining a low RMSE (6.32 kg) and high accuracy (Cb = 0.998) and reproducibility index (CCC = 0.914).

Finally, another two equations were developed (Eq. [38] and (Eq. [39] in Table 5) to improve the precision of the previous Eq. [33] ad Eq. [34] which used SF and HHF, respectively; using BM to do so. Eq. [38] had improved Eq. [34] precision from 89.6% to 98.5%. Concurrent with precision, the accuracy (Cb from 0.992 to 0.998) and reproducibility index (CCC from 0.897 to 0.914) were increased as well. For Eq. [33], the improvement came along with Eq. [39] and the BMs that helped to explain the

variation observed in CFch while SF was considerate as the main independent predictor. An increase in precision from 82.5% to 90.4% was observed. Also, concurrent with precision, reproducibility index increased from 0.903 to 0.923) with accuracy been held constant and high. The main BMs influencing CFch were HBW and GC while used along with HHF, and RD and PGL while used along with SF.

Predicting empty body chemical fat. The equations developed to predict EBFch are shown in Table 5 (Eq.[40] to [47]). All equations had good fitness and accounted for more than 86% of the variation. The Eq. [40], [41] and [42] were adjusted to estimate the EBFch while using single independent variables as SBW, CFch and HHF. The equations were quite precise (r2 of 0.882, 0.972 and 0.928, respectively). Also all three equations were highly accurate (Cb of 0.999) and presented a good reproducibility index (CCC > 0.939). According to Eq. [40] about 311g/kg of SBW is EBFch. In other words, for a an animal, crosbred F1 Nellore x Angus, to present an average amount of 83.22 kg of EBFch in its body, as actually was observed in this database, the animal had to weight bout 409 kg which was quite similar to the 407 kg observed. Furthermore, the Eq. [40] supported by Eq. [32] assumes that the amounts of EBFch and CFch (-26.57/0.176 or 44.24/0.311) are negligible until the animal reaches a SBW of 140 to 150 kg which could be interpreted as the minimum SBW at which the animals should be maintained before weaning or supplementation starts. Supplementation would have a higher response since the fat deposition starts to be significant at this time, not compromising any aspect of its regular growth. Fernandes et al. (2010) reported an increase of 162 g of EBF/kg, and De Paula et al. (2013) an increase of 149 g of EBF/kg. The information that can come out of it is that Fernandes et al. (2010) animals started the significant fat deposition at about between 100 and 128 kg and De Paula et al. (2013) animals started at 68 to 76 kg. From this point forward both group of animals should been taken care in a sense to provide nutritional support

and allow potential growth to manifest. The implicit indirect information is that those equation were develop according the animals' body composition which reflects the genetic potential of breed, gender and plane of nutrition and as earlier it starts this fat deposition, earlier the supplement should take place since the regular diet might not suffice the desired growth rate. Since both authors worked with similar genetic groups, this difference might be associated with or within type or level of supplement offered and the forage quality due to rain or draught variation among years.

The Eqs. [41] (Table 5), used CFch as the only independent variable to estimate EBFch. It presented a high precision (r^2 of 0.972) and a small RMSE (5.54). Also, the equation was highly accurate (Cb = 0.999) and presented a high reproducibility index (CCC = 0.983). It could be understood as with CFch representing around 60% of the EBFch which indeed is really close by the observed value (55%) and the slope accounted for a average of 8.5% of the EBFch. Eq. [42] (Table 5) uses HHF instead, been precise in explain the variation observed in EBFch (r2 of 0.928).Also presented a high accuracy (Cb = 0.999) and presented a high reproducibility index (CCC = 0.939). Shrunk BW was combined with SF (Eq. [43] in Table 5), which despite of the fact of being precise, accurate and reproducible, did not improve the SBW prediction while used alone. Again SBW was combined with HHF (Eq. [44] in Table 5) which increased precision (r^2 = 0.924), accuracy (Cb = 0.999) and reproducibility index (CCC = 0.959). About that point forward the BMs were added to SBW (Eqs. [46] in Table 5), HHF (Eqs. [47] in Table 5) by itself (Eqs. [45] in Table 5). Despite of the fact that the equations were precise, accurate and reproducible, only Eq. [47] actually did improve the power of prediction of Eq. [40] (r2 = 0.945; Cb = 0.999; and CCC = 0.960). The main BMs influencing EBFch were HBW while used along with HHF, and RD and HBW while used alone.

In conclusion, our results suggested that BM can be used as a tool to predict TBS, BV, SF, InF, CF, EBF, CFch and EBFch, either alone or in association with SBW and other postmortem body characteristics which might increase the precision of prediction of confined F1 Nellore x Angus bulls and steers. Because of the changes in composition that might occur in the body due to breed, sex, age, and nutritional practices, the equations developed in this study are recommended to be used only under these conditions. Further studies should evaluate the use of these equations and BM under different production systems.

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Table 1 - Description statistics of the data

Item	N	Mean	Max	Min	SD
Age	40	16.08	19	12	2.4
		Body weight, kg			
Full	40	414.00	603.00	231.50	100.13
Shrunk	40	407.16	588.50	225.00	99.76
Empty	40	370.34	541.42	199.41	93.74
		Body characteristics			
Body surface, m^2	40	1.98	2.53	1.47	0.28
Body volume, m^3	40	0.38	0.55	0.21	0.10
Body density, kg/m^3	40	1076.75	1144.80	882.00	40.44
		Body components			
Carcass, kg	40	232.81	336.10	122.10	62.03
FT, cm	38	5.03	11.58	0.4	3.27
		Fat, kg			
Internal	40	18.88	37.61	4.05	9.63
Subcutaneous	40	6.61	15.64	1.03	3.67
Carcass	40	40.00	77.21	8.97	19.66
Empty Body	40	58.88	113.7	13.02	28.9
HH section	40	0.91	1.82	0.18	0.49
		Chemical fat, kg			
Carcass	40	45.85	90.22	14.02	20.24
Empty body	40	83.22	148.2	29.67	34.11
		Body measurements, cm			
Hook bone width	40	44.03	52.00	35.00	4.57
Pin bone width	40	29.30	37.40	22.00	3.86
Abdomen width	40	54.94	68.00	40.00	6.21
Body length	40	135.41	159.50	89.00	22.11
Rump height	40	130.43	139.00	120.00	4.50
Height at withers	40	123.30	138.00	15.50	18.27
Pelvic girdle length	40	45.58	55.00	36.00	4.40
Rib depth	40	66.21	82.00	53.00	7.31
Girth circumference	40	173.61	199.00	136.00	16.56
Rump depth	40	48.58	55.50	41.00	3.72
Body diagonal length	40	98.71	111.00	85.00	6.63
Thorax width	40	41.25	52.00	28.50	6.18

