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Prediction of the energy value of cattle diets based on the chemical composition of feeds

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The chemical composition of a feed/diet is the main determinant of its ability to supply nutrients to meet the demands for animal maintenance and production, especially regarding energy supply, which is obtained through digesting and metabolizing the organic components of feeds. Feed composition tables are reliable because they provide exact mean values for energy concentrations. However, there are variations in field conditions that cannot be properly contemplated by data tabulation. Thus, the use of chemical composition to predict the ability of a feed to supply energy can facilitate the work of nutritionists when formulating diets in specific situations, so they can be more exact and appropriate for each productive situation.

INTRODUCTION

Obtaining estimates of digestibility coefficients is a basic aspect for quantifying the energy value of feeds or diets, especially with regard to total digestive nutrients (TDN), and allows diets to be balanced adequately to meet animal requirements for maintenance and production.

Although it is a static digestive parameter that can be represented by a point estimate, the estimation of the digestibility coefficient of a whole feed or its individual chemical components is a troublesome and time-consuming process when carried out using classic *in vivo* methods (Detmann et al., 2006a).

Throughout the world, including Brazil, efforts have been made to compile data to build tables that can be used as a possible alternative for technicians and farmers who need to know the composition of feeds, including energy content. Those efforts were based on the fact that large size samples would tend to point with greater precision and accuracy to the populational mean of the characteristics of the feed (effect known as "law of large numbers") that, in thesis, would increase the accuracy of diets calculated based on these values (Detmann et al., 2008a).

Although the tabled feed energy values tend to be reliable from a statistical point of view, the feeds used in different production systems can differ from the average information; that is, they have a distribution, often normal, but with distinct deviations from the populational mean. Thus, diets calculated based on average composition will tend to give productions deviated from those initially planned at intensity similar to the deviation of the characteristics of the feed used compared to the populational mean (Detmann et al., 2008a).

This situation is particularly intense in the tropics, especially for forages, because the characteristics of the feeds produced reflect climatic and edaphic oscillations (e.g., temperature, precipitation, solar radiation, soil fertility) more strongly than in non-tropical regions.

These aspects influence feed energy content and substantial effort is required to reduce the current dependency on mean values derived from composition tables. Although studies with great contribution in this context were developed some decades ago (e.g., Conrad et al., 1984; Weiss et al., 1992), the main milestone is the seventh edition of the American tables for dairy cattle (NRC, 2001), in which tabulated data of energy content were not routinely used anymore, but rather alternatives to estimate the energy content of feeds on a "case-by-case" basis were suggested. Thus, deviations between the production characteristics foreseen in diet balancing and those effectively obtained in the field would be minimized (Detmann et al., 2008a).

The energy content prediction system for feeds offered to cattle adopted by the NRC (2001) is based on the influence of chemical composition on the capacity to supply energy. The method is based on a system of summative equations in which, for each group of chemical compounds with potential for energy contribution (CP, crude protein; EE, ether extract; NFC, non-fibrous carbohydrates; and NDF, neutral detergent fiber) is given a sub-model responsible to estimate the fractions that are truly digestible, with later corrections regarding fecal metabolic losses and intake level.

Although it effectively accounts for the characteristics of feeds used in production systems (that is, laboratory analyses and not estimates of populational means) and has a theoretical base (Conrad et al., 1984; Weiss et al., 1992), the system adopted by the NRC (2001) did not present a satisfactory efficiency of prediction when applied to feeds obtained under tropical conditions (Rocha Jr. et al., 2003; Costa et al., 2005; Silva et al., 2007; Detmann et al., 2008b; Campos et al., 2010; Magalhães et al., 2010; Azevêdo et al., 2011; Sampaio et al., 2012), which constrained its effective application.

Due to this limitation, new sub-models to predict the digestible fractions of CP, EE, NFC, and NDF were developed and evaluated under tropical conditions (Detmann et al, 2004a; 2006a; 2006b; 2006c; 2007; 2008b; 2008c; 2010a). The unified assessment of these sub-models, that constitutes a new summative system, showed that they are capable of more exact prediction of the TDN content in diets offered to cattle in Brazil (Detmann et al., 2008b; Magalhães et al., 2010; Azevêdo et al., 2011; Sampaio et al., 2012), creating an alternative to applying the model adopted by the NRC (2001) and culminating in the adoption of the prediction system in the second edition of the BR-CORTE System (Detmann et al., 2010b).

However, because a few limitations were detected in the sub-models originally proposed, new information was generated from experimental assessments and/or meta-analyses and from new approaches to the assessment of feed chemical composition. Thus, the system for predicting the dietary TDN has been improved, that implies modifications to the model originally adopted in the second edition of the BR-CORTE System (Detmann et al., 2010b).

DESCRIPTION OF THE MODEL

Sub-models for EE and NFC

No significant theoretical or empirical alterations were made to the sub-models applied to the non-fibrous components EE and NFC in the second edition of the BR-CORTE System. They are based on the Lucas test (Lucas and Smart, 1959) to obtain the true digestibility coefficients, and on the assumptions of the factorial system (Blaxter and Mitchell, 1948; Lucas, 1960) to distinguish between the metabolic fecal fraction and the truly non-digestible fraction.

Under these assumptions, apparently undigested fecal matter can be defined for the non-fibrous components (EE or NFC) as follows:

$$F = U + M + E \quad (4.1),$$

where: F, fecal mass (g/day); U, truly undigested fraction (g/day); M, metabolic fecal fraction (g/day); and E, endogenous fecal fraction (g/day).

In this context, the metabolic fraction is defined as the fecal portion obtained from digestive tract secretions (Lucas, 1960) and microbial debris (Van Soest, 1994). Conversely, the endogenous fecal fraction corresponds to the fecal portion obtained by secretions of metabolic "waste" by cells of the gastrointestinal tract (Lucas, 1960).

Using these definitions, the identity exposed in (4.1) can be related to daily intake, as follows:

$$I - F = I - (U + M + E) \quad (4.2a),$$

$$I - F = I - U - M - E \quad (4.2b),$$

$$\frac{I - F}{I} = \frac{I - U - M - E}{I} \quad (4.2c),$$

$$Da = 1 - \frac{U}{I} - \frac{M}{I} - \frac{E}{I} \quad (4.2d),$$

where: I, intake (g/day); Da, apparent digestibility coefficient (g/g).

The endogenous fecal fraction can be represented by a mathematical function proportional to the metabolic mass of the animal (Blaxter and Mitchell, 1948; Lucas, 1960), given by:

$$\frac{E}{I} = \frac{\varepsilon \times W^{\frac{3}{4}}}{I} = \frac{\varepsilon}{I} \times W^{\frac{3}{4}} \quad (4.3),$$

where: W, animal weight (g); and ε, constant related to the endogenous release in the gastrointestinal tract per unit of metabolic mass (g/g × day^{-1}).

The ratio (ε/C) would only be considered significant if, and only if, intake assumes extremely small values (Lucas, 1960), possibly at feeding levels below maintenance. Thus under maintenance or production conditions, we have:

$$\lim_{I \to I^{\circ}} \frac{\varepsilon}{I} \times W^{\frac{3}{4}} = 0 \quad (4.4),$$

where: I°, intake under maintenance or production (g/day).

In this way, the equation (4.2d) is rewritten as:

$$Da = (1 - \frac{U}{I}) - \frac{M}{I} \quad (4.5a),$$

$$Da = Dt - \frac{M}{I} \quad (4.5b),$$

where: Dt, true digestibility coefficient (g/g).

Multiplying both terms of the equation (4.5b) by intake, we have:

$$I \times Da = (I \times Dt) - M \quad (4.6),$$

We can obtain the Da value by deriving equation (4.6) in terms of intake as:

$$\frac{d(I \times Da)}{dI} = \frac{d(I \times Dt)}{dI} - \frac{dM}{dI} \therefore Da = Dt - \frac{dM}{dI} \quad (4.7).$$

Thus the apparent digestibility coefficient (Equation 4.7) can be represented by two different components: the first, which represents the constant true digestibility coefficient; and the second, which represents fecal metabolic fraction, which varies according to intake.

Converting equation (4.7) based on dietary content, we have:

$$R \times Da = (R \times Dt) - (R \times \frac{dM}{dI}) \quad (4.8a),$$

$$adR = tdR - MC \quad (4.8b),$$

where: R, dietary content (% DM); MC, fecal metabolic contribution, expressed as dietary content (% DM); adR, apparently digestible diet fraction (% DM); and tdR, truly digestible diet fraction (% DM).

Two datasets, obtained from experiments carried out with dairy cows or growing and finishing cattle under tropical conditions, were used to estimate the parameters described in equation (4.8b) for EE (n = 108) and NFC (n = 84) (Detmann et al., 2006a; 2006c). True digestibility coefficients were found similar between animal categories. Furthermore, the metabolic fecal contribution varied between animal categories (Detmann et al., 2006a; 2006c), which is consistent with the assumptions reported by Lucas and Smart (1959) and by those represented in equation (4.8).

The sub-models used to estimate the truly digestible fractions are:

$$tdEE = 0.86 \times EE \quad (4.9),$$

$$tdNFC = 0.95 \times NFC \quad (4.10),$$

where: tdEE, truly digestible EE (% DM); EE, diet content of EE (% DM); tdNFC, truly digestible NFC (% DM); NFC, diet content of NFC (% DM).

As there were no differences among animal categories regarding the true digestibility coefficient, equations (4.9) and (4.10) can be applied similarly to dairy cows and growing and finishing cattle. Thus, the differences between animal categories are based on the apparently digestible fraction, that is, by the fecal metabolic contribution, using the estimates shown in Table 4.1.

Table 4.1 - Fecal metabolic contribution (% dry matter) of ether extract (EE), non-fibrous carbohydrates (NFC) and crude protein (CP) for animals fed *ad libitum*

	Animal Category	
Component	Dairy Cows	Growing and Finishing Cattle
EE	0.21	0.18
NFC	5.72	5.11
CP	0.97	1.61
FM_{TDN}[1]	7.16	7.13
FM_{DE}[2]	0.314	0.322

[1]FM_{TDN}, total fecal metabolic fraction to estimate the TDN content (FM_{TDN} = CP + NFC + 2.25×EE). [2] FM_{DE}, fecal metabolic fraction to estimate the digestible energy content (Mcal/kg DM).

In the second edition of the BR-CORTE System, different fecal metabolic fractions were estimated for animals fed at maintenance and production conditions. However, starting in the third edition of the BR-CORTE System, estimates of dietary energy content for animals fed at maintenance level will no longer be considered, because of their limited application.

Individual validation procedures were previously carried out on the apparently digestible fractions of EE and NFC by using datasets independent of those used to fit the sub-models (Detmann et al., 2006a; 2006c; 2008b; Magalhães et al., 2010; Azevêdo et al., 2011; Sampaio et al., 2012). Those assessments showed that the sub-models adopted in the BR-CORTE System are more accurate and precise than those adopted by the NRC (2001).

Sub-model for NDF

In biological terms, the sub-model developed to estimate the digestible fraction of NDF kept its base by fractioning this component into potentially digestible and indigestible fractions, according to the equation:

$$dNDF = D \times pdNDF \quad (4.11a),$$

$$dNDF = D \times (NDFap - iNDF) \quad (4.11b),$$

where: dNDF, digestible NDF (% DM); pdNDF, potentially digestible NDF (% DM); D, digestibility coefficient of the pdNDF (g/g); and iNDF, indigestible NDF (% DM).

Both sub-models used to predict the digestible fraction of NDF in the second edition of the BR-CORTE System and in the NRC (2001) were based on chemical approximations and on a non-linear exponential relationship between lignin and iNDF, adapted from the assumptions of the Surface Law (Conrad et al., 1984; Weiss et al., 1992). For this relationship, the lignin constraint factor on NDF ruminal degradation is the base parameter (Detmann et al., 2004a). The mathematical structure of both models is given by:

$$dNDF = D \times \{(NDFap - L) \times [1 - (\frac{L}{NDFap})^{F}]\} \quad (4.12),$$

where: dNDF, digestible NDF (% DM); D, digestibility coefficient of pdNDF (g/g); NDFap, NDF content expressed with corrections for contaminant ash and protein (% DM)[1]; L, lignin content (% DM); and F, lignin constraint factor on NDF ruminal degradation.

The first constraint observed for equation (4.12) is the use of constant lignin constraint factor for NDF ruminal degradation [0.667, NRC (2001); 0.85, Detmann et al. (2010b)]. This assumption implies that the lignin would act homogeneously in determining the size of the iNDF fraction, and consequently the pdNDF fraction, in any feed. However, the lignin to iNDF ratio varies among forage types (Palmonari et al., 2016) and between forage and concentrates. Thus,

[1] In the sub-model adopted by the NRC (2001), the concentration of NDF is corrected only for the contaminant protein.

this assumption compromises the accuracy of the digestible NDF estimates.

The pdNDF and iNDF fractions are asymptotic biological concepts; that is, they are defined when the time of exposure to the microbial enzymatic systems in the rumen tends toward infinity (Detmann et al., 2008a). In analytical terms, the accurate assessment of these fractions is only obtained by long-term biological trials (*in situ* ruminal incubation at times equal or greater than 240 hours; Casali et al., 2008; Valente et al., 2011). These analytical procedures demand a long time to obtain the estimates of iNDF and pdNDF and restrict the assessments because they demand the availability of fistulated animals. However, long term *in situ* ruminal incubation is the most accurate way to estimate the iNDF and pdNDF fractions and is the recommended procedure to insert values in the equation base of the sub-model (Equation 4.11b).

However, considering the limitations of the theoretical bases associated with equation (4.12) and presuming situations in which *in situ* ruminal incubations cannot be performed, an alternative to estimate iNDF content from chemical characteristics was developed by analyzing samples of feeds used in Brazil. With this approach, the association between iNDF and chemical characteristics of forages (n = 371) and concentrates (n = 65) was investigated. However, during the process of fitting the equations, stronger correlations with the chemical characteristics were observed for the pdNDF fraction compared to the iNDF fraction. Thus, to obtain more robust equations, they were fitted to estimate the pdNDF fraction, considering that it represents the complement of the iNDF fraction in relation to the total NDF. The basic characteristic for estimation was the direct association of pdNDF and the contents of NDF corrected for ash and protein (NDFap), for both forages (Figure 4.1) and concentrates (Figure 4.2), and in corrections for the pdNDF fraction size in function of other chemical characteristics of the feeds [acid detergent fiber (ADF) and lignin]. Different relationships were obtained for the different feed groups (forages and concentrates), that is an improvement compared to the homogeneous relationship previously assumed by the structure of Equation (4.12).

