PREDICTION OF THE ENERGY VALUE OF CATTLE DIETS BASED ON THE CHEMICAL COMPOSITION OF FEEDS

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INTRODUCTION

The digestibility coefficients constitute a basic aspect of quantifying energetic values of feed and diets. These coefficients estimates allow accessing the total digestible nutrients (TDN) contents that permit dietary balance to meet the animal demands for maintenance and production.

However, although digestibility coefficients constitute static digestive parameters (they can be represented by a point estimate), estimating digestibility is laborious and time consuming with traditional *in vivo* methods (Detmann et al., 2006a).

Substantial efforts have been undertaken to compile data for technicians and producers to understand feed composition, including its energetic content. Such efforts were based on the fact that large samples tend to have greater precision and accuracy to capture feed characteristics. These data volume attributes, referred to as the law of large numbers, increase the accuracy of tabulated feed characteristics (Detmann et al., 2008a).

Although the tabulated energy values of feeds tend to be reliable from a statistical perspective, feeds used in different production systems may vary from the population mean. Thus, feed characteristics calculated based on averages tend to deviate from what was initially planned in a manner similar to feed characteristic deviations from population mean (Detmann et al., 2008a).

This situation is particularly noticeable among forages produced in the tropics in comparison to non-tropical regions. These tropical areas are subjected to substantial climatic and edaphic fluctuations (e.g., temperature, precipitation, solar radiation and soil fertility) that influence feed characteristics.

As such, tropical climates influence the energetic content of feeds; efforts are needed to ease dependence on average values obtained from composition tables. Several studies have started to address these issues (e.g., Conrad et al., 1984; Weiss et al., 1992). The U.S. tables for dairy cattle (7th ed.) are highlighted (NRC, 2001). Tabulated data outlining the energetic content of feeds were eliminated to estimate the energetic content of feeds on a case-by-case basis. Therefore, deviations could be avoided between the estimated characteristics of feed and values obtained from the field (Detmann et al., 2008a).

The system foundation for predicting the energetic content of cattle feeds has been adopted by the NRC (2001), and centers on the influence of chemical composition on energy value of feeds. The method is based on a summative equations system that estimates the true digestible fractions, with corrections for intake level and metabolic fecal loss. The following chemical compound groups are evaluated under this system: crude protein (CP); ether extract (EE); non-fibrous carbohydrates (NFC); and neutral detergent fiber (NDF).

However, while presenting a theoretical basis for estimating feed characteristics (Conrad et al., 1984; Weiss et al., 1992), the NRC system has been

ineffective for feeds produced in the tropics (Rocha Jr. et al., 2003; Detmann et al., 2008b; Azevêdo, 2009; Magalhães et al., 2010), which compromises its effective application.

Recently, sub-models were developed and validated to predict digestible fractions of CP, EE, NFC and NDF under tropical conditions (Detmann et al, 2004a; 2006a; 2006b; 2006c; 2007; 2008b; 2008c; 2010). These sub-models, constituting a new summative system, accurately predicted TDN values (Detmann et al., 2008b; Azevêdo, 2009; Magalhães et al., 2010) and provided an alternative to the NRC model for cattle fed in the tropics.

DESCRIPTION OF THE NEW MODEL

Sub-models for EE and NFC

The development of sub-models for non-fibrous components EE and NFC was based on the Lucas test (Lucas & Smart, 1959) to obtain true digestibility coefficients, and on the factorial system (Blaxter & Mitchell, 1948; Lucas, 1960) to distinguish between metabolic and truly undigested fecal fractions.

Based on these assumptions, we can summarize the apparent undigested fecal mass of the different non-fibrous components (EE or NFC) as:

$$F = U + M + E \quad (1),$$

where *F* is the fecal mass (g/d), *U* is the truly undigested fraction (g/d), *M* is the metabolic fecal fraction (g/d), and *E* is the endogenous fecal fraction (g/d).

In this context, the metabolic fraction is defined as the fecal portion obtained from secretions by the digestive tract (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).

From these definitions, we can relate the undigested fecal mass in equation (1) to daily intake follows:

$$I - F = I - (U + M + E) \quad (2a),$$

$$I - F = I - U - M - E \quad (2b),$$

$$\frac{I - F}{I} = \frac{I - U - M - E}{I} \quad (2c),$$

$$D_a = 1 - \frac{U}{I} - \frac{M}{I} - \frac{E}{I} \quad (2d),$$

where *I* is intake (g/d); and D_a is the apparent digestibility coefficient (g/g).