Table 2 - Pearson correlation coefficients among the variables utilized in the development of the equations[1]

	SBW	EBW	FT	InF	SF	CF	EBF	CFch	EBFch	HHF	TBS	BV	HBW	PBW	BL	RH	HW	RD	GC	AW	PGL	BDL	TW
SBW	-	0.998	0.889	0.906	0.848	0.923	0.930	0.905	0.936	0.890	0.962	0.989	0.909	0.715	0.893	0.610	0.512**	0.934	0.904	0.924	0.887	0.811	0.954
EBW		-	0.881	0.898	0.845	0.918	0.924	0.901	0.934	0.894	0.965	0.988	0.903	0.723	0.901	0.625	0.510**	0.931	0.907	0.916	0.886	0.822	0.956
FT			-	0.890	0.918	0.942	0.936	0.915	0.928	0.901	0.834	0.888	0.861	0.589	0.783	0.555	0.425**	0.894	0.786	0.808	0.822	0.757	0.867
InF				-	0.881	0.942	0.973	0.921	0.960	0.929	0.859	0.905	0.891	0.645	0.790	0.569	0.456**	0.850	0.813	0.865	0.862	0.725	0.883
SF					-	0.961	0.947	0.890	0.914	0.928	0.800	0.841	0.803	0.644	0.767	0.612	0.454**	0.832	0.782	0.782	0.791	0.726	0.822
CF						-	0.994	0.952	0.972	0.946	0.884	0.916	0.865	0.655	0.804	0.582	0.466**	0.889	0.847	0.857	0.834	0.761	0.880
EBF							-	0.954	0.981	0.953	0.887	0.925	0.885	0.660	0.810	0.586	0.469**	0.888	0.847	0.871	0.854	0.759	0.893
CFch								-	0.984	0.905	0.851	0.898	0.869	0.667	0.814	0.555	0.439**	0.881	0.805	0.812	0.842	0.794	0.871
EBFch									-	0.940	0.893	0.925	0.899	0.676	0.823	0.599	0.461**	0.889	0.846	0.848	0.864	0.791	0.908
HHF										-	0.849	0.892	0.839	0.618	0.779	0.608	0.447**	0.853	0.825	0.806	0.812	0.754	0.858
TBS											-	0.951	0.896	0.696	0.869	0.618	0.475**	0.908	0.892	0.882	0.873	0.754	0.948
BV												-	0.887	0.716	0.891	0.610	0.502**	0.929	0.892	0.910	0.877	0.811	0.934
HBW													-	0.694	0.866	0.556	0.453**	0.867	0.849	0.860	0.903	0.782	0.926
PBW														-	0.791	0.506	0.440**	0.630	0.717	0.685	0.704	0.630	0.718
BL															-	0.615	0.485**	0.908	0.835	0.839	0.903	0.876	0.890
RH																-	0.312**	0.602	0.524	0.572	0.615	0.549	0.578
HW																	-	0.476	0.478	0.590	0.446	0.314	0.524
RD																		-	0.841	0.856	0.869	0.818	0.900
GC																			-	0.840	0.783	0.776	0.867
AW																				-	0.830	0.706	0.894
PGL																					-	0.764	0.880
BDL																						-	0.781

[1] Correlations followed by no superscript indicate $P<0.001$.

**correlations with *P-value* between 0.001 and 0.05.

SBW is shrunk body weight, EBW is empty body weight, FT is fat thickness, InF is internal fat, SF is subcutaneous fat, CF is carcass fat, EBF is empty body fat, CFch is chemical fat in carcass, EBFch is chemical fat in empty body, HHF is section HH fat, TBS is total body surface, BV is body volume, HBW is hook bone width, PBW is pin bone width, BL is body length, RH is rump height, HW is height at withers, RD is rib depth , GC is girth circumference, AW is abdomen width, PGL is pelvic girdle length, , BDL is body diagonal length, and TW is thorax width.

Table 3 - Regression equations for predicting total body surface (TBS) and body volume (BV) [1]

#	Equations [2]	Statistics		
		n	RMSE	r^2
	Total body surface, m^2			
[6]	$TBS = 0.89838(\pm 0.007867^{***}) + 0.33951(\pm 0.02298^{***}) \times TBS_{cylinder}$	40	0.10341	0.852
[7]	$TBS = 0.99436(\pm 0.04926^{***}) + 0.00256(\pm 1.1759 \times 10^{-4***}) \times SBW$	40	0.07326	0.924
[8]	$TBS = 0.75066(\pm 0.10189^{***}) + 0.00184(\pm 3.3783 \times 10^{-4***}) \times SBW + 0.01312(\pm 0.00542^{*}) \times TW$	39	0.06248	0.946
	Body volume, m^3			
[9]	$BV = 0.06689(\pm 0.01311^{***}) + 0.9158(\pm 0.91858^{***}) \times BV_{cylinder}$	38	0.02280	0.942
[10]	$BV = -0.01182((\pm 0.00313^{***}) + 9.6 \times 10^{-4}(\pm 7.39 \times 10^{-6***}) \times SBW$	34	0.00453	0.998
[11]	$BV = -0.38922(\pm 0.06323^{**}) + 0.04549\ (\pm 0.01501^{**}) \times HHF + 0.00470(\pm 1.14 \times 10^{-3***}) \times RD + 9.5766 \times 10^{-4}(\pm 4.5789 \times 10^{-4*}) \times GC + 0.00451(\pm 1.23 \times 10^{-3***}) \times AW$	39	0.02200	0.949

[1] TBS is the observed total body surface, m^2; SBW is the shrunk BW, kg; HW is height at withers, cm; HBW is hook bone width, cm; RH is rump height; and BV is body volume, m^3. Values within parentheses are SE of the parameter estimate, and *, **, and *** indicate $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively.;RMSE is root mean square error.