For forages and concentrates, the equations are, respectively:

$$pdNDF(F) = 3.38 + 0.883 \times NDFap - 0.834 \times ADF + 0.0065 \times ADF^2 - 0.197 \times L$$

(s_{XY} = 3.37; R^2 = 0.895) (4.13),

$$pdNDF(C) = -1.19 - 10.16 \times D + 1.012 \times NDFap - 0.052 \times ADF$$

(s_{XY} = 0.71; R^2 = 0.998) (4.14),

where: pdNDF(F) and pdNDF(C), pdNDF contents in forages and concentrates, respectively (% DM); NDFap, neutral detergent fiber corrected for contaminant ash and protein (% DM); ADF, acid detergent fiber without corrections for contaminant ash and protein (% DM); L, lignin content measured by the acid hydrolysis method (% DM); D, "dummy" variable associated with the concentrate type, where D = 1 for concentrates containing fiber with lesser potential degradation [cotton meal, cake and seed; sunflower meal and cake; wheat bran; and ground ear corn (GEC)] and D = 0 for the other concentrate feeds.

However, the estimates of iNDF or pdNDF fractions obtained by chemical approximations may present limitations, because simple chemical characteristics would not be able to reproduce or represent all the biological events associated with plant growth and with the establishment of physical and chemical interactions among the components of the cell wall responsible for establishing the sizes of these fractions.

The second constraint observed for Equation (4.12) is the use of constant values for the digestibility coefficient of pdNDF [0.75; NRC (2001)]. Although the sub-model used in the second edition of the BR-CORTE System took into account for differences between animal categories [0.67 for dairy cows, and 0.84 for growing and finishing cattle; Detmann et al., 2010b], the pdNDF digestibility coefficient is presumed as constant within animal categories, that, similarly to that adopted by the NRC (2001), does not consider all the influences from intake level, diet chemical composition, and feed type on the ruminal degradation of the potentially degradable fiber.

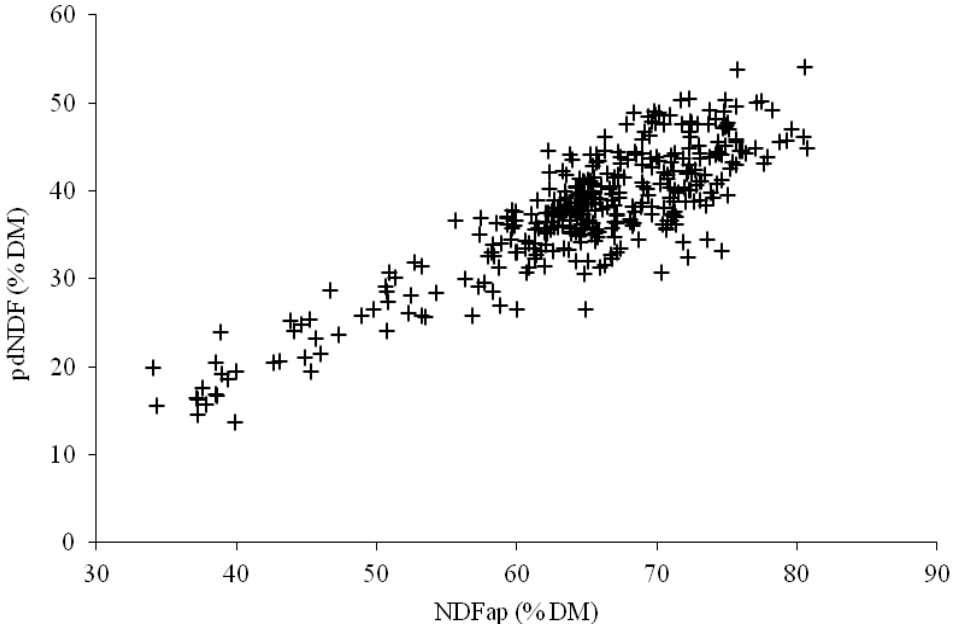

Figure 4.1 - Relationship between the contents of neutral detergent fiber corrected for ash and protein (NDFap) and potentially digestible neutral detergent fiber (pdNDF) in forage samples (n = 371).

To overcome this situation, a meta-analytical approach was performed with regard to the association between chemical composition, diet composition, and intake level, and the digestibility coefficient of pdNDF, using data from diets offered *ad libitum* to dairy cows (n = 45) and growing and finishing cattle (n = 213) in Brazil. The results showed different relationships for the animal categories and the equations are as follows:

$$D_{GF} = 80.21 \times FOR - 0.0166 \times DMI^2 + 2.658 \times iNDF + 3.691 \times CP + 0.0507 \times (DMI \times iNDF) - 2.9673 \times (FOR \times iNDF) - 3.9990 \times (FOR \times CP) \quad (4.15),$$

$$D_L = 249.32 + 1.180 \times CONC - 12.422 \times DMI + 0.2313 \times DMI^2 - 0.0475 \times (CONC \times DMI) \quad (4.16),$$

where: D_{GF} and D_L, digestibility coefficient of pdNDF for growing and finishing cattle and dairy cows, respectively (%); FOR, "dummy" variable associated with the forage type used, where FOR = 0 for corn and sorghum silages and FOR = 1 for grass forages and sugarcane; DMI, voluntary DM intake (g/kg body weight); iNDF, iNDF content in the diet (% DM); CP, CP content in the diet (% DM); and CONC, concentrate level in the diet (% DM).

It is emphasized that the equations presented a good fit (Figures 4.3 and 4.4) and allowed different aspects of the diet that effectively influence the ruminal utilization of potentially digestible fiber to be contemplated.

However, a limitation inherent to equations (4.15) and (4.16) is observed for the diet calculation, because estimates of some output parameters (i.e., forage:concentrate ratio, dietary content of CP and iNDF) are needed to perform the calculation itself, which makes it an iterative process. This could make the computer procedures difficult.

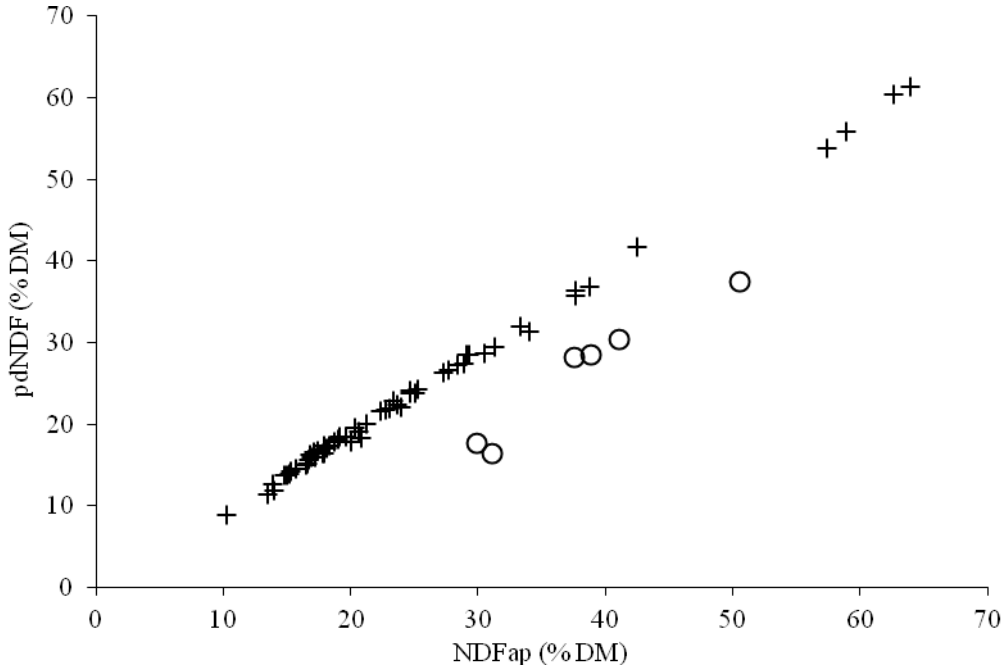

Figure 4.2 - Relationship between the contents of neutral detergent fiber corrected for ash and protein (NDFap) and potentially digestible neutral detergent fiber (pdNDF) in concentrate samples (n = 65; ○ = concentrates containing fiber with lesser potential degradation; + = other concentrate feeds).

Thus, an alternative system was developed based on assessing diets obtained from 60 animals fed exclusively on forage (i.e., corn silage, sugarcane, *Brachiaria* grass hay, *Cynodon* hay, grass silage), in which pdNDF passage and degradation rates were estimated based on rumen evacuation (Allen and Linton, 2007). The base model to quantify the digestible fraction of NDF is given by:

$$dNDF = [\frac{kd}{kd + kp} \times pdNDF] \times IAF \quad (4.17a),$$

$$dNDF = [\frac{kd}{kd + kp} \times (NDFap - iNDF)] \times IAF \quad (4.17b),$$

where: kd, pdNDF degradation rate (h^{-1}); kp, pdNDF ruminal passage rate (h^{-1}); and IAF, intestinal digestibility adjustment factor.

The models adopted to describe the pdNDF forage degradation and passage rates are given by (Figures 4.5 and 4.6):

$$kd = 0.00329 \times DMI \quad (s_{XY} = 0.0106) \quad (4.18),$$

$$kp(F) = \frac{0.287}{iNDF} \quad (s_{XY} = 0.0048) \quad (4.19a),$$

$$kp(F) = \frac{0.287}{(NDFap - pdNDF)} \quad (4.19b),$$

where: DMI, voluntary DM intake (g/kg body weight); kp(F), pdNDF passage rate for forage (h^{-1}); and iNDF, iNDF content in the forage (% DM).

Equation (4.19b) is suggested when equation (4.13) is used for estimating the pdNDF fraction.

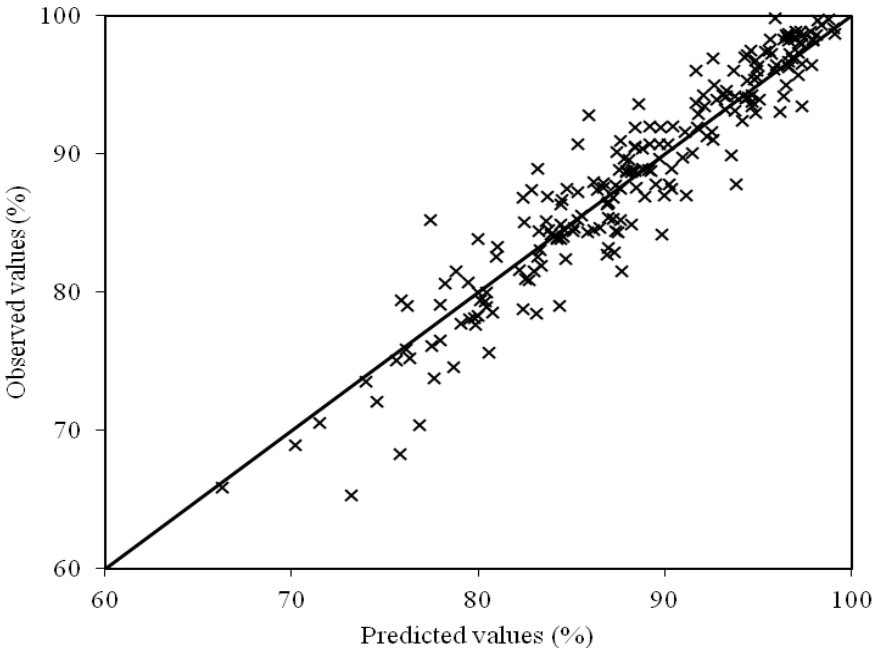

Figure 4.3 - Relationship between predicted and observed values for the digestibility coefficient of potentially digestible NDF in growing and finishing cattle (Equation 4.15; the continuous line represents the equality line; s_{XY} = 2.96; R^2 = 0.900; lack-of-fit: P>0.07).

The IAF was estimated from information available in the dataset, and no influence was observed for dietary characteristics on the proportion of pdNDF digested in the rumen and intestines. The mean proportion of the pdNDF digested in the rumen was 89±1.9%. Thus, FAI = 1.12 (FAI = 1/0.89).

The dataset used is limited because it is composed only of forage-based diets (without concentrate). Considering that concentrates present smaller particle size than those observed in forage, it is logical to suppose shorter retention time for concentrate fiber. The quantity of information that contrasts passage rates of fiber of forage and concentrates within a same experiment is limited for Brazilian conditions. Thus, an approximation was made from the experiment by Bürger et al. (2000), presuming that the ruminal passage rate of concentrate fiber is approximately 1.8 times that observed for forage fiber. Thus:

$$kp(C) = kp(F) \times 1.8 \qquad (4.20),$$

where: kp(C), pdNDF passage rate for concentrates (h^{-1}).

As there is little information collected under Brazilian conditions on diets consisting exclusively of concentrates, it is suggested that the ruminal passage rate for this feeding condition be calculated according to the equation proposed by the NRC (2001):

$$kp = 0.02904 + 0.001375 \times DMI - 0.00020 \times CONC \qquad (4.21),$$

where: DMI, voluntary DM intake (g/kg body weight); and CONC, concentrate level in the diet (% DM).

It is important to emphasize that equation (4.21) refers to the total concentrate DM and not to the pdNDF itself. However, considering that its application would be restricted to diets consisting only of concentrates, it is assumed that, in these circumstances, the pdNDF passage rate approximates the whole concentrate passage rate. However, this assumption still needs validation for Brazilian conditions.