[2] $TBS_{cylinder} = BLS_{cylinder} + Sbt$; $BLS_{cylinder} = 2\pi \times RB \times BL / 10^4$; $BV_{cylinder} = \pi \times RB^2 \times BL / 10^6$; $RB = GC / 2\pi$; $Sbt = 2 \times (\pi \times RB^2) / 10^4$; where $BLS_{cylinder}$ is lateral surface area, m^2; RB is radius of the body, cm; Sbt is base and top (parallel planes) surface area, m^2; $\pi = 3.1416$; and BL is body length, cm.

Table 4 - Regression equations developed to predict subcutaneous, internal, carcass and empty body physical fat [1]

#	Equations	Statistic		
		n	RMSE	r^2
	Subcutaneous fat, kg			
[12]	SF = -11.18801(±1.89620***) + 0.05781(±0.00455***) × SBW	38	2.81128	0.812
[13]	SF = 4.8788(±0.85396***) + 0.08281(±0.00737***) × SFp	39	3.24023	0.767
[14]	SF = 14.15103(±0.41974***) × HHF	39	2.70192	0.967
[15]	SF = -43.85944(±4.21482***) + 0.46246(±0.11835***) × RD + 0.46976(±0.14568**) × AW	37	2.70129	0.831
[16]	SF = 0.06442(±0.00576***) × SBW - 0.14071(±0.02434***) × BDL	38	2.83947	0.957
	Internal fat, kg			
[17]	InF = -16.7191(±2.77290***) + 0.08743(±0.00662***) × SBW	40	4.12373	0.816
[18]	InF = -27.0780(±7.30185***) + 11.92453(±1.81319***) × HHF +0.79717(±0.19571***) × HBW	40	3.04053	0.900
[19]	InF = -65.78786(±6.33111***) + 1.19649(±0.27867***) × HBW + 0.58235(±0.20513**)× AW	40	4.05772	0.822
[20]	InF = -40.12912(±7.83057***) + 0.07040(±0.01467***) × SBW+ 1.08230(±0.28939***) × HBW - 0.12549(±0.05568*) × BL	39	3.27467	0.887
	Carcass fat, kg			
[21]	CF = - 31.52247(±4.38786***) + 0.17322(±0.01058***) × SBW	38	6.44774	0.830
[22]	CF = -7.18645(±3.40523*) + 0.04725(±0.01381***) × SBW + 30.05248(±2.86083***) × HHF	36	3.44263	0.984
[23]	CF = -17.16076(±8.09374*) + 33.89318(±2.2393***) × HHF + 0.46882(±0.17766*) × AW	37	3.64072	0.988
[24]	CF = -131.65579(±13.16269***) + 1.62971(±0.59079***) × HBW + 1.50892(±36963***) × RD	40	8.39993	0.874
[25]	CF = -13.33679(±3.17561***) + 1.72069(±0.15796***) × SF + 0.07623(±0.01144***) × SBW	40	3.77966	0.981
	Empty body fat, kg			
[26]	EBF = -50.79258(±7.25296***) + 0.26936(±0.0731***) × SBW	40	10.78627	0.861
[27]	EBF = 1.47813(±0.01101***) × CFp	39	2.98501	0.998
[28]	EBF = 6.17034(±2.26500***) + 56.37593(±2.20346***) × HHF	38	6.53411	0.946
[29]	EBF = -13.53639(±4.63661**) + 0.08457(±0.01862***) × SBW + 41.36009(±3.83082***) × HHF	36	4.70583	0.974
[30]	EBF = -190.33396(±17.21913***) + 2.66169(±0.77070**) × HBW+ 1.98242(±0.47859***) × RD	39	10.86232	0.848
[31]	EBF = 0.27818(±0.01915***) × SBW – 0.41650(±0.06148***) × RH	40	10.98706	0.972

[1] SF is subcutaneous fat, kg; SBW is the shrunk BW, kg; BL is body length, cm; HW is height at withers, cm; PBW is Pin bone width, cm; RD is rib depth, cm; GC is girth circumference, cm; InF (internal fat) = KPH + fat visceral; CF is carcass fat; HHF is section HH fat, kg; EBF is empty body fat, kg; RMSE is root mean square error. Values within parentheses are SE of the parameter estimate, and *, **, and *** indicate $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively. Intercepts that were not different from zero were removed from the final equation;. SFp (subcutaneous fat predict, kg) = TBS × FT × 912 / 100, where BS is body surface, m^2 and FT is fat thickness, cm.

Table 5 - Regression equations to predict the carcass and empty body chemical fat [1]

#	Equations	Statistic		
		N	RMSE	r^2
	Carcass chemical fat, kg			
[32]	CFch = -26.57832(±5.34680***) + 0.17635(±0.01285***) × SBW	39	7.87046	0.831
[33]	CFch = 11.03675(±2.89406***) + 2.74138(±0.20448***) × SF	39	8.46439	0.825
[34]	CFch = 9.24595(±2.29708***) + 39.18126(±2.19905***) × HHF	39	6.66808	0.896
[35]	CFch = -124.58706(±11.16720***) + 1.48117(±0.50238**) × HBW + 1.58685(±0.31338***) × RD	38	7.04100	0.866
[36]	CFch = -14.25500(±5.72338*) + 0.11260(±0.002067***) × SBW + 1.06169(±0.29013***) × SF	39	6.81204	0.874
[37]	CFch = 0.04119(±0.00875***) × SBW + 31.16144(±3.50651***) × HHF	39	6.32431	0.983
[38]	CFch = 36.22536(±2.42635***) × HHF + 1.18618(±0.41119**) × HBW – 0.23176(±0.10276*) × GC	39	6.12624	0.985
[39]	CFch = -83.80479(±15.38547***) + 0.99235(±0.25591***) × SF + 1.03508(±0.30240**) × RD+ 1.05872(±0.45477*) × PGL	38	5.96851	0.904
	Empty body chemical fat, kg			
[40]	EBFch = -44.23711(±7.68119***) + 0.31118(±0.01847***) × SBW	39	11.30666	0.882
[41]	EBFch = 7.95763(±2.20494***) + 1.63143(±0.04460***) × CFch	39	5.54006	0.972
[42]	EBFch = 20.40204(±3.19200***) +67.66538(±3.05578***) × HHF	39	9.26590	0.928
[43]	EBFch = -22.86750(±7.92366**) + 0.19657(±0.02856***) × SBW + 2.01026(±0.39413***)× SF	40	9.43084	0.924
[44]	EBFch = 0.09081(±0.01110***) × SBW + 49.99575(±4.4559***) × HHF	39	8.01804	0.992
[45]	EBFch = -214.54508(±19.34077***) + 3.58432(±0.86318***) × HBW + 2.10080(±0.53683***) × RD	39	12.19488	0.862
[46]	EBFch = -103.10948(±27.55943***) + 0.23388(±0.04474***) × SBW + 2.06942(±0.97643*) × HBW	40	11.62225	0.884
[47]	EBFch = -55.21285(±19.73035***) + 51.00698(±5.03122***) × HHF + 2.06807(±0.53448***) × HBW	39	7.89448	0.945

[1] CFch is the carcass chemical fat, kg; SBW is the shrunk BW, kg; SF is subcutaneous fat, kg; HHF is section HH fat, kg; RD is rib depth, cm; EBFch is the empty body chemical fat, kg; RMSE is root mean square error. Values within parentheses are SE of the parameter estimate, and *, **, and *** indicate $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively. Intercepts that were not different from zero were removed from the final equation.

GENERAL CONCLUSIONS

Among the evaluated variables to study efficiency of animal production, all have indicated that bulls are more efficient than steers. Though, taking into account the point of view of biological growth, bulls rather than steers, could be explored, laying diet manipulation compensate for differences between fat proportions in the animals body.

Many factors can influence growth patterns such as age, type of animals, genetics, physiological maturity, sex, breed, level of feeding, and so forth, which opens discussions about to the applicability of the growth models. Frequent evaluations should be carried in order to identify whether or not these models still predict body changes accurately and precisely for the current and different realities. Overtime calibration and new models might be necessary in attempt to better predict body composition.

It is possible to define the growth pattern based upon the proportions that the animal body changes its shapes relating such differences to fat depots. Once established, mathematical models can be developed in order to provide a tool to simulate growth pattern of bovines optimizing its efficiency of production.

APPENDIX

Table 1 – Animal identification (AN), treatment (TREAT), shrunk body weight initial (SBWi), shrunk body weight final (SBWf), empty body weight initial (EBWi), empty body weight final (EBWf), cold carcass weight (CCW), cold carcass yield (CCY), fat thickness (FT), body fat initial (FATi), body fat final (FATf), body protein initial (PROTi), body protein final (PROTf).

AN	TREAT	SBWi	SBWf	EBWi, kg	EBWf, kg	CCW, kg	CCY, %	FT, cm	FATi, kg	FATf, kg	PROTi, kg	PROTf, kg
28	RFS	235.0	235.0	207.3	212.3	129.20	54.98	0.40	35.41	40.73	39.89	38.56
38	RFS	248.0	248.0	218.7	214.0	129.25	52.12	0.75	32.58	32.87	40.92	39.64
42	RFS	225.0	225.0	198.5	201.6	122.10	54.27	0.55	30.44	31.19	39.69	34.19
46	RFS	265.0	265.0	233.7	229.5	136.65	51.57	0.85	34.24	38.30	46.69	49.34
9	RFB	277.0	277.0	245.1	240.7	147.15	53.12	1.15	36.41	32.18	48.05	46.93
19	RFB	230.0	230.0	203.6	199.4	123.50	53.70	0.60	35.50	29.67	38.92	41.47
35	RFB	240.5	240.5	212.8	218.4	132.20	54.97	0.55	42.86	32.21	40.94	42.76
45	RFB	263.0	263.0	232.8	235.4	136.70	51.98	1.10	49.66	41.21	42.70	47.00
6	380S	275.0	436.0	242.6	392.4	247.35	56.73	7.70	37.54	94.48	47.26	69.57
14	380S	223.0	322.0	196.7	291.7	187.15	58.12	3.00	30.45	64.69	38.32	51.67
20	380S	231.5	376.0	204.2	345.5	225.55	59.99	5.30	31.61	71.30	39.78	59.26
26	380S	230.0	405.0	202.9	368.1	230.20	56.84	6.40	31.40	66.14	39.52	82.66
44	380S	242.0	382.0	213.4	354.9	225.15	58.94	3.80	33.04	82.32	41.59	62.24
3	380B	260.0	380.0	230.1	344.7	216.05	56.86	2.42	42.37	60.64	43.93	64.25
5	380B	205.0	343.0	181.4	308.0	183.25	53.43	3.00	33.41	51.88	34.64	70.75
7	380B	245.5	418.0	217.3	373.3	228.95	54.77	4.50	40.01	74.77	41.48	68.53
11	380B	261.0	346.5	231.0	320.5	201.75	58.23	2.96	42.53	70.73	44.10	59.69
29	380B	220.0	375.0	194.7	339.4	206.70	55.12	3.00	35.85	59.83	37.17	65.71
43	380B	267.0	435.0	236.3	388.5	242.85	55.83	6.30	43.51	92.59	45.11	72.73
2	440S	270.0	458.0	238.1	424.6	272.50	59.50	7.36	36.86	111.48	46.40	78.27
10	440S	205.0	402.5	180.8	368.7	230.70	57.32	5.28	27.99	93.40	35.23	70.87
16	440S	248.0	480.0	218.7	439.7	274.70	57.23	9.40	33.86	119.15	42.62	82.64
30	440S	227.0	510.0	200.2	453.4	281.10	55.12	7.86	30.99	109.78	39.01	88.38
32	440S	230.5	438.5	203.3	402.1	256.00	58.38	5.24	31.47	107.81	39.61	72.94
13	440B	260.0	507.5	230.1	462.3	292.00	57.54	9.32	42.37	99.40	43.93	87.14
15	440B	243.0	436.0	215.1	402.4	262.95	60.31	3.70	39.60	79.89	41.06	75.22
17	440B	217.0	430.0	192.0	389.6	238.80	55.53	2.76	35.36	72.27	36.67	71.08

Table 1 - Continue...