Sub-model for CP

First, the sub-model used to evaluate the CP digestible fraction was based on the same assumptions adopted for EE and NFC (Detmann et al., 2006b), according to equations (4.1) to (4.8), resulting in:

$$tdCP = 0.78 \times CP \qquad (4.22),$$

where: tdCP, truly digestible CP (% DM); and CP, diet content of CP (% DM).

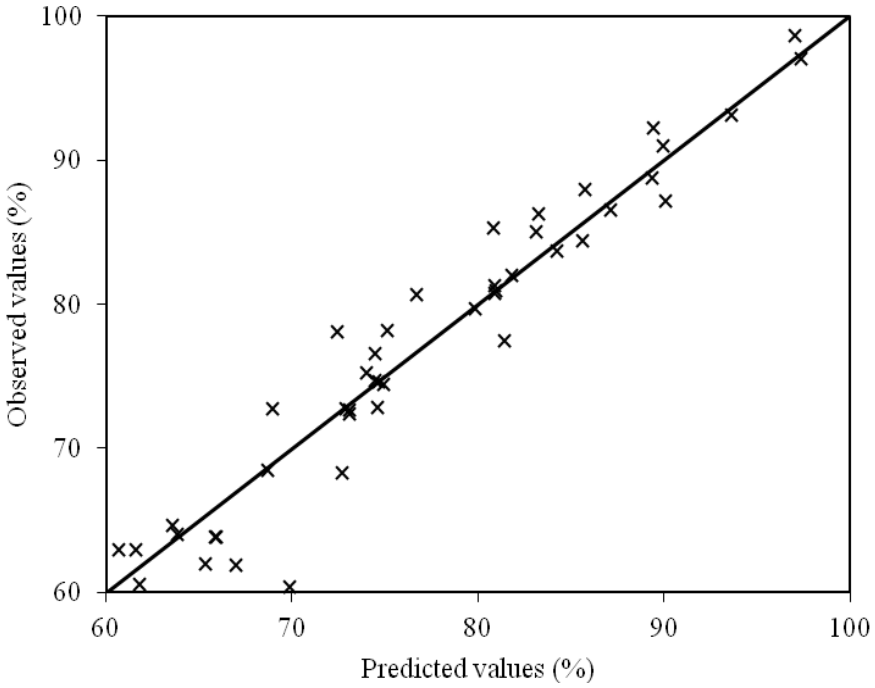

Figure 4.4 - Relationship between predicted and observed values for the digestibility coefficient of potentially digestible NDF in dairy cows (Equation 4.16; the continuous line represents the equality line; s_{XY} = 3.46; R^2 = 0.933; lack-of-fit: P>0.67).

In this case, conversion to the apparently digestible fraction (considering different animal categories) is performed by using the estimates of the corresponding fecal metabolic contribution (Table 4.1).

However, later observations showed that, because of the intense and complex association of nitrogen compounds and the insoluble fiber in tropical feeds, the CP could not be considered as a homogeneous nutritional entity (Detmann et al., 2008c). In spite of this, Azevêdo et al. (2011) observed that applying the uni-compartmental concept, in which the CP is presumed as a homogeneous nutritional entity, gave more accurate estimates when some agroindustry by-products and residues were assessed. Thus, although the concept represented by Equation (4.22) is not generally recommended, it could be used in the evaluation of energy content for agroindustry by-products.

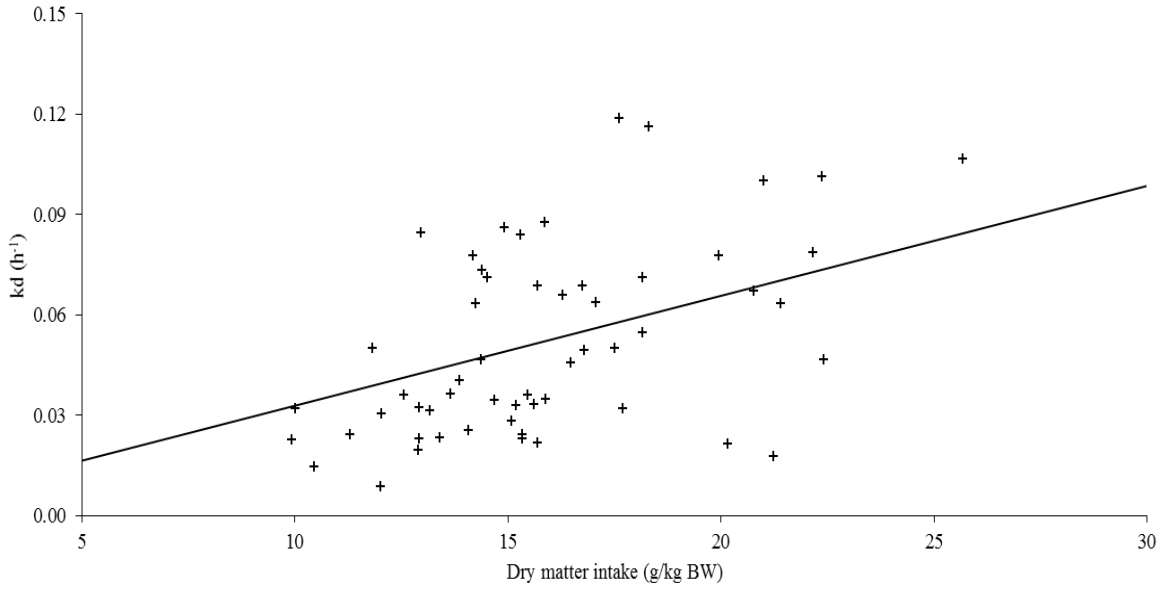

Figure 4.5 - Relationship between voluntary dry matter intake and degradation rate (kd) of potentially digestible neutral detergent fiber in forage-based diets (continuous line represents Equation 4.18).

Based on the evidence for the heterogeneous digestive pattern of the CP, a sub-model was developed considering two sub-compartments (Detmann et al., 2008c), whose chemical approximations are given by:

$$CCCP \cong CP - CWCP \quad (4.23a),$$

$$CWCP \cong NDIP \quad (4.23b),$$

where: CCCP, cell content CP; CWCP, cell wall CP; and NDIP, neutral detergent insoluble protein; all terms are expressed as % DM.

According to derivations by Detmann et al. (2008c), the CCCP would have a homogeneous digestive pattern similar to that of other non-fibrous components (EE and NFC) (Equation 4.8). On the other hand, by assumption, the digestion pattern of the CWCP would be similar to that observed for the NDF. In this way, the truly digestible fraction of the CP would be expressed, considering the chemical approximations represented in Equation (4.23), by:

$$tdCP = tD_{CCCP} \times CCCP + D_{pdCWCP} \times pdCWCP \quad (4.24a),$$

$$tdCP = tD_{CCCP} \times (CP - NDIP) + D_{pdCWCP} \times (NDIP - UNDIP) \quad (4.24b),$$

where: tdCP, truly digestible CP (% DM); tD_{CCCP}, true digestibility coefficient of the CCCP (g/g); pdCWCP, potentially digestible CWCP (% DM); D_{pdCWCP}, digestibility coefficient of the potentially digestible CWCP (g/g); and UNDIP, undegradable neutral detergent insoluble protein (% DM).

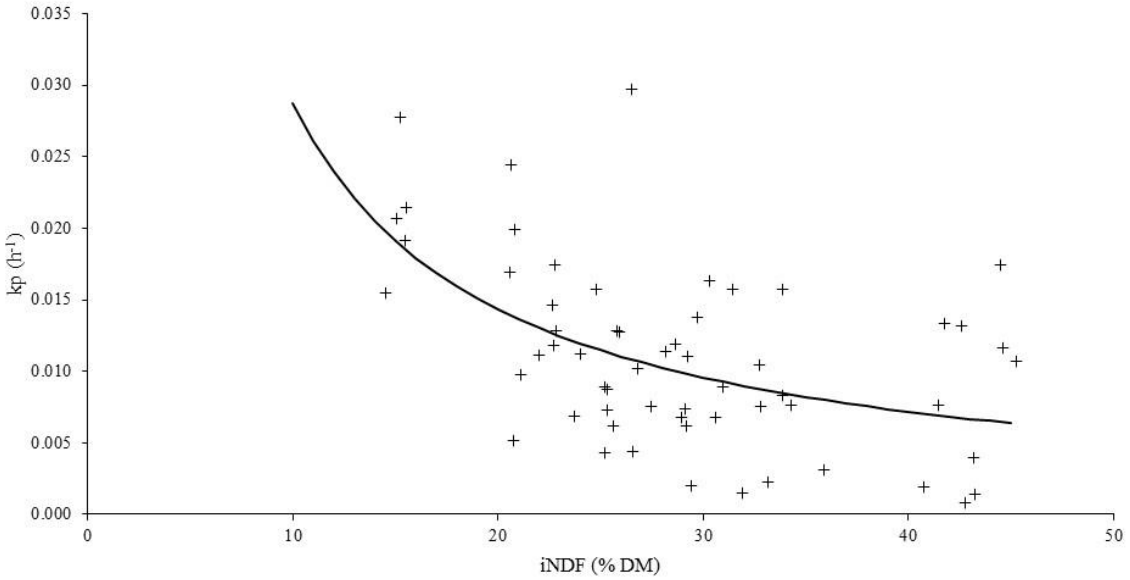

Figure 4.6 - Relationship between diet concentration of indigestible neutral detergent fiber (iNDF) and passage rate (kp) of potentially digestible neutral detergent fiber in forage-based diets (the continuous line represents Equation 4.19).

In the second edition of the BR-CORTE System, 0.98 g/g was used as the estimate for the true digestibility coefficient of CCCP (Van Soest, 1994; Detmann et al., 2006c; 2008c). However, for a better agreement to the estimates obtained from Brazilian data, this coefficient was altered to 0.95 g/g, similar to that one applied to estimate the truly digestible NFC (Equation 4.10). Following the assumptions adopted in the second edition of the BR-CORTE System, the digestibility coefficients of CWCP were presumed to be similar to those used for the fibrous portion of the feed/diet, which are no longer constant but vary in function of the diet and feeding conditions, as described in equations (4.15) to (4.21).

The analytical concept of UNDIP was defined by Detmann et al. (2004b) as an approaching to the parametric value of undegradable cell wall protein, which consists of the residual CP associated with the iNDF.

However, as pointed out previously, such an analytic approximation can be a hindrance in some situations, because fistulated animals may not be available. Thus, an alternative equation was developed to obtain the UNDIP value from the acid detergent insoluble protein (ADIP) using data from feeds produced under tropical conditions (Detmann et al., 2010a; n = 540), that is given by:

$$UNDIP = NDIP \times e^{-(0.8188+0.1676\times ADIP)} \quad (4.25),$$

where: ADIP, acid detergent insoluble protein (% DM), the other terms were previously defined (% DM).

When the chemical approximation for UNDIP is adopted, Equation (4.24b) can be rewritten as:

$$tdCP = 0.95\times(CP - NDIP) + D_{pdCWCP}\times\{NDIP\times[1-e^{-(0.8188+1.1676\times ADIP)}]\} \quad (4.26).$$

The chemical approximation of UNDIP via ADIP has some limitations, because the UNDIP is a biological concept with high variability (Henriques et al., 2007; Detmann et al., 2010a). Thus, this solution should be used with caution; it is preferable, when feasible, to estimate the UNDIP by a biological method (i.e., long term incubation procedure). Sampaio et al. (2012) observed that estimating UNDIP by *in situ* incubations (protein associated with the iNDF) gave more exact and precise estimates of digestible CP compared to using the chemical approximation.

When using empirical approximation to calculate the digestibility coefficient of the pdNDF fractions (Equations 4.18 to 4.21), the

truly digestible CP fraction should be calculated separately for the forage and concentrate fractions of the diet by adapting Equation (4.26):

$$tdCP = 0.95 \times (CP - NDIP) + \frac{kd}{kd + kp} \times \{NDIP \times [1 - e^{-(0.8188 + 1.1676 \times ADIP)}]\} \quad (4.27).$$

In calculating the digestible CWCP, we chose not to adopt the correction factor for intestinal digestion, because intestinal digestion of the fiber was considered to take place primarily in the large intestine. In this case, the CWCP digested in this compartment would be basically used for microbial growth, with no contribution for total metabolizable protein.

Detmann et al. (2008c), Magalhães et al. (2010) and Sampaio et al. (2012) observed that the bi-compartmental concept produced more accurate estimates of the apparently digestible CP in diets based on tropical forage than did the uni-compartmental concept. Thus the use of the bi-compartmental concept is recommended, and the use of the single compartment model should be only recommended to evaluate agroindustry by-products.

Summative system for TDN and conversion to digestible and metabolizable energy

The TDN diet content (% DM) is obtained by the algebraic sum of the estimates produced for each sub-model for each digestible fraction, according to the animal category, from the following equation:

$$TDN = adCP + adNFC + dNDF + 2.25 \times adEE \quad (4.28a),$$

$$TDN = (tdCP - CM_{CP}) + (tdNFC - CM_{NFC}) + dNDF + 2.25 \times (tdEE - CM_{EE}) \quad (4.28b),$$

$$TDN = tdCP + tdNFC + dNDF + 2.25 \times tdEE - (CM_{CP} + CM_{NFC} + 2.25 \times CM_{EE}) \quad (4.28c),$$

$$TDN = tdCP + tdNFC + dNDF + 2.25 \times tdEE - FM_{TDN} \quad (4.28d),$$

where: TDN, dietary TDN (% DM); adCP, adNFC, adEE, apparent digestible fractions of CP, NFC and EE, respectively (% DM); tdCP, tdNFC, tdEE, truly digestible fractions of CP, NFC and EE, respectively (% DM); dNDF, digestible NDF (% DM); CM_{CP}, CM_{NFC}, CM_{EE}, fecal metabolic contributions from CP, NFC and EE, respectively (% DM); FM_{TDN}, total fecal metabolic fraction for the TDN calculation (% DM; Table 4.1); and 2.25. the Atwater's constant to equalize lipids and carbohydrates.