AN	TREAT	SBWi	SBWf	EBWi (kg)	EBWf (kg)	CCW, kg	CCY, %	FT, cm	FATi, kg	FATf, kg	PROTi, kg	PROTf, kg
25	440B	223.5	436.0	197.8	402.4	254.85	58.45	.	36.42	80.63	37.76	74.46
39	440B	213.0	448.5	188.5	411.3	259.95	57.96	7.10	34.71	90.61	35.99	76.31
49	440B	252.0	482.5	223.0	443.9	287.15	59.51	3.74	41.07	92.65	42.58	85.07
12	500S	263.0	580.5	232.0	517.8	327.25	56.37	11.58	35.91	145.03	45.19	101.45
18	500S	210.0	468.0	185.2	427.8	276.65	59.11	10.22	28.67	120.23	36.09	89.15
22	500S	201.5	462.5	177.7	424.1	267.75	57.89	8.20	27.51	124.05	34.63	78.31
48	500S	215.0	519.0	189.6	472.3	300.50	57.90	7.50	29.35	134.40	36.95	96.03
40	500S	238.0	520.5	209.9	470.5	296.10	56.89	10.62	32.49	148.20	40.90	90.39
1	500B	270.0	548.0	239.0	514.0	335.65	61.25	9.20	44.00	131.01	45.62	106.91
21	500B	208.0	488.0	184.1	456.8	295.50	60.55	5.56	33.90	92.55	35.14	97.36
37	500B	199.5	437.0	176.6	402.0	255.10	58.38	3.54	32.51	84.71	33.71	79.84
23	500B	233.0	443.0	206.2	408.0	259.20	58.51	.	37.97	85.28	39.37	82.16
47	500B	268.5	588.5	237.6	541.4	336.10	57.11	8.50	43.75	138.70	45.37	112.56
4	MAINTS	215.0	264.0	189.6	235.2	147.30	55.80	0.60	29.35	59.62	36.95	45.29
8	MAINTS	188.5	223.5	166.3	201.8	127.70	57.14	0.50	25.74	35.56	32.39	40.06
34	MAINTS	223.0	245.0	196.7	220.7	133.95	54.67	0.70	30.45	41.75	38.32	50.78
50	MAINTS	260.5	319.0	229.8	290.0	186.65	58.51	0.60	35.56	55.71	44.77	51.43
27	MAINTB	247.0	300.0	218.6	282.0	170.35	56.78	1.46	40.25	50.45	41.73	54.00
31	MAINTB	235.0	254.0	208.0	233.7	144.00	56.69	1.00	38.30	37.66	39.71	48.42
33	MAINTB	245.5	278.0	217.3	254.6	156.55	56.31	1.90	40.01	45.97	41.48	51.91
41	MAINTB	223.0	265.5	197.4	241.1	146.60	55.22	1.40	36.34	43.06	37.68	44.31

Table 2 - Animal identification (AN), body initial energy content (ENERGi), body final energy content (ENERGf), accumulated body fat (Δfat), accumulated body protein (Δptn), metabolizable energy intake (MEI), metabolizable energy intake per metabolic unit size (MEI/MUS), retained energy (RE), heat production (HP).

AN	TREAT	ENERGi, Mcal	ENERGf, Mcal	Δfat, kg	Δptn, kg	MEI, Mcal/d	MEI/MUS, Kcal/kg$^{0.75}$	RE,Mcal/EBW$^{0.75}$	HP, Kcal/kg$^{0.75}$/d
6	380S	619.65	1281.23	56.94	22.32	26.83	304.33	0.120	184.12
14	380S	502.48	900.07	34.25	13.35	21.45	303.93	0.091	213.28
20	380S	521.64	1005.03	39.69	19.48	23.71	295.88	0.098	198.03
26	380S	518.26	1088.81	34.74	43.14	29.95	356.39	0.108	248.52
44	380S	545.29	1125.47	49.28	20.65	24.18	295.70	0.112	183.68
3	380B	646.18	933.07	18.27	20.32	25.63	320.42	0.096	224.03
5	380B	509.49	887.43	18.47	36.12	26.29	357.59	0.110	247.42
7	380B	610.15	1090.01	34.76	27.05	29.25	344.48	0.126	218.52
11	380B	648.67	1002.11	28.20	15.59	22.13	292.12	0.113	179.47
29	380B	546.77	933.67	23.98	28.54	24.27	306.91	0.110	197.36
43	380B	663.58	1281.21	49.07	27.61	28.55	326.29	0.151	175.34
2	440S	608.39	1490.14	74.62	31.88	31.28	334.47	0.096	238.43
10	440S	461.92	1278.41	65.42	35.64	20.94	248.85	0.095	153.50
16	440S	558.81	1586.98	85.30	40.03	25.35	264.02	0.107	156.98
30	440S	511.50	1531.29	78.79	49.37	28.20	287.01	0.104	182.55
32	440S	519.38	1425.56	76.34	33.33	25.44	283.26	0.100	182.98
13	440B	646.18	1426.69	57.03	43.21	29.21	293.00	0.105	187.84
15	440B	603.93	1176.00	40.29	34.16	27.34	304.32	0.088	216.45
17	440B	539.31	1080.89	36.90	34.41	25.00	285.05	0.084	201.53
25	440B	555.47	1178.59	44.21	36.69	27.95	311.09	0.092	218.86
39	440B	529.37	1282.83	55.90	40.32	29.10	318.64	0.106	213.05
49	440B	626.30	1351.56	51.59	42.49	29.22	302.10	0.101	201.20
12	500S	592.61	1936.45	109.12	56.25	29.06	267.76	0.096	171.46
18	500S	473.19	1633.80	91.56	53.06	24.90	264.78	0.094	171.11
22	500S	454.04	1608.54	96.54	43.68	24.39	260.95	0.094	167.23

Table 2 - Continue...

AN	TREAT	ENERGi, Mcal	ENERGf, Mcal	Δgor, kg	Δptn, kg	MEI, Sal/d	MEI/MUS, Kcal/kg$^{0.75}$	*RE,Mcal/EBW$^{0.75}$	HP, Kcal/kg$^{0.75}$/d
48	500S	484.46	1805.90	105.05	59.08	26.84	264.94	0.100	164.99
40	500S	536.28	1903.76	115.70	49.49	28.68	283.86	0.103	180.87
1	500B	671.04	1835.51	87.01	61.29	30.07	278.54	0.111	167.60
21	500B	516.95	1420.05	58.65	62.22	26.34	266.58	0.093	173.15
37	500B	495.82	1247.36	52.20	46.14	22.76	253.45	0.085	168.41
23	500B	579.08	1265.79	47.31	42.79	23.75	261.57	0.080	181.49
47	500B	667.31	1939.76	94.95	67.19	33.48	298.32	0.116	182.05
4	MAINTS	484.46	816.30	30.27	8.34	7.77	129.34	0.048	81.38
8	MAINTS	424.74	560.58	9.82	7.67	7.01	130.98	0.027	104.16
34	MAINTS	502.48	679.31	11.30	12.46	8.28	144.50	0.033	111.13
50	MAINTS	586.98	814.22	20.14	6.67	9.41	133.97	0.037	96.87
27	MAINTB	613.87	779.31	10.20	12.27	9.30	135.13	0.039	96.44
31	MAINTB	584.05	627.61	-0.63	8.72	8.25	138.01	0.026	111.60
33	MAINTB	610.15	725.43	5.96	10.43	9.07	142.21	0.035	107.50
41	MAINTB	554.23	655.16	6.72	6.63	8.54	139.52	0.031	108.46

*EBW is empty body weight

Table 3 - Animal identification (AN), treatment (TREAT), ether extract intake (EEI), crude protein intake (CPI), neutral detergent fiber corrected for ash and protein intake (NDFapI), non-fiber carbohydrate intake (NFCI), ash intake (ASH), total digestible nutrient intake (TDNI), dry matter intake (DMI), digestible energy intake (DE), metabolizable energy intake (MEI).

AN	TREAT	EEI, kg/d	CPI, kg/d	NDFapI, kg/d	NFCI, kg/d	ASH, kg/d	TDNI, kg/d	DMI, kg/d	DE, Mcal/d	DE, Mcal/kg	MEI, Mcal/kg
6	380S	0.24	0.84	2.30	3.96	0.40	5.05	7.58	22.00	2.90	3.54
14	380S	0.20	0.67	1.88	3.09	0.32	3.75	5.69	17.59	3.09	3.77
20	380S	0.22	0.75	1.95	3.53	0.36	4.17	6.23	19.45	3.12	3.81
26	380S	0.28	0.95	2.47	4.37	0.43	4.98	7.46	24.56	3.29	4.01
44	380S	0.23	0.75	2.00	3.49	0.36	4.02	6.03	19.83	3.29	4.01
3	380B	0.25	0.79	2.19	3.69	0.38	4.44	6.71	21.02	3.13	3.82
5	380B	0.25	0.83	2.24	3.87	0.39	4.38	6.55	21.56	3.29	4.01
7	380B	0.28	0.91	2.44	4.28	0.43	4.83	7.23	23.99	3.32	4.04
11	380B	0.20	0.65	1.88	3.05	0.30	3.99	6.03	18.14	3.01	3.67
29	380B	0.22	0.77	2.02	3.60	0.35	4.15	6.19	19.90	3.22	3.92
43	380B	0.27	0.88	2.40	4.14	0.42	4.80	7.22	23.41	3.24	3.96
2	440S	0.25	0.95	2.74	4.11	0.49	6.63	10.07	25.65	2.55	3.11
10	440S	0.19	0.71	2.12	3.11	0.37	3.68	5.57	17.17	3.08	3.76
16	440S	0.22	0.83	2.48	3.68	0.44	4.27	6.40	20.79	3.25	3.96
30	440S	0.24	0.91	2.68	4.04	0.47	4.45	6.69	23.12	3.46	4.22
32	440S	0.22	0.81	2.47	3.50	0.42	4.28	6.44	20.86	3.24	3.95
13	440B	0.24	0.91	2.57	4.06	0.47	4.85	7.24	23.95	3.31	4.04
15	440B	0.22	0.82	2.37	3.64	0.42	4.76	7.09	22.42	3.16	3.85
17	440B	0.20	0.78	2.19	3.50	0.40	4.57	6.81	20.50	3.01	3.67
25	440B	0.23	0.89	2.47	3.90	0.45	4.53	6.75	22.92	3.40	4.14
39	440B	0.24	0.90	2.56	4.00	0.46	5.05	7.54	23.86	3.16	3.86
49	440B	0.24	0.91	2.60	3.99	0.46	4.81	7.22	23.96	3.32	4.05
12	500S	0.24	0.91	2.69	3.98	0.46	4.76	7.15	23.83	3.33	4.06
18	500S	0.21	0.78	2.22	3.53	0.39	4.42	6.62	20.42	3.09	3.76
22	500S	0.21	0.78	2.36	3.46	0.40	4.32	6.53	20.00	3.06	3.73
48	500S	0.23	0.88	2.54	3.94	0.44	4.39	6.55	22.01	3.36	4.10
40	500S	0.25	0.92	2.74	4.07	0.47	4.54	6.83	23.52	3.44	4.20

Table 3 - Continue...