Digestible energy (DE) content is estimated by considering the specific energy contribution of each truly digestible fraction and discounting the energy of the fecal metabolic fraction:

$$DE = 0.056 \times tdCP + 0.042 \times tdNFC + 0.042 \times dNDF + 0.094 \times tdEE - FM_{DE} \quad (4.29),$$

where: DE, digestible energy (Mcal/kg DM); and $FM_{ED,}$ fecal metabolic fraction for the DE calculation (Mcal/kg DM; Table 4.1). The other terms were defined previously.

The DE is converted to metabolizable energy (ME) by using the equation developed in the Laboratory of Animal Metabolism and Calorimetry at the Veterinary Medicine College of the Federal University of Minas Gerais:

$$ME = 0.9455 \times DE - 0.3032 \quad (4.30),$$

where: ME, metabolizable energy (Mcal/kg DM).

RECOMMENDED CHEMICAL ANALYSIS METHODS

The methods for chemical analysis of feeds suggested to assess the DM, organic matter (MO), CP, EE, ADF, NDIP, ADIP, iNDF, UNDIP, and lignin contents are summarized in Table 4.2. Generally, the methods applied to chemical analysis follow the recommendations established in the book Methods for Feed Analysis (Métodos para Análise de Alimentos) of the National

Institute of Animal Science and Technology (Instituto Nacional de Ciência e Tecnologia de Ciência Animal) (INCT-CA, Detmann et al., 2012), with some exceptions highlighted in the text. These exceptions are due to the absence of methods in the referred book or alterations already defined and that will be established in the second edition that is still in preparation.

To assess the total nitrogen content or CP, the Kejldhal method (method INCT-CA N-001/1) is recommended, with the following modification: use a 20:1 sodium sulfate-to-copper sulfate ratio in the digestion step (Silva et al., 2016). The same modifications should also be applied to the assessments of the nitrogenous compounds associated with the fibrous fractions (NDIP, ADIP, and UNDIP).

Table 4.2 - Summary of suggested methods to analyze feeds to predict the dietary TDN

Component	Method	General Description	Reference
DM	Pre-drying	55-60ºC/48-72 hours; equipment: forced ventilation oven	1
	Definitive drying	a. 105ºC/3 hours, for feeds with urea content higher than 10%; b. 105ºC/16 hours, for the other materials; equipment: non-ventilated oven, desiccator	2, 3
CP	Kjeldahl	Digestions in sulfuric acid (400ºC), distillation with sodium hydroxide, and titration with hydrochloric acid	4*
EE	Randall	Immersion time: 30 minutes; washing (dipping) time: 60 minutes; solvent condensation rate: 3-5 drops/sec; suggested extractor: petroleum ether	5
Ash	Calcination	600ºC/3-4 hours; equipment: furnace, desiccator	6
Organic Matter	By difference	OM = 100 – Ash	6
NDF, ADF	Detergent system	Contents assessed by conventional extractions under reflux (*Fibertech*) or by micro-extraction in autoclave	*
NDIP, ADIP	Detergent system	Assessment by the Kjeldahl method after extraction with the respective detergents	7*
NDIA	Detergent system	Assessment of the residual mineral matter in the NDF	8*
iNDF	*in situ* Incubation	*In situ* incubation for 288 hours using F57 (Ankom®) or non-woven textile (NWT, 100 g/m²) filter bags. Sample mass: 20 mg DM/cm² surface. Extract with neutral detergent	9
UNDIP	*in situ* incubation	Assessment of the protein associated with iNDF by the Kjeldahl method	9, 7*
Lignin	Sulfuric acid	Solubilization of cellulose by hydrolysis in H_2SO_4 (72% w/w) after prior treatment of the sample with acid detergent	10*

[1] Method INCT-CA G-001/1. [2] Method INCT-CA G-003/1. [3] Thiex and Richardson (2003). [4] Method INCT-CA N-001/1. [5] Method INCT-CA G-005/1. [6] Method INCT-CA M-001/1. [7] Method INCT-CA N-004/1 and N-005/1. [8] Method INCT-CA M-002/1. [9] Method INCT-CA F-008/1. [10] Method INCT-CA F-005/1. * See comments in the text.

The NDF and ADF content should be estimated by extractions using *Fibertech*-type equipment (Van Soest and Robertson, 1985; Mertens, 2002) or in an autoclave (Barbosa et al., 2015), according to the recommendations for reagents provided by INCT-CA (Detman et al., 2012). The NDF and ADF contents should be analyzed using filtering crucibles. For both cases, the use of *filter bags* should be regarded with caution because inaccuracies

in the NDF contents have been observed (Gomes et al., 2011a; Barbosa et al., 2015). Consequent adaptations are also demanded for the analyses of NDIP, ADIP, neutral detergent insoluble ash (NDIA), and lignin. In particular, the NDF analysis should be carried out using a heat stable α-amylase (Mertens, 2002) with the proper correction for the NDIP and NDIA contents (Detmann and Valadares Filho, 2010). Using sodium sulfite is not recommended because the solubilization of protein associated with fiber, lignin, and other compounds (Gomes et al., 2012). The ADF is analyzed sequentially to the NDF.

It is pointed out, however, that using filter bags and extractors adapted to this type of recipient (e.g., Ankom^{220}) is still recommended for the iNDF assessments. The extractor must function with a pressurized environment. Equipment adapted for use in atmospheric pressure leads to obtaining biased data (Gomes et al., 2011a).

The calculation of NDFap content is given by:

$$NDFap = NDF \times \frac{(100 - NDIP - NDIA)}{100} \quad (4.31),$$

where: NDFap, neutral detergent fiber corrected for contaminant ash and protein (% DM); NDF, neutral detergent fiber (% DM); NDIP, neutral detergent insoluble protein (% NDF); NDIA, neutral detergent insoluble ash (% NDF).

The NDF content (Equation 4.31) should be corrected so that the total NFC content of the feed is not underestimated and the energy contribution of the part of CP (NDIP) is not calculated in duplicate. On the other hand, correction avoids erroneous calculating of a part of mineral matter (NDIA) as an energetic component of feeds (Detmann et al., 2008b; Detmann and Valadares Filho, 2010).

In this context, the NFC content is obtained using the following equation (Detmann and Valadares Filho, 2010):

$$NCF = OM - [(CP - CPu + Ur) + EE + NDFap] \quad (4.32),$$

where: CPu, urea-derived CP (% DM); and Ur, urea content in the feeds (% DM).

DISCUSSION OF THE MAIN CHARACTERISTICS AND MODIFICATIONS TO THE MODEL

In comparison with the second edition of the BR-CORTE System (Detmann et al., 2010b), the structure of the sub-models used to predict the truly digestible fraction of the EE and NFC was maintained (Equations 4.9 and 4.10), because validation studies had confirmed its accuracy (Detmann et al., 2008b; Magalhães et al., 2010; Azevêdo et al., 2011; Sampaio et al., 2012), and confirmed the central hypothesis that both components could be treated as homogeneous nutritional entities and that their digestive pattern can be adequately interpreted by the Lucas test (Lucas and Smart, 1959; Lucas, 1960).

In addition, as reported in the second edition of the BR-CORTE System (Detmann et al., 2010b), the better performance of the summative system developed under Brazilian conditions can be partly attributed to the better adequacy of the fecal metabolic fractions (Table 4.1), which are necessary for proper conversion of the truly digestible fractions of EE, NFC, and CP to fractions compatible with apparent digestibility (the base used to calculate the TDN concentration). The fecal metabolic fraction is directly influenced by the nutrient flow to the large intestines, that implies alterations in cecal microbial activity (Ørskov, 1988), and by the level of fibrous components in the diet (Arroyo–Aguilu and Evans, 1972), which are notably different between animals fed under tropical and non-tropical conditions (Detmann et al., 2008b).

However, the sub-model initially proposed to assess the digestible NDF (Equation 4.12) presented low precision (Detmann et al., 2008b; Azevêdo et al., 2011; Sampaio et al., 2012), especially for growing and finishing cattle (Detmann et al., 2007).

The low prediction efficiency of this sub-model was attributed to two main factors. First, the use of a constant lignin constraint factor on NDF ruminal (parameter F; Equation 4.12), a characteristic also intrinsic to the sub-model adopted by the NRC (2001). The estimate of the parameter F adopted in the second edition of the BR-CORTE System was derived by Detmann et

al. (2004a), who evaluated samples of tropical forages through the analysis of lignin by the method of oxidation in potassium permanganate. However, the set of samples used by these authors was somewhat restricted, because it did not include concentrate feeds and consisted largely of samples of tropical grasses under grazing (e.g., *Brachiaria* grass). It was understood, however, that the relationship between lignin and iNDF could not be considered homogeneous among feeds (Palmonari et al., 2016). Therefore, these facts were used to support the first modification in the theoretical assumptions to estimate the digestible fraction of NDF.

As previously emphasized, the iNDF fraction, and consequently the pdNDF fraction, is an asymptotic biological concept; that is, it is defined when there are no restrictions regarding the time when the feed is degraded by the rumen's microbial enzymatic systems (Detmann et al., 2008a). The high variability among samples for the iNDF concentration and consequently the pdNDF indicates that, although lignin is the main determining factor of the extension of fiber degradation (Van Soest, 1994), simple gravimetric analyses may not be capable of properly predicting all the determining factors of the asymptotic limits of the degradation (Detmann et al., 2008b). Thus, direct analysis of the iNDF by long term *in situ* rumen incubation trials would be a more plausible biological alternative for fractioning the NDF in feeds.

Nevertheless, there are limitations to carrying out such trials because animals fistulated in the rumen need to be available, and a long period of time is required (Casali et al., 2008; Valente et al., 2011). Thus, empirical prediction equations were developed by analyzing forage (n = 371) and concentrate samples (n = 65), and the results are expressed in equations (4.13) and (4.14), respectively (Figures 4.1 and 4.2). To fit these equations, associations with various feed components were properly investigated [i.e., NDF, NDFap, ADF, ADF corrected for contaminant ash and protein (ADFap), lignin assessed by acid hydrolysis and oxidation with permanganate]. One of the greatest advantages regarding the assumptions adopted in the second edition of the BR-CORTE System is the use of different models for forages and concentrates.

As previously pointed out, correlations between the different chemical characteristics considered and the iNDF fraction were weaker compared to those obtained for the pdNDF fraction (Table 4.3), which may reflect the greater proportion of pdNDF compared to iNDF in the total DM of the feeds. As these fractions are complementary to each other, better fits of the models were obtained considering the pdNDF fraction as the dependent variable. However, although complementary in relation to the total NDF, the pdNDF and iNDF fractions, expressed as DM percentage, were shown not to be correlated (Table 4.3) due, in most part, to the high variability of the NDF contents among feeds and to a lesser extent, to the high variability in the partitioning of the NDF into the potentially digestible and indigestible fractions among feeds.

The basic characteristic for fitting models for predicting the pdNDF fraction for forages and concentrates was the strong correlation observed with NDFap content (Table 4.3; Figures 4.1 and 4.2). This relationship seems to be logical, as, with rare exceptions, the pdNDF fraction corresponds to the most of the total NDF, thus showing a direct relationship of proportionality. These correlations were slightly stronger when compared with that for NDF (Table 4.2) possibly because of the small influence of cell wall protein and minerals on the potential of fiber degradation. In this sense, relations with other fiber characteristics were added to the models based on the NDFap concentration in order to incorporate discriminatory elements among feeds in function of the potential utilization of the fiber in the rumen.

Especially for forages, the linear and quadratic effects of the ADF and the linear effect of lignin concentration were added to the model to predict the pdNDF fraction (Equation 4.13).

Lignin plays a central role on the extent of fiber degradation in the rumen (Van Soest, 1994). The negative correlations between lignin and the pdNDF fraction for forages corroborate this statement, implying a negative regression coefficient in equation (4.13). Although evidence points to stronger correlations between the potential degradation of the tropical forage NDF and lignin analyzed by oxidation in permanganate (Gomes et al., 2011b), the set of samples

assessed here showed a better association based on lignin contents assessed by the hydrolysis in sulfuric acid (Table 4.3). Thus the analysis methods were modified compared to the second edition of the BR-CORTE System (Table 4.2) and the recommendation of the method by oxidation in permanganate was removed. From a pragmatic point of view, this recommendation was shown to be advantageous, because the hydrolysis in sulfuric acid method requires less labor, has fewer analytical steps and lower cost compared to the method of oxidation in permanganate. However, it should be pointed out that the using hydrolysis method may lead to overestimation of the lignin concentration in feeds with a high cutin content, due to the joint consideration of these components (lignin and cutin) in the residue assessed as lignin (Van Soest, 1994). For most feeds, the cutin contribution has little relevance. However, for cutin-rich feeds, such as castor seeds by-products (meal and cake) and cactus, the method of oxidation in permanganate may produce more reliable results for the lignin concentration.

Table 4.3 - Pearson's linear correlations coefficients for the concentrations of the pdNDF and iNDF fractions and different chemical characteristics in forages and concentrates

Characteristic[1]	Feed[2]			
	Forages		Concentrates	
	pdNDF	iNDF	pdNDF	iNDF
NDF	0.838 (<0.001)	0.541 (<0.001)	0.950 (<0.001)	0.427 (<0.001)
NDFap	0.868 (<0.001)	0.576 (<0.001)	0.967 (<0.001)	0.408 (<0.001)
ADF	0.539 (<0.001)	0.632 (<0.001)	0.811 (<0.001)	0.344 (0.004)
ADFap	0.534 (<0.001)	0.603 (<0.001)	0.803 (<0.001)	0.340 (0.005)
Lignin (H)	-0.553 (<0.001)	-0.106 (0.040)	0.059 (0.643)	0.911 (<0.001)
Lignin (Ox)	-0.505 (<0.001)	-0.080 (0.131)	0.502 (<0.001)	0.391 (0.001)
pdNDF × iNDF	0.095 (0.067)		0.163 (0.195)	

[1] NDF, neutral detergent fiber; NDFap, NDF corrected for contaminant ash and protein; ADF, acid detergent fiber; ADFap, ADF corrected for contaminant ash and protein; Lignin (H), lignin assessed by hydrolysis in sulfuric acid; Lignin (Ox), lignin assessed by oxidation in potassium permanganate. [2] Values in parenthesis represent the descriptive level of probability for H_0: $\rho = 0$.

Unlike that observed for NDF, the corrections for ash and protein did not improve the correlations between pdNDF and ADF (Table 4.3). Thus, the model (Equation 4.13) was based on the ADF concentrations without corrections. Although the ADIP is required to estimate the truly digestible fraction of the CP by using chemical approximation (Equations 4.26 and 4.27), excluding the use of the ADFap reduces the analytical labor, because it eliminates acid detergent insoluble ash (ADIA) analysis from the laboratory routine. It is pointed out that sequential ADF extraction removes a large part of the cell wall protein and biogenic silica (Van Soest, 1994), making the ADIP and ADIA participation lower than the NDIP and NDIA participation in the total DM of the sample, that seems to further justifies the correlations between pdNDF and ADFap being similar or weaker compared to the correlations between pdNDF and ADF.

Although the correlation between pdNDF and ADF was initially positive (Table 4.3), it was included in the model with a negative effect on pdNDF (Equation 4.13). This inversion in the direction of association reflects a limitation of the Pearson correlation coefficient when applied to a group of variables highly correlated, because the

estimate of correlation for any pair of variables can hide the influence from the other variables assessed (Spiegel, 1971). However, in spite of the inversion in the direction of association, including the ADF in the model improved its fit and contributed significantly to the explanation of the relationship ($P \leq 0.04$). The quadratic pattern of Equation (4.13) suggests that there would be a minimum pdNDF content in function of the ADF, with subsequent increase. However, the effect of ADF on pdNDF is continually decreasing in the mathematical domain of its concentrations. The study of the partial derivative of the pdNDF concentration in function of the ADF concentration indicates that increases in pdNDF would only occur in limits within the field of the extrapolation and under biologically unlikely ADF concentrations (ADF≥64.2% DM).

The presence of ADF in the model (Equation 4.13) should be noted with caution, however. From a theoretical point of view, it must be emphasized that the ADF does not meet any correct definition of dietary fiber or insoluble fiber (Mertens, 2003), and therefore should not be considered a valid or useful nutritional concept. Using ADF in equations to predict digestibility ignores the physiological basis that relates the fibrous components to digestibility. Digestion of all the insoluble fiber fractions is limited mainly by lignification. In this context, establishing relationships between ADF and digestion characteristics, mainly for insoluble fiber, are inconsistent from a nutritional point of view (Detmann, 2010) and represent only statistical associations. Biologically, negative correlations between ADF and insoluble fiber digestibility should be attributed to lignin rather than the ADF *per se* (Detmann, 2010). Thus, the negative effect of the ADF observed in the model, even in the presence of lignin (Equation 4.13), seems to reflect only the effect of the proportional participation of the different insoluble macro-components of the cell wall (cellulose, hemicellulose and lignin) in the forage NDF, that might influence its potential of degradation due to their different chemical bonds and physical interactions and the different participation of these components in the different plant tissues, that vary in participation in the plant depending on the species and stage of maturity.

For concentrate feeds, the linear negative effect of the ADF was added to the model to predict the pdNDF fraction (Equation 4.14). Although the lignin concentrations measured by oxidation correlated negatively with pdNDF (Table 4.3), its inclusion in the model did not make any significant contribution ($P > 0.46$). As emphasized previously, the central effects on the NDF potential degradation should be attributed to lignin (Van Soest, 1994) and correlations between this characteristic and the ADF should be seen only as statistical associations. Thus, for concentrate feeds, the ADF seems to directly reflect lignin action, because lignin would be proportionally more representative in the acid detergent insoluble residue (cellulose + lignin) compared to the neutral detergent insoluble residue (hemicellulose + cellulose + lignin). On the other hand, assessing lignin in concentrates can present inherent difficulties due to its low concentration that decreases the precision of the gravimetric measurements. Thus, the advantage highlighted here for the ADF in concentrate feeds is due to the fact that lignin is contained in the ADF, allowing its quantification in a residue with greater mass, without needing a second chemical procedure to separate the cellulose, that also makes the analyses more practical, faster and cheaper.

A “dummy” variable was introduced in the model applicable to the pdNDF concentration in concentrates to correct the estimates for feeds with fiber with lesser potential degradation (Equation 4.14). This correction was incorporated only at intercept, because the slope of both the groups of concentrated feeds in function of the NDFap concentration was similar (Figure 4.2). Although the feed group with fiber with lesser potential degradation in the dataset includes only cotton by-products and wheat bran, subsequent assessment using the CQBAL 3.0 database (Valadares Filho et al., 2015) showed that correction by the dummy variable would also be applicable to sunflower by-products (meal and cake) and GEC.

The second factor that influences the low precision of the NDF digestible fraction

in the sub-model adopted in the second edition of the BR-CORTE System is the adoption of fixed digestibility coefficients for the pdNDF fraction, a limitation pointed out previously by Detmann et al. (2010b). The pdNDF digestibility coefficient results from the integration between the dynamics of degradation and transit in the ruminant gastrointestinal tract and, consequently, all the factors with potential influence on these characteristics. Although the pdNDF digestibility coefficients previously adopted were different among animal categories, they were derived from the joint analysis of a small number of experiments (Detmann et al., 2007), that did not permit contemplation of the widely different dietary situations observed in Brazilian conditions. This question is particularly relevant for growing and finishing cattle, because the data originally used presented a great number of observations derived from experiments with animals managed on low-quality tropical pastures (Detmann et al., 2007), that, together with the problems reported previously for estimating the iNDF, seem to have implied a positive bias on the estimates of the digestible NDF for this animal category.

The first proposal to obtain estimates for the digestibility coefficient was based on a meta-analytical evaluation of diets (hereafter denoted as the meta-analytical approximation). The integration of different studies by meta-analytical techniques has the obvious advantage of contemplating a wide range of dietary conditions, which would not be feasible to obtain in one or few experiments. Data from 45 diets with dairy cows and 213 diets with growing and finishing cattle (treatment means) were compiled. In principle, the objective was to fit a single equation to both animal categories, aiming at greater reliability due to the larger number of dietary conditions. However, the initial assessments showed that illogical associations from a biological point of view were being indicated by the equations (e.g., positive association between dietary EE and fiber digestion), a possible reflection of occurrence of the Simpson Paradox, that indicates the reversion of the direction of an association when data are combined from several groups to form a single group (Moore, 1995). In this way, different equations were fitted to each group. The backward regression method was adopted (Draper and Smith, 1966) and the regression parameters were adjusted for the random effects of the different experiments. However, a preselecting of the independent variables was done by inspecting the Pearson linear correlations.

For growing and finishing cattle, the strongest correlations with the pdNDF digestibility coefficient were observed for dietary CP ($r = 0.18$; $P<0.03$) and voluntary iNDF intake ($r = 0.25$; $P<0.01$). However, due to difficulties in obtaining estimates of the iNDF intake, this variable was replaced in the process of fit by voluntary DM intake (whose estimation can be obtained by the BR-CORTE System) and dietary iNDF, because the multiplication of both resulted in the iNDF intake. Distinction between different forage groups was necessary for the correct fit of the equation, and they were grouped in forages with high (i.e., corn and sorghum silages) and low (i.e., sugarcane, grass hay, grass silage, fresh grass) starch content (Equation 4.15; Figures 4.7 and 4.8).

The assessment of Equation (4.15) showed a positive effect of dietary iNDF content on pdNDF digestibility for low- (Figure 4.7) and high-starch (Figure 4.8) forages. This effect is associated with the fact that the indigestible fiber fraction has, proportionally, greater rumen fill effect compared to the potentially degradable fraction, because it is only removed from the rumen by passage (Waldo et al., 1972; Detmann et al., 2015). The increase in the rumen fill effect of the NDF with the greater participation of the iNDF fraction implies longer retention times, increasing the exposure time of the pdNDF fraction to the action of the rumen microorganisms. This effect of the dietary iNDF content was more prominent when high-starch forages were considered (Figure 4.8)

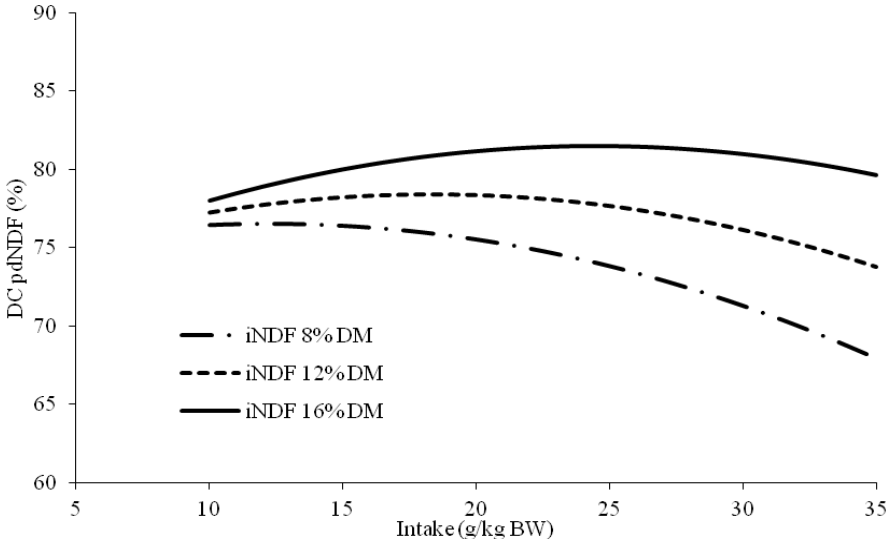

Figure 4.7 - Variations in the digestibility coefficient of potentially digestible neutral detergent fiber (DC pdNDF) according to voluntary dry matter intake and iNDF diet content for growing and finishing cattle fed forage with low starch content (Equation 4.15; presuming diet with 12% CP based on the DM).

Due to the effect of the interaction between forage type and dietary CP, positive effects associated with an increase in diet CP were only significant for high-starch forages (Equation 4.15). Clearly positive effects of nitrogenous compounds availability in the diet on effective fiber utilization in the rumen are normally observed when nitrogen deficient diets are offered to animals (Detmann et al., 2009), a characteristic little observed in the dataset used in the present study. However, with the increase in starch participation in the diet, deleterious effects on fiber utilization can be observed, that are attributed to falls in rumen pH to values below the adequate for fibrolytical activity or to an increased competition for substrates among fibrolytic and non-fibrolytic species (Mertens and Loften, 1980; Mould et al., 1983; Arroquy et al., 2005; Carvalho et al., 2011). However, results obtained in tropical conditions show that increase in diet availability of nitrogenous compounds can reduce competition between microbial species, reducing the deleterious effect of starch on ruminal fiber utilization (Costa et al., 2009; Lazzarini et al., 2016). This seems to justify the positive effect of the CP diet concentration on the pdNDF digestibility in high-starch forage (Equation 4.15).

Generally, for growing and finishing cattle, a negative effect of intake on pdNDF digestibility was observed (Girard and Dupuis, 1988; Figures 4.7 and 4.8). Under normal feeding conditions (without drastic imbalances) it is understood that the rumen passage rate is greatly influenced by intake (Pittroff and Kothmann, 1999). Thus, higher intakes are associated with higher passage rates and consequently lower rumen retention time and lower time for microbial action on the fiber. However, it was observed that the effect of intake on the pdNDF digestibility coefficient decreases as the quality of the diet decreases (increase in iNDF content), making the values practically stable in all range of the voluntary intake evaluated here (Figures 4.7 and 4.8). It is understood that voluntary intake by cattle is regulated by multiple mechanisms that act simultaneously. However, variations in the dietary conditions can make the regulating mechanisms alter in importance in the total sum of the influences that determine the voluntary intake (Detmann et al., 2014). In this sense, with a decreased diet quality, physical intake regulation mechanisms can become more prominent due to longer retention time of the digesta in the rumen, decreasing the influence of the intake level on passage rate and making the intake influence lesser evident regarding the pdNDF digestibility.

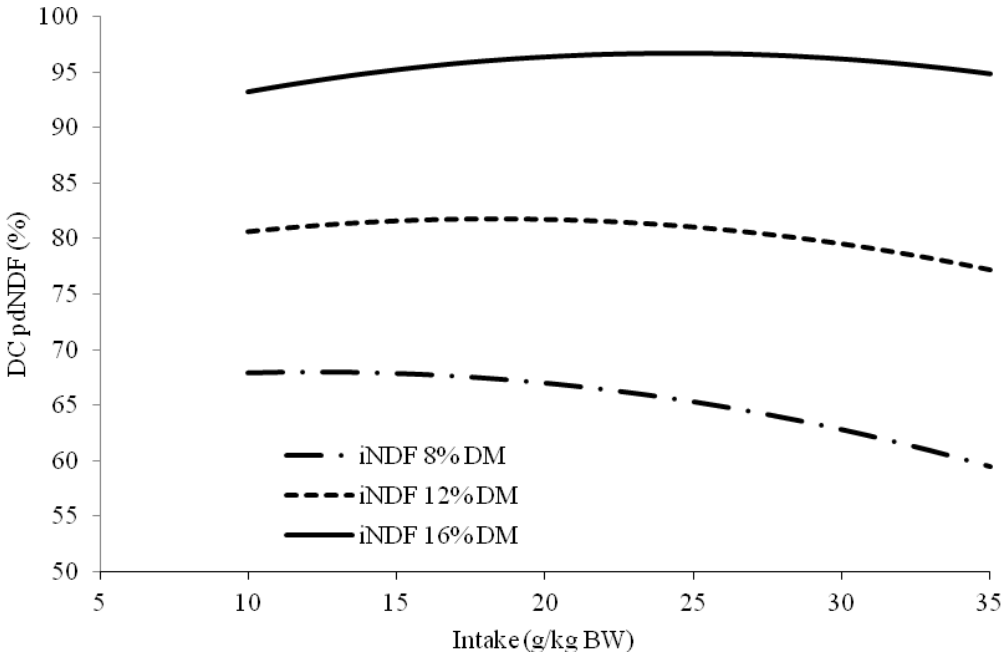

Figure 4.8 - Variations in the digestibility coefficient of the potentially digestible neutral detergent fiber (DC pdNDF) according to voluntary dry matter intake and iNDF diet content for growing cattle fed forage with high starch content (corn or sorghum silage; Equation 4.15; presuming diet with 12% CP based on the DM).