AN	TREAT	EEI, kg/d	CP, kg/d	NDFap, kg/d	NFCap, kg/d	ASH, kg/d	TDNI, kg/d	DMI, kg/d	DE, Mcal/d	DE, Mcal/kg	MEI, Mcal/kg
1	500B	0.26	0.95	2.83	4.16	0.48	5.05	7.63	24.66	3.23	3.94
21	500B	0.23	0.83	2.53	3.67	0.44	4.51	6.85	21.60	3.16	3.85
37	500B	0.19	0.73	2.14	3.25	0.38	3.43	5.15	18.66	3.63	4.42
23	500B	0.20	0.74	2.18	3.27	0.38	3.87	5.85	19.47	3.33	4.06
47	500B	0.27	1.02	3.04	4.54	0.53	5.77	8.64	27.46	3.18	3.87
4	MAINTS	0.07	0.26	0.84	1.17	0.14	1.61	2.44	6.37	2.61	3.18
8	MAINTS	0.06	0.23	0.74	1.04	0.12	1.40	2.12	5.75	2.71	3.31
34	MAINTS	0.07	0.27	0.85	1.19	0.14	1.76	2.66	6.79	2.55	3.11
50	MAINTS	0.09	0.32	1.01	1.42	0.16	1.83	2.80	7.72	2.76	3.37
27	MAINTB	0.08	0.30	0.95	1.33	0.16	1.90	2.88	7.63	2.65	3.23
31	MAINTB	0.07	0.27	0.84	1.18	0.14	1.67	2.51	6.76	2.70	3.29
33	MAINTB	0.08	0.30	0.92	1.30	0.15	1.89	2.86	7.43	2.60	3.17
41	MAINTB	0.08	0.28	0.87	1.23	0.15	1.76	2.66	7.00	2.63	3.21

Table 4 - Animal identification (AN), treatment (TREAT), total digestible nutrient in the diet (TDN), total crude protein intake (CPt), microbial crude protein intake (MCP), rumen undegradable protein (RUP), metabolizable protein (MP), body retained protein (RP).

AN	TREAT	TDN, %DM	CPt, g/d	MCP,g/d	RUP, g/d	MP, g/d/kg$^{0.75}$	RP, kg	RP, g g/d/kg$^{0.75}$	MP, g/d	RP g/d
6	380S	66.61	842.25	605.68	236.58	7.67	22.32	3.09	576.89	232.45
14	380S	65.88	669.46	449.73	219.73	7.50	13.35	2.25	463.61	139.05
20	380S	66.97	754.49	500.34	254.15	7.76	19.48	3.01	523.54	202.92
26	380S	66.76	951.31	597.75	353.56	9.58	43.14	6.47	665.41	449.39
44	380S	66.63	745.67	482.54	263.13	7.50	20.65	3.11	519.33	215.14
3	380B	66.18	794.83	533.09	261.75	7.89	20.32	3.83	550.57	267.36
5	380B	66.85	825.40	525.84	299.56	9.31	36.12	7.68	576.18	475.22
7	380B	66.82	913.49	580.07	333.41	8.96	27.05	5.00	637.98	355.90
11	380B	66.25	646.71	479.17	167.54	6.51	15.59	3.03	440.70	205.09
29	380B	67.02	767.53	497.76	269.77	8.09	28.54	5.68	534.38	375.54
43	380B	66.56	882.14	576.50	305.65	8.26	27.61	4.89	613.48	363.34
2	440S	65.79	950.07	795.36	154.71	8.15	31.88	2.83	632.80	219.84
10	440S	66.15	711.35	442.18	269.17	7.38	35.64	3.64	498.33	245.80
16	440S	66.74	829.31	512.53	316.78	7.52	40.03	3.57	581.44	276.04
30	440S	66.60	914.30	534.34	379.96	8.40	49.37	4.43	645.95	340.52
32	440S	66.49	812.51	513.57	298.94	7.82	33.33	3.17	567.84	229.90
13	440B	66.94	914.50	581.41	333.09	7.96	43.21	4.52	638.58	363.12
15	440B	67.10	823.68	571.22	252.46	7.71	34.16	3.90	567.55	287.08
17	440B	67.07	783.58	548.44	235.13	7.66	34.41	4.11	539.11	289.17
25	440B	67.10	887.52	543.49	344.03	8.64	36.69	4.28	623.06	308.34
39	440B	66.98	901.72	606.19	295.53	8.66	40.32	4.70	624.39	338.81
49	440B	66.66	907.88	577.59	330.29	8.12	42.49	4.58	633.89	357.04
12	500S	66.46	913.28	570.61	342.67	7.50	56.25	3.53	639.32	300.81
18	500S	66.82	779.51	530.48	249.03	7.35	53.06	3.87	538.73	283.73
22	500S	66.20	776.71	518.82	257.90	7.45	43.68	3.23	538.36	233.60
48	500S	67.06	878.03	527.18	350.85	7.97	59.08	4.07	618.07	315.94
40	500S	66.50	915.35	544.90	370.44	8.14	49.49	3.34	645.09	264.66

Table 4 - Continue...