The model adopted for dairy cows was shown to be simpler compared to the model adopted for growing and finishing cattle (Equation 4.16; Figure 4.9). For this animal category, the pdNDF digestibility correlated negatively with the diet concentrate level ($r = -0.31$; $P<0.05$) and voluntary DM intake ($r = -0.36$; $P<0.04$). Negative correlation between the pdNDF digestibility coefficient and the CP concentration in the diet was also observed ($r = -0.47$; $P<0.01$). However, its inclusion did not result in a significant contribution to the fit of the equation, possibly because of the strong correlation between concentrate level and CP concentration in the diet ($r = 0.64$; $P<0.01$). In other words, the effects of the CP would be confounded with concentrate level in the diet. The greater simplicity of the model applicable to dairy cows is a possible reflection of the greater homogeneity of the diets offered to this animal category compared to those offered to growing and finishing cattle.

In general, increases in voluntary intake decreased pdNDF digestibility for reasons similar to those discussed for growing and finishing cattle (Figure 4.9). Similarly, the increase in concentrate content, expressed by an interaction with voluntary dry matter intake (Equation 4.16), has negative effects on fiber digestibility. However, these effects become larger as the level of concentrate and total intake increase. Higher concentrate and voluntary intake levels imply a greater NFC intake, compromising the conditions favorable to rumen fiber degradation due to the lower pH and greater competition between microbial species, as previously discussed.

The range of pdNDF digestibility coefficients obtained for dairy cows shows that the coefficient previously adopted for this animal category in the second edition of the BR-CORTE System (0.67) was underestimated for most dietary conditions.

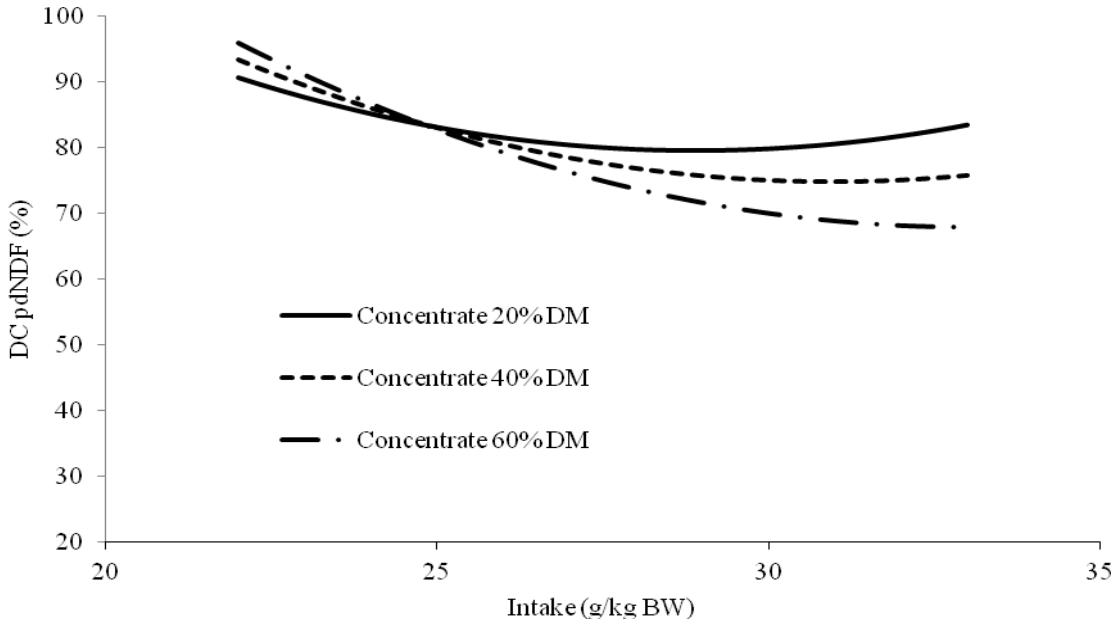

Figure 4.9 - Variations in the potentially digestible neutral detergent fiber digestibility coefficient (DC pdNDF) according to voluntary dry matter intake and concentrate level in diet for dairy cows (Equation 4.16).

Although equations (4.15) and (4.16) presented good fit (Figures 4.3 and 4.4), these models are based exclusively on experimental data and not on biological or theoretical bases. Therefore, even with good fit, the model should be considered specific for the conditions under which the data were obtained (Forbes and France, 1993) and their predictive value is restricted to the mathematical domain of the independent variables of each model. Thus, atypical diet combinations (e.g. diets containing corn silage with 22% iNDF and 15% CP for growing and finishing cattle) could produce biologically implausible pdNDF digestibility values. Especially for dairy cows, the conformation of the fitted model (Equation 4.16) indicates that it should not be applied for voluntary intakes greater than 32-34 g/kg body weight, because intakes greater than these were not observed in the dataset used for the meta-analytical assessments.

Although the meta-analytical approximation is based on the interpretation of empirical data, an intrinsic limitation is observed for this approximation. The fitted models require as input characteristics of the diet that are observed after their formulation (i.e., dietary contents of CP and iNDF, and concentrate levels in the diet). This makes the prediction process iterative, that is, the process of assessing the dietary energy starts from initial estimates for these variables supplied by the user. The output is assessed and used to back feed the model. The new solution obtained is again assessed and the cycle is repeated until the animal energy requirements and the energy supplied by the diet converge.

Thus, an alternative and more easily applied sub-model was developed (Equation 4.17) based on empirical information on the rumen dynamics of pdNDF assessed in cattle fed exclusively with forage (hereafter denoted as "empirical approximation"). Although data of animals fed with diets consisting of forage and concentrate are available, they were not used in order to develop a simplified sub-model that could be applied to individual feeds without needing information on the composition of the final diet. In addition, discrete adjustments regarding the animal categories were not contemplated in the empirical approximation, but were restricted to differences in the intake level and basal forage of the diet.

In this sense, the pdNDF degradation rate can be predicted from the voluntary DM intake (variable that can be estimated by the BR-CORTE System) by a positive and linear relationship. The positive association between the pdNDF degradation rate and voluntary

intake (Equation 4.18; Figure 4.5) is based on the fact that the rumen fill effect of fiber, particularly its potentially degradable fraction, is negatively associated with its degradation rate in the rumen (Waldo et al., 1972; Detmann et al., 2015). Thus, it should be understood that the relationship expressed by Equation (4.18) is based on increase in diet quality.

The pdNDF passage rate of forage showed a simple, negative and curvilinear association with iNDF concentration in the basal forage of the diet, and this ratio was best described by a hyperbolic model (Equation 4.19; Figure 4.6). Although the iNDF and pdNDF fractions have different passage rates in the rumen (Lund et al., 2007), increase in the forage iNDF fraction increases the total rumen fill effect of NDF, because the iNDF fraction only disappears from the rumen by a single pathway (passage) and therefore, has lower turnover rate compared to the pdNDF fraction. In this way, both the equations fitted (Equations 4.18 and 4.19) present biological coherence with the idea of assessing pdNDF availability from integrating the rumen dynamics of transit and degradation (Equation 4.17).

However, the integration of transit and degradation refers only to the ruminal events and does not consider the possible utilization of pdNDF in the large intestine, which complements the total digestibility of this fraction. Thus, an intestinal digestibility adjustment factor (IAF) was adopted to compensate the post rumen digestive events. In the evaluated dataset, it was observed that, on average, 89% of the total pdNDF digestion took place in the rumen, that culminated in the adoption of IAF = 1.12 (1/0.89). This proportion was close to that suggested by other authors for non-tropical conditions (Huhtanen et al., 2010).

A limitation of the empirical approximation is the absence of data associated with the passage rate of concentrate pdNDF. This type of information is scarce in Brazil. Therefore, the fit for the concentrate passage rate was based on the pdNDF passage rate of the basal forage and on the rate of passages of fiber from concentrates and forages obtained by Bürger et al. (2000) (Equation 4.20). However, these adjustments may be modified as new information is obtained for Brazilian conditions.

As described previously for lactating cows (Figure 4.9), including concentrates in the diet can affect the digestibility coefficient of the pdNDF, particularly at the level of the rumen. This pattern shows there are effects associated with including concentrates that can affect the pdNDF degradation rate (BCNRM, 2016). Alterations in the degradation rate can cause alterations in the fiber passage rate (Allen, 1996). However, such impacts are not directly contemplated in the empirical approximation and their consideration in future approximations may increase the predictive capacity of the model.

As the pdNDF passage rate is estimated based on the iNDF concentration in basal forage, it would be impossible to obtain estimates for diets formulated exclusively with concentrates. As data of the rumen transit and degradation dynamics for this particular type of diet do not exist for Brazilian conditions, it was chosen to recommend the equation adopted by the NRC (2001) (Equation 4.21).

The structure of the sub-model adopted to estimate the truly digestible fraction of the CP was maintained in relation to the second edition of the BR-CORTE System (Equations 4.24 to 4.27). The only alterations made concerned the digestibility coefficients of the CP fraction associated with the cell content and cell wall. In the first case, for a better agreement to the estimates obtained with Brazilian data, this coefficient was altered from 0.98 to 0.95, converging to that which is applied to estimate the truly digestible NFC (Equation 4.10). Considering that the CP associated with the cell wall presents, by assumption, digestive pattern similar to that is observed for the fibrous portion of the feed/diet, its digestibility coefficients should be modified according to the sub-model used to estimate the pdNDF digestible fraction (Equations 4.15 to 4.21).

It is emphasized, however, that estimating the UNDIP from the ADIP was proposed to speed the prediction process (Detmann et al., 2010a). However, caution should still be maintained, because the UNDIP (biological analytical concept) and

ADIP (chemical analytical concept) relationship is not very precise due to the high biological variability of the availability of nitrogen compounds associated with the fiber (Henriques et al., 2007; Detmann et al., 2010a). In this context, using the ADIP as predictive element should be understood only as chemical approximation, without any biological foundation being ascribed to its action on nitrogen compound digestibility.

To better understand the modifications in these sub-models regarding the second edition of the BR-CORTE System, a comparative assessment was performed using the chemical composition of forages (n = 16) and concentrates (n = 8) recorded in the CQBAL 3.0 dataset (Valadares Filho et al., 2015). The feeds were selected based on their routine use in cattle feeding, availability of all the items of chemical composition necessary to the estimation process, and the availability of observed TDN values. It is emphasized, however, that this validation process should be seen with caution, because the items regarding chemical composition can be derived from different sources and furthermore, the situations are not clear in which the TDN concentrations were assessed *in vivo*. The assessments are centered on the NDF and CP digestible fractions, because modifications were not established for the sub-models applied to estimate the EE and NFC digestible fractions.

Generally, marked differences were not observed among the meta-analytical and empirical approximations presented here or the sub-models adopted in the second edition of the BR-CORTE System for the NDF and CP digestible fraction values for concentrates. All the approximations produced TDN values close to those observed in the CQBAL 3.0 dataset (Figures 4.10 and 4.11).

However, marked differences were observed when forage samples were considered (Figure 4.10). The summative system adopted in the second edition of the BR-CORTE System tended to overestimate the TDN content in forages as a reflex of the higher estimates of the digestible NDF. As emphasized previously, the combination of using the fixed digestibility coefficient and a constant protection factor associated with lignin (Equation 4.12) tends to overestimate this fraction, especially in growing and finishing cattle. In this sense, the empirical approximation (Equations 4.17 to 4.20) produced lower NDF digestible fraction estimates (Figure 4.10), so that the TDN levels in forages were more similar to the values observed *in vivo* (Figure 4.11). On the other hand, the meta-analytical approximation (Equation 4.15) gave lower values of the digestible NDF, producing TDN values substantially lower than the values observed *in vivo*. Considering the similarity among all the approximations for the truly digestible fraction of the forage CP (Figure 4.10), the main differences between approximations are in the process of estimating the NDF digestible fraction.

To better understand the differences between approximations, a simplified evaluation of the composition of prediction error was carried out based on derivations reported by Kobayashi and Salam (2000):

$$MSPE = \frac{1}{n}\sum_{i=1}^{n}(x_i - y_i)^2 \quad (4.33),$$

$$SB = (\bar{x} - \bar{y})^2 \quad (4.34),$$

$$MSV = MSPE - SB = \frac{1}{n}\sum_{i=1}^{n}[(x_i - \bar{x}) - (y_i - \bar{y})]^2 \quad (4.35),$$

where: MSPE, mean squared prediction error; x_i, predicted values (% DM); y_i, observed values (% DM); SB, squared bias; and MSV, mean squared variation.

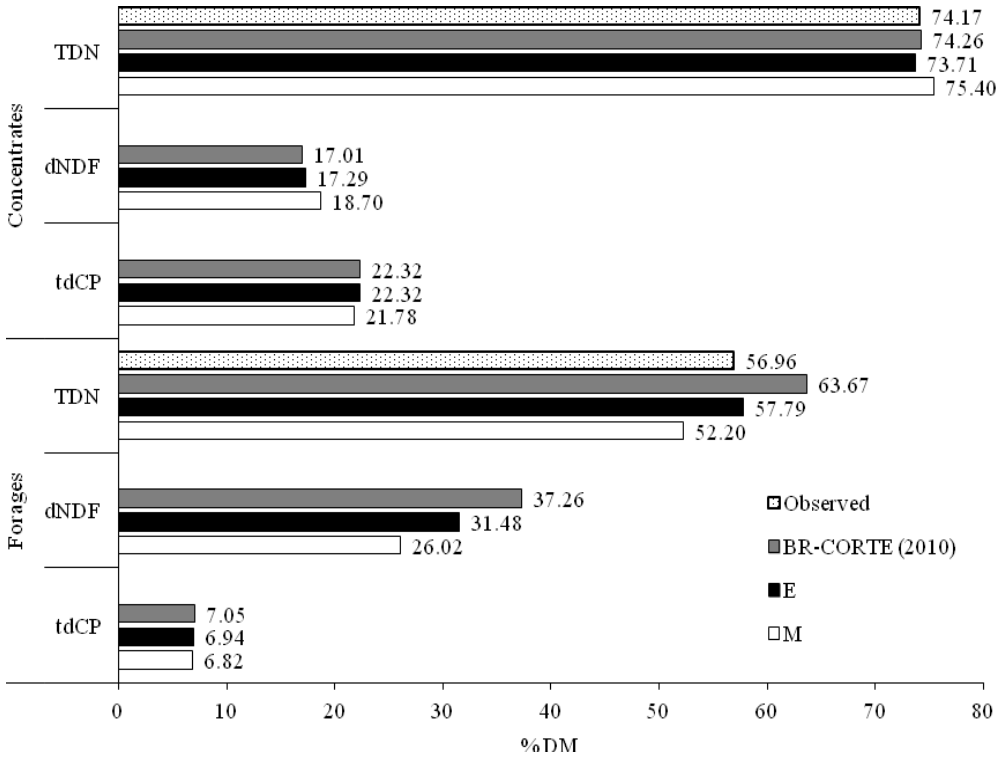

Figure 4.10 - Estimates of the truly digestible CP (tdCP), digestible NDF (dNDF) and the TDN content obtained by the sub-models adopted by the BR-CORTE (2010) and the meta-analytical (M) and empirical (E) approximations for growing and finishing cattle and TDN contents obtained from CQBAL 3.0 (forages, n = 16; concentrates, n = 8). The empirical and meta-analytical models considered intake of 22 g/kg body weight. For the meta-analytical model, a mean concentration was adopted of 12% CP and 14% iNDF in the diet. For the empirical and meta-analytical models applied to concentrates, corn silage was considered as the basal forage.

Due to the intrinsic limitation in the dataset obtained from the CQBAL 3.0, as previously mentioned, it was chosen not to carry out a more rigorous assessment of prediction error. The simplified partitioning used here (Equations 4.33 to 4.35) allowed the basic identification of the composition of the mean squared prediction error (MSPE) in relation to limitations in the accuracy (SB) or precision (MSV) of the models.

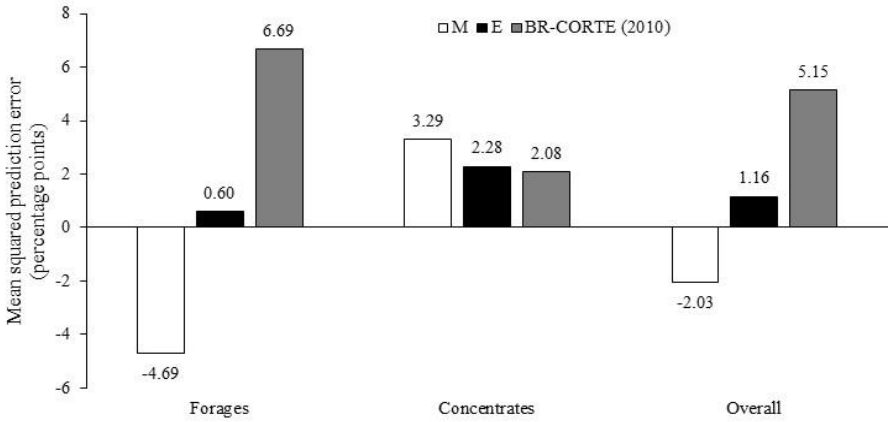

Figure 4.11 - Mean prediction error for TDN content (percentage points) in concentrate and forage feeds obtained by the sub-models adopted by the BR-CORTE (2010) and by the meta-analytical (M) and empirical (E) approximations for fiber and protein for growing and finishing cattle in relation to the mean TDN values observed according to data from CQBAL 3.0 (forages, n = 16; concentrates, n = 8). To verify the assumptions applied to each model, please consult Figure 4.10.

In this sense, the general assessment of the dataset showed that large gains in accuracy and precision were obtained only for forages because only a slight difference was observed regarding concentrate feeds (Figure 4.12).

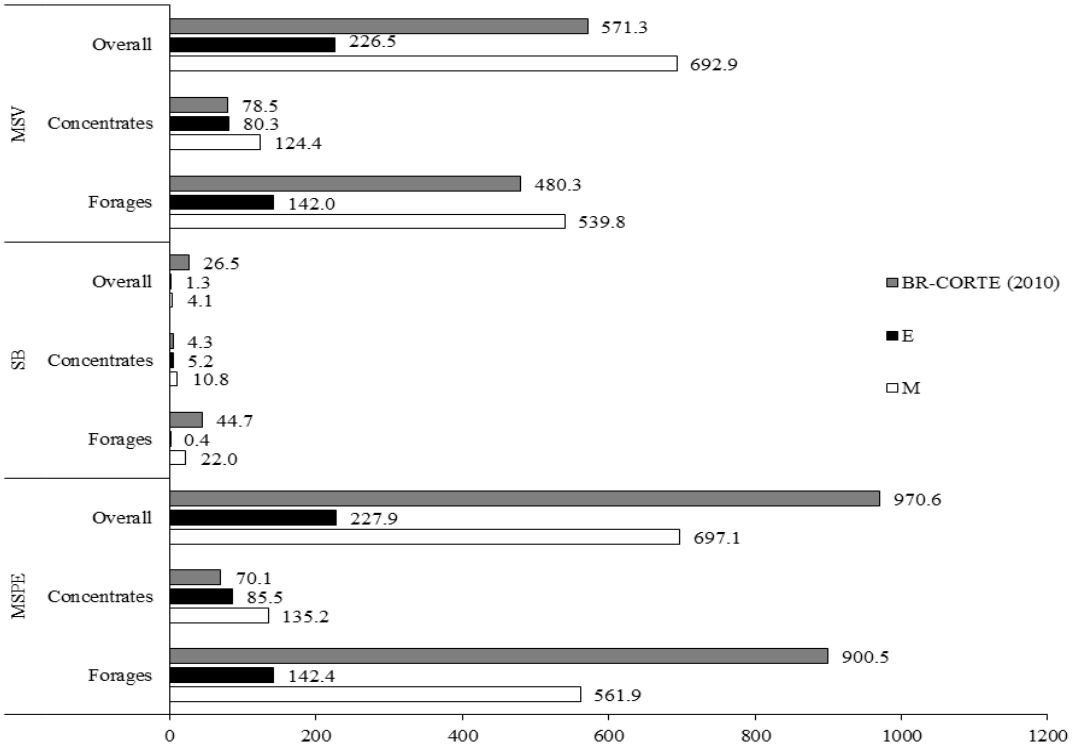

Figure 4.12 - Mean squared prediction error (MSPE), squared bias (SB) and mean squared variation (MSV) for the TDN contents in concentrate and forage feeds obtained by the sub-models adopted by the BR-CORTE (2010) and by the meta-analytical (M) and empirical (E) approximations for fiber and protein for growing and finishing cattle in relation to the mean TDN values observed according to data from CQBAL 3.0 (forages, n = 16; concentrates, n = 8). To verify the assumptions applied to each model, please consult Figure 4.10.

The empirical approximation produced more accurate estimates compared to the sub-models adopted in the second edition of the BR-CORTE System. The digestibility coefficient of the pdNDF for growing and finishing cattle previously adopted by the BR-CORTE System (0.84) was shown to be lower than the mean pdNDF digestibility for forage samples considering the empirical approximation (0.867). Even so, higher estimates were observed of the NDF digestible fraction, culminating in overestimation of the TDN concentration. This fact warns for the presence of positive biases in the pdNDF fraction estimation by Equation (4.12). However, the biggest gains were observed for the precision of the estimates, that, as emphasized previously, was the main limitation in the assessment of the digestible NDF (Detmann et al., 2007; 2008b; Azevêdo et al., 2011). Although the equations used for this approximation are relatively simple (Equations 4.17 to 4.20), considering the particularities of the basal forage (i.e., iNDF content) instead of constant coefficients for the pdNDF digestibility seems to have reflected in similar variations and stronger correlations with values observed *in vivo*. Thus, the empirical approximation was shown to be a more exact and precise alternative to replace the sub-model previously adopted by the BR-CORTE System to estimate the digestible NDF, with consequent applications on the CP digestible fraction.

Although developed from a large number of *in vivo* observations, the meta-analytical approximation showed limitations regarding accuracy (Figures 4.11 and 4.12) and precision (Figure 4.12) for TDN content in forage. This pattern could lead to its non-recommendation. However, it should be pointed out that the estimates of the digestible NDF and CP obtained by this approximation were based only on initial estimates for the end composition of the diet (Figures 4.10 and 4.11). As emphasized previously, using such approximation is an iterative process, in which sequential fits from the outputs are necessary to reach convergence between energy requirements and energy intake. Thus, it would be expected that the first output (obtained from initial values defined by the user) would produce low-precision estimates. In this way, the performance observed here for the meta-analytical approximation may not reflect its true characteristics. However, due to the lack of data, assessment procedures and mainly validation procedures of this approximation could not be developed, which would be recommended.

EXAMPLE OF APPLICATION

Productive Situation - growing and finishing Nellore cattle (feedlot).
Diet: forage:concentrate ratio 50:50 (dry matter basis), 12%CP.
Expected intake: 25 g DM/kg body weight.
Forage: corn silage.
Concentrate: mixture of corn grain (86.43% DM), soybean meal (10.07% DM), urea:ammonia sulfate (U:AS; 9:1) (1.5% DM) and mineral mixture (MM; 2.0% DM).

Table 4.4 - Chemical composition of the feeds and of the total diet (% DM)

Item	Silage	Ground corn	Soybean meal	U:AS	MM	Concentrate	Diet
DM	30.92	87.64	88.61	100	100	88.11	45.80
OM	94.74	97.60	92.85	100	0	95.20	94.97
CP	7.26	9.11	48.78	260	-	16.70	12.00
Ur	-	-	-	100	-	1.50	0.75
CPu	-	-	-	260	-	3.90	1.95
EE	3.16	4.07	1.71	-	-	3.69	3.43
NDFap	51.77	10.19	10.72	-	-	9.89	30.83
ADF	23.79	4.18	3.75			3.99	13.89
Lignin	4.97	1.16	1.33	-	-	1.14	3.06
NFC	32.55	74.23	31.64	-	-	67.34	49.95
NDIP	1.14	0.87	2.38	-	-	0.99	1.06
ADIP	0.57	0.35	1.34	-	-	0.44	0.51

Example A – meta-analytical approach to assess energy derived from NDF and CP

A.1. Calculation of the truly digestible EE fraction (Equation 4.9)

$$tdEE = 0.86 \times EE = 0.86 \times 3.43 = 2.95\%$$

A.2. Calculation of the truly digestible NFC fraction (Equation 4.10)

$$tdNFC = 0.95 \times NFC = 0.95 \times 49.95 = 47.45\%$$

A.3. Calculation of the digestible NDF fraction (Equations 4.11, 4.13, 4.14, and 4.15)

$$pdNDF(F) = 3.38 + 0.883 \times NDFap - 0.834 \times ADF + 0.0065 \times ADF^2 - 0.197 \times L$$
$$pdNDF(F) = 3.38 + 0.883 \times 51.77 - 0.834 \times 23.79 + 0.0065 \times (23.79^2) - 0.197 \times 4.97$$
$$pdNDF(F) = 31.95\%$$

$$pdNDF(C) = -1.19 - 10.16 \times D + 1.012 \times NDFap - 0.052 \times ADF$$
$$pdNDF(C) = -1.19 - 10.16 \times 0 + 1.012 \times 9.89 - 0.052 \times 3.99$$
$$pdNDF(C) = 8.61\%$$

$$pdNDF(Diet) = pdNDF(F) \times 0.5 + pdNDF(C) \times 0.5 = 31.95 \times 0.5 + 8.61 \times 0.5 = 20.28\%$$

$$iNDF(Diet) = NDFap - pdNDF = 30.38 - 20.28 = 10.55\%$$

$$D_{GF} = 80.21 \times FOR - 0.0166 \times DMI^2 + 2.658 \times iNDF + 3.691 \times CP$$
$$+ 0.0507 \times (DMI \times iNDF) - 2.9673 \times (FOR \times iNDF) - 3.9990 \times (FOR \times CP)$$

$$D_{GF} = 80.21 \times 0 - 0.0166 \times 25^2 + 2.658 \times 10.55 + 3.691 \times 12$$
$$+ 0.0507 \times (25 \times 10.55) - 2.9673 \times (0 \times 12.05) - 3.9990 \times (0 \times 12) = 75.33\%$$

$$dNDF = D \times pdNDF$$
$$dNDF = 75.33\% \times 20.28 = 15.27\%$$

A.4. Calculation of the truly digestible CP fraction (Equations 4.15 and 4.26)

$$tdCP = tD_{CCCP} \times (CP - NDIP) + D_{pdCWCP} \times \{NDIP \times [1 - e^{-(0.8188 + 1.1676 \times ADIP)}]\}$$
$$tdCP = 0.95 \times (12.00 - 1.06) + 0.7533 \times \{1.06 \times [1 - e^{-(0.8188 + 1.1676 \times 0.51)}]\}$$
$$tdCP = 0.95 \times 10.94 + 0.7533 \times (1.06 \times 0.7569)$$
$$tdCP = 10.39 + 0.60 = 10.99\%$$

A.5. TDN Calculation (Equation 28d; Table 4.1)

$$TDN = tdCP + tdNFC + dNDF + 2.25 \times tdEE - FM_{TDN}$$
$$TDN = 10.99 + 47.45 + 15.27 + 2.25 \times 2.95 - 7.13$$
$$TDN = 80.35 - 7.13 = 73.22\%$$

A.6. DE Calculation (Equation 4.29; Table 4.1)

$$DE = 0.056 \times tdCP + 0.042 \times tdNFC + 0.042 \times dNDF + 0.094 \times tdEE - FM_{DE}$$
$$DE = 0.056 \times 10.99 + 0.042 \times 47.45 + 0.042 \times 15.27 + 0.094 \times 2.95 - 0.322 = 3.205 \text{ Mcal/kg DM}$$