AN	TREAT	TDN, %DM	CPt, g/d	MCP,g/d	URP, g/d	MP, g/d/kg$^{0.75}$	RP, kg	RP, g g/d/kg$^{0.75}$	MPI, g/d	PR g/d
1	500B	66.23	954.19	606.13	348.07	7.80	61.29	4.85	666.37	414.11
21	500B	65.93	830.32	541.57	288.75	7.63	62.22	5.55	577.60	420.38
37	500B	66.67	734.54	411.81	322.73	7.44	46.14	4.44	521.74	311.72
23	500B	66.17	737.61	464.43	273.18	7.03	42.79	3.94	515.78	289.11
47	500B	66.80	1017.81	692.83	324.98	8.02	67.19	5.18	703.40	453.98
4	MAINTS	66.10	263.50	193.61	69.89	3.23	8.34	0.87	179.82	48.22
8	MAINTS	66.20	232.26	168.49	63.77	3.18	7.67	0.89	158.85	44.33
34	MAINTS	66.28	267.62	211.56	56.07	3.28	12.46	1.31	180.25	72.00
50	MAINTS	65.48	318.59	219.71	98.89	3.39	6.67	0.60	219.72	38.53
27	MAINTB	66.14	304.14	228.46	75.67	3.29	12.27	1.28	206.75	80.71
31	MAINTB	66.48	269.25	199.83	69.41	3.20	8.72	1.00	183.42	57.34
33	MAINTB	66.01	295.06	226.71	68.35	3.32	10.43	1.14	199.77	68.62
41	MAINTB	66.29	279.29	211.73	67.56	3.33	6.63	0.77	189.56	43.63

Table 5 - Animal identification (AN), treatment (TREAT), internal fat (InF), subcutaneous fat (ScF), intramuscular fat (ImF), carcass fat (CF), Hanks and Howe section (HH), muscle in the HH section (MHH), fat in the HH section (HHF), bone in the HH section (BHH).

AN	TREAT	InF, kg	ScF, kg	ImF, kg	CF, kg	HH, kg	MHH, kg	HHF, kg	BHH, kg
28	RFS	5.03	1.15	4.07	5.22	2.26	1.40	0.25	0.63
38	RFS	7.20	1.56	5.22	6.77	1.92	1.16	0.26	0.50
42	RFS	4.05	1.03	3.63	4.66	2.46	1.60	0.18	0.69
46	RFS	7.92	2.26	5.60	7.86	2.08	1.22	0.27	0.58
9	RFB	6.41	2.74	5.34	8.08	2.37	1.45	0.27	0.64
19	RFB	5.34	1.34	5.11	6.44	1.92	1.20	0.19	0.53
35	RFB	4.44	1.53	3.95	5.48	2.29	1.39	0.30	0.65
45	RFB	6.07	2.31	5.85	8.16	2.15	1.33	0.25	0.55
6	380S	23.59	9.19	15.42	24.61	3.96	2.15	1.13	0.71
14	380S	12.47	4.64	8.91	13.55	2.94	1.67	0.62	0.67
20	380S	16.94	6.25	10.61	16.86	3.61	2.03	0.74	0.79
26	380S	18.43	7.11	14.35	21.45	3.52	1.90	0.90	0.72
44	380S	14.86	6.40	11.63	18.03	3.47	2.02	0.79	0.74
3	380B	12.68	5.21	9.83	15.04	2.88	1.69	0.53	0.67
5	380B	12.92	3.91	9.90	13.81	2.91	1.76	0.53	0.63
7	380B	16.46	9.20	13.60	22.80	3.79	1.93	1.12	0.74
11	380B	11.99	3.99	11.16	15.15	3.08	1.93	0.64	0.68
29	380B	13.41	5.02	9.53	14.55	3.12	1.84	0.54	0.74
43	380B	15.23	6.69	16.68	23.37	3.23	2.01	0.37	0.85
2	440S	27.48	9.58	18.30	27.88	4.77	2.58	1.42	0.77
10	440S	22.75	6.63	13.85	20.48	4.33	2.25	1.18	0.88
16	440S	27.89	9.41	19.75	29.16	4.82	2.48	1.42	0.90
30	440S	31.62	7.01	20.31	27.31	4.00	2.17	1.14	0.69
32	440S	26.57	6.63	18.95	25.58	4.11	2.17	1.12	0.80
13	440B	17.62	8.12	16.82	24.94	3.87	2.25	0.97	0.63
15	440B	16.81	5.57	13.19	18.76	4.43	2.54	1.05	0.80
17	440B	18.73	4.30	11.33	15.63	3.86	2.38	0.73	0.77
25	440B	20.78	6.04	13.73	19.77	3.92	2.35	0.91	0.66

Table 5 – Continue…

AN	TREAT	InF, kg	ScF, kg	ImF, kg	CF, kg	HH, kg	MHH, kg	HHF, kg	BHH, kg
39	440B	15.92	8.47	15.60	24.06	4.32	2.32	1.10	0.90
49	440B	18.30	6.26	14.17	20.43	4.81	2.92	0.93	0.93
12	500S	37.03	10.875	25.70	36.57	5.470	2.790	1.650	1.010
18	500S	27.97	15.640	20.27	35.91	4.965	2.345	1.765	0.810
22	500S	30.79	12.670	18.75	31.42	4.475	2.340	1.340	0.765
48	500S	36.49	12.630	27.33	39.96	5.185	2.630	1.550	0.965
40	500S	37.61	12.400	23.54	35.94	5.205	2.530	1.820	0.820
1	500B	26.77	11.105	26.35	37.46	6.230	3.435	1.795	1.000
21	500B	23.14	6.385	13.90	20.29	5.120	2.800	1.260	1.010
37	500B	19.18	4.560	12.75	17.31	4.380	2.735	0.780	0.840
23	500B	21.04	6.175	12.70	18.88	4.330	2.420	0.985	0.875
47	500B	35.29	12.545	24.30	36.85	5.425	2.845	1.630	0.915
4	MAINTS	9.63	1.050	5.80	6.85	2.310	1.370	0.265	0.625
8	MAINTS	7.04	0.400	4.98	5.38	2.145	1.385	0.180	0.570
34	MAINTS	8.57	1.505	5.95	7.45	1.835	1.065	0.270	0.490
50	MAINTS	11.31	2.440	6.98	9.43	2.935	1.775	0.445	0.700
27	MAINTB	8.51	1.630	6.50	8.13	2.850	1.690	0.380	0.765
31	MAINTB	8.31	0.915	4.47	5.39	2.330	1.465	0.203	0.655
33	MAINTB	10.91	2.411	6.27	8.68	2.675	1.680	0.301	0.690
41	MAINTB	10.00	1.929	5.38	7.31	2.300	1.335	0.315	0.645