A.7. ME Calculation (Equation 4.30)

$$ME = 0.9422 \times DE - 0.303$$
$$ME = 0.9455 \times 3.205 - 0.303 = 2.727 \text{ Mcal/kg DM}$$

Example B – Empirical approach to assess the energy derived from NDF and CP

B.1. Calculation of the NDF digestible fraction (Equations 4.13, 4.14, 4.17, 4.18, 4.19b, and 4.20)

$$pdNDF(F) = 3.38 + 0.883 \times NDFap - 0.834 \times ADF + 0.0065 \times ADF^2 - 0.197 \times L$$
$$pdNDF(F) = 3.38 + 0.883 \times 51.77 - 0.834 \times 23.79 + 0.0065 \times (23.79^2) - 0.197 \times 4.97$$
$$pdNDF(F) = 31.95\%$$

$$pdNDF(C) = -1.19 - 10.16 \times D + 1.012 \times NDFap - 0.052 \times ADF$$
$$pdNDF(C) = -1.19 - 10.16 \times 0 + 1.012 \times 9.89 - 0.052 \times 3.99$$
$$pdNDF(C) = 8.61\%$$

$$kd = 0.00329 \times DMI = 0.00329 \times 25 = 0.0823$$

$$kp(F) = \frac{0.287}{iNDF(F)} = \frac{0.287}{(NDFap - pdNDF)} = \frac{0.287}{(51.77 - 31.95)} = 0.0145$$

$$kp(C) = kp(F) \times 1.8 = 0.0145 \times 1.8 = 0.0261$$

$$dNDF(F) = [(\frac{0.0823}{0.0823 + 0.0145}) \times 31.95] \times 1.12 = 30.42\%$$

$$dNDF(C) = [(\frac{0.0823}{0.0823 + 0.0261}) \times 8.64] \times 1.12 = 7.34\%$$

$$dNDF(Diet) = 0.5 \times dNDF(F) + 0.5 \times dNDF(C) = 0.5 \times 30.42 + 0.5 \times 7.34 = 18.88\%$$

B.2. Calculation of the truly digestible CP fraction (Equations 4.18, 4.19b, 4.20, and 4.27)

$$tdCP(F) = 0.95 \times (7.26 - 1.14) + \frac{0.0823}{0.0823 + 0.0145} \times \{1.14 \times [1 - e^{-(0.8188 + 1.1676 \times 0.57)}]\}$$
$$tdCP(F) = 0.95 \times 6.12 + 0.8502 \times (1.14 \times 0.7733)$$
$$tdCP(F) = 5.81 + 0.75 = 6.56\%$$
$$tdCP(C) = 0.95 \times (16.70 - 0.99) + \frac{0.0823}{0.0823 + 0.0261} \times \{0.99 \times [1 - e^{-(0.8188 + 1.1676 \times 0.44)}]\}$$
$$tdCP(C) = 0.95 \times 15.71 + 0.7592 \times (0.99 \times 0.7362)$$
$$tdCP(C) = 14.92 + 0.55 = 15.47\%$$

$$tdCP(Diet) = 0.5 \times tdCP(F) + 0.5 \times tdCP(C) = 0.5 \times 6.56 + 0.5 \times 15.47 = 11.02\%$$

B.3. TDN Calculation (Equation 4.28d; Table 4.1)

$$TDN = tdCP + tdNFC + dNDF + 2.25 \times tdEE - FM_{TDN}$$
$$TDN = 11.02 + 47.45 + 18.88 + 2.25 \times 2.95 - 7.13$$
$$TDN = 83.99 - 7.13 = 76.86\%$$

B.4. DE Calculation (Equation 4.29; Table 4.1)

$$DE = 0.056 \times tdCP + 0.042 \times tdNFC + 0.042 \times dNDF + 0.094 \times tdEE - FM_{DE}$$
$$DE = 0.056 \times 11.02 + 0.042 \times 47.45 + 0.042 \times 18.88 + 0.094 \times 2.95 - 0.322 = 3.358 \text{ Mcal/kg DM}$$

B.5. ME Calculation (Equation 4.30)

$$ME = 0.9455 \times DE - 0.303$$
$$ME = 0.9455 \times 3.358 - 0.303 = 2.872 \text{ Mcal/kg DM}$$

FEED COMPOSITION TABLES

Tables of the chemical composition and energy content of selected feeds for growing and finishing cattle are presented below. The chemical composition data were taken from the CQBAL 3.0 dataset. The energy contents were estimated according to the equations described in Table 4.5.

Table 4.5 - Indication of equations used to estimate the energy content of the feeds listed in Tables 4.6 to 4.9

Fraction	Equations	Table
tdEE	9	-
tdNFC	10	-
NDFd	13, 14, 17, 18, 19b and 20	-
tdCP	18, 19b, 20 and 27	-
TDN	28d	4.1
DE	29	4.1
ME	30	-

To calculate the dNDF and tdCP fractions, a voluntary intake of 22 g DM/kg body weight was presumed. Specifically, for the calculation of these fractions in concentrate feeds, corn silage was considered as basal forage. In comparison, the TDN values were also calculated based on the second edition of the BR-CORTE System, but using the pdNDF digestibility coefficient suggested for dairy cows.

Due to the overestimation of TDN concentration caused by the sub-model applicable to the digestible NDF for growing and finishing cattle (Figures 4.10 and 4.11), the BR-CORTE System for dietary formulation (online version) uses the pdNDF digestibility coefficient for dairy cows as an alternative to obtain TDN values closer to those obtained *in vivo*. However, as emphasized before, the pdNDF digestibility coefficient for dairy cows adopted in the second edition of the BR-CORTE System (0.67) is underestimated, while the assessment of the pdNDF fraction from lignin using Equation (4.12) seems to generate overestimations. Thus the model would present negative bias for the digestibility coefficient and positive bias for pdNDF fraction size, that would indicate incoherence in its use.

Table 4.6 - Chemical composition and energy concentration in forages (*in natura* moist forages)

Items	Feeds											
	Alfalfa	Black oats	*Brachiaria brizantha* (0-30 d)	*Brachiaria brizantha* (91-120d)	*Brachiaria decumbens* (31-45 d)	*Brachiaria decumbens* (46-60 d)	Sugarcane	Coast cross	Cameroon elephant grass (61-90 d)	Tifton Grass 85	Tanzanian grass	Forage cactos
DM	25.30	19.43	17.15	27.72	22.39	27.14	28.77	32.62	16.68	26.96	23.31	11.30
OM	90.62	90.45	89.98	92.30	90.33	91.04	96.55	91.49	90.22	90.91	88.63	88.04
CP	90.97	18.78	12.32	4.80	11.66	9.39	2.76	12.03	8.89	12.91	9.45	4.24
EE	3.70	3.22	1.20	1.16	1.79	2.23	1.34	2.50	2.41	2.00	2.53	1.80
NFC	26.08	21.83	15.28	10.87	21.48	19.84	42.72	7.73	10.85	10.68	7.59	52.92
NDFap	39.87	46.62	61.18	75.47	55.40	59.58	49.73	69.23	68.07	65.32	69.06	29.08
ADF	26.63	27.41	34.68	42.87	28.19	36.76	33.52	35.78	43.91	36.91	41.58	18.61
Lig	7.47	4.06	4.44	6.41	3.82	5.18	5.86	6.13	7.10	7.49	5.89	4.93
ADIP	1.69	0.72	2.55	1.59	0.90	2.28	0.12	1.93	0.97	3.75	1.31	0.82
NDIP	4.99	5.28	3.00	3.87	5.14	3.38	0.46	5.81	2.56	6.81	3.30	1.40
TDN[1]	60.1	60.9	54.7	49.4	57.1	56.0	63.1	51.8	50.4	51.0	50.1	62.8
TDN[2]	62.2	60.5	55.5	54.0	58.2	56.8	63.0	56.7	53.4	55.5	52.7	63.2
DE[2]	2.86	2.75	2.47	2.30	2.56	2.48	2.66	2.51	2.33	2.47	2.31	2.68
ME[2]	2.39	2.29	2.02	1.88	2.12	2.04	2.21	2.07	1.90	2.03	1.88	2.23

[1] TDN calculated as described in BR-CORTE (2010) for dairy cows; [2] TDN, DE and ME calculated according to the new equation system (Table 4.5).

Table 4.7 - Chemical composition and energy concentration in conserved forages (hays and silages)

Items	Hays						Silages					
	Alfalfa	Oats	*Brachiaria brizantha*	*Brachiaria decumbens*	Coast cross	Tifton 85	Sugarcane	Elephant grass	Corn	Soybean	Sorghum	Tifton (pre-dried)
DM	89.32	87.42	87.95	88.68	88.90	88.94	26.12	27.70	31.11	25.83	29.76	47.76
OM	88.38	91.82	93.30	93.26	92.91	92.20	95.14	90.29	94.23	91.78	93.59	91.12
CP	18.77	11.96	4.13	6.64	8.57	9.69	3.77	5.47	7.24	17.79	6.45	16.62
EE	2.85	1.77	1.22	1.77	1.48	1.55	1.71	2.23	2.84	9.45	2.53	2.41
NFC	23.77	27.93	8.82	6.64	10.14	9.92	27.64	15.32	33.81	15.43	26.02	10.60
NDFap	42.99	50.16	79.13	78.21	72.72	71.04	62.02	67.27	50.34	49.11	58.59	61.49
ADF	37.52	41.13	49.59	46.52	40.59	38.72	43.03	48.71	30.26	35.69	31.27	32.00
Lig	9.74	7.04	7.26	6.82	6.05	6.13	8.13	7.47	4.87	8.91	5.10	4.76
ADIP	2.14	2.15	0.36	0.80	1.75	1.16	0.38	0.76	0.87	1.95	0.93	1.14
NDIP	3.94	3.63	0.58	3.83	3.45	4.74	0.61	1.19	1.31	3.11	2.37	5.53
TDN[1]	54.0	56.8	49.2	49.3	51.8	51.0	55.5	50.5	63.3	62.8	59.2	55.4
TDN[2]	55.1	56.2	53.7	54.2	55.8	55.4	58.0	52.5	63.2	65.1	61.2	57.8
DE[2]	2.53	2.49	2.29	2.33	2.43	2.42	2.46	2.25	2.72	2.94	2.62	2.61
ME[2]	2.09	2.05	1.86	1.90	1.99	1.98	2.03	1.83	2.27	2.48	2.18	2.17

[1] TDN calculated as described in BR-CORTE (2010) for dairy cows; [2] TDN, DE and ME calculated according to the new equation system (Table 4.5).

Table 4.8 - Chemical composition and energy concentration in energy concentrates

Items	Feeds								
	Oats (grain)	Soybean hulls	Rice meal	Wheat bran	Millet (grain)	Corn (grain)	Sorghum (grain)	Citric pulp	Cassava scraps
DM	90.44	90.30	89.03	87.97	88.95	87.91	88.12	88.45	87.66
OM	93.59	94.18	89.17	93.32	94.19	97.54	97.87	91.72	95.83
CP	14.06	12.73	13.22	17.13	13.35	9.05	9.67	6.93	2.80
EE	3.82	2.20	16.32	3.51	4.49	4.02	2.94	3.11	0.45
NFC	48.09	15.88	39.02	33.07	53.95	72.48	73.90	60.36	78.97
NDFap	27.62	63.37	20.60	39.61	22.40	11.99	11.36	21.32	13.61
ADF	22.92	49.15	11.88	13.19	7.21	4.00	6.07	20.76	7.19
Lig	3.51	3.64	4.49	3.80	1.41	1.18	1.80	1.84	1.64
ADIP	0.14	2.29	0.55	0.94	1.40	0.18	0.05	0.08	0.47
NDIP	1.57	5.61	1.81	0.28	2.41	1.39	0.87	2.72	0.64
TDN[1]	72.2	69.5	83.7	68.5	77.7	83.8	82.8	76.1	79.7
TDN[2]	80.4	74.8	81.0	71.2	82.9	86.6	86.0	78.0	81.6
DE[2]	3.53	3.27	3.54	3.20	3.63	3.73	3.71	3.33	3.44
ME[2]	3.04	2.79	3.04	2.72	3.13	3.22	3.21	2.84	2.95

[1] TDN calculated as described in BR-CORTE (2010) for dairy cows; [2] TDN, DE and ME calculated according to the new equation system (Table 4.5).

Table 4.9 - Chemical concentration and energy concentration in protein concentrates

Items	Feeds								
	Cottonseed	Cotton meal 38%	Cotton cake	Sunflower meal	Gluten 21 meal	Glutenose	Peanut meal	Soybean meal	Soybean (grain)
DM	90.76	89.92	90.68	91.06	88.77	90.57	89.23	88.57	90.88
OM	95.78	91.07	95.14	93	92.20	96.81	92.47	92.89	93.71
CP	22.99	39.63	29.74	31.81	23.93	63.90	58.38	48.71	38.46
EE	19.32	1.43	9.43	1.94	2.78	2.73	0.40	1.86	19.05
NFC	7.71	20.55	10.05	10.76	29.79	23.93	11.50	28.86	20.78
NDFap	45.76	29.46	45.92	48.49	35.70	6.25	22.19	13.46	15.42
ADF	35.24	22.94	34.92	34.64	10.68	3.75	10.96	9.47	12.12
Lig	7.39	3.66	9.68	5.40	1.19	0.26	2.22	1.62	2.29
ADIP	2.06	1.05	1.67	0.91	0.25	2.13	1.12	0.39	2.67
NDIP	3.33	3.38	5.73	4.22	3.09	4.48	3.13	2.78	6.51
TDN[1]	84.9	67.0	71.04	67.5	70.2	85.75	74.0	76.86	94.99
TDN[2]	87.0	66.7	84.73	66.5	77.3	84.84	77.8	79.25	96.47
DE[2]	3.92	3.29	3.91	3.18	3.52	4.38	3.45	3.94	4.51
ME[2]	3.40	2.81	3.39	2.70	3.03	3.84	2.96	3.42	3.97

[1] TDN calculated as described in BR-CORTE (2010) for dairy cows; [2] TDN, DE and ME calculated according to the new equation system (Table 4.5).

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