The endogenous fecal fraction may be represented by the following mathematical function proportional to the metabolic mass of the animal (Blaxter & Mitchell, 1948; Lucas, 1960):

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

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

The ratio (ε/I) is only considered significant if the intake is extremely low (Lucas, 1960), possibly below maintenance levels. Thus, under maintenance or production conditions, we can assume:

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

where *I*° is the intake under maintenance or production feeding conditions (g/d).

We can then rewrite equation (2d) as:

$$D_a = (1 - \frac{U}{I}) - \frac{M}{I} \quad (5a),$$

$$D_a = D_t - \frac{M}{I} \quad (5b),$$

where D_t is the true digestibility coefficient (g/g).

Multiplying both terms of equation (5b) by the intake, we calculate the following relationship:

$$I \times D_a = (I \times D_t) - M \quad (6).$$

We can obtain the D_a value by deriving equation (6) in terms of intake as:

$$\frac{d(I \times D_a)}{dI} = \frac{d(I \times D_t)}{dI} - \frac{dM}{dI} \therefore D_a = D_t - \frac{dM}{dI} \quad (7).$$

Thus, the apparent digestibility coefficient (equation 7) may be represented by the following two components: 1) the constant coefficient of true digestibility; and 2) the metabolic fecal fraction, which varies according to intake.

By converting equation (7) based on dietary content, we find:

$$R \times D_a = (R \times D_v) - (R \times \frac{dM}{dI}) \quad (8a),$$

$$R_{ad} = R_{td} - MC \quad (8b),$$

where R is the dietary content; MC is the metabolic fecal contribution, expressed as dietary content; R_{ad} is the apparent digestible dietary fraction; and R_{td} is the truly digestible dietary fraction. All terms are expressed as the percent of dry matter (DM).

Two data sets were used to estimate the parameters described in equation (8b) for EE (n = 108) and NFC (n = 84) (Detmann et al., 2006a; 2006c). These data were obtained from experiments conducted under tropical conditions with dairy cows or growing and finishing cattle.

For the components evaluated, 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 assumptions reported by Lucas & Smart (1959) and by those represented in equation (8).

The sub-models used to estimate the truly digestible fractions were calculated as:

$$EE_{td} = 0.86 \times EE \quad (9),$$

$$NFC_{td} = 0.95 \times NFC \quad (10),$$

where EE_{td} is the truly digestible EE; EE is the diet content of EE; NFC_{td} is the truly digestible NFC; and NFC is the diet content of NFC. All terms are expressed as the percent of DM.

As no differences in the true digestibility coefficients were observed across animal categories, equations (9) and (10) are equally applied to dairy cows and growing and finishing cattle. Therefore, the distinction between these animal categories is based exclusively on the apparent digestible fraction by using metabolic fecal contributions estimates presented in Table 1.

Table 1 - Metabolic fecal contribution of ether extract (EE), non-fibrous carbohydrates (NFC), and crude protein (CP) as a function of animal category and feeding level (% of DM)

	Animal Category			
	Dairy Cows		Growing and Finishing Cattle	
Component	Maintenance²	Production	Maintenance²	Production
EE	0.10	0.21	0.09	0.18
NFC	4.05	5.72	3.35	5.11
CP	0.43	0.97	1.17	1.61
FM_{TDN}¹	4.71	7.16	4.72	7.13

¹ FM_{NDT} =fecal metabolic TDN; FM_{NDT} = CP + NFC + 2.25×EE. ² In the case of maintenance conditions, we consider non-dairy cows with no weight variations and cattle under maintenance from other categories (zero weight variation).

Based on cattle receiving restricted (maintenance) or unrestricted (production) diets (Costa et al., 2005), differentiated metabolic fecal fractions were estimated for maintenance feeding conditions (Table 1).

Individual validation procedures were previously implemented for the apparent digestible fractions of EE and NFC using databases independent of those used to build the sub-models (Detmann et al., 2006a; 2006c; 2008b; Magalhães et al., 2010). These validations demonstrated that the new sub-models were more accurate and precise than those originally adopted by the NRC (2001).

Sub-model for NDF

In biological terms, the sub-model developed to estimate the digestible NDF was based on dividing this component into potentially digestible and indigestible fractions, according to the equations:

$$NDF_d = D \times NDFpd \quad (11a),$$

$$NDF_d = D \times (NDF - NDFi) \quad (11b),$$

where NDF_d is the digestible NDF; *NDFpd* is the potentially digestible NDF, *D* is the digestibility coefficient of the *NDFpd* (g/g), and *NDFi* is the indigestible NDF. All terms are expressed as the percent of DM.

The NDFpd and NDFi fractions constitute asymptotic biological concepts, and their accurate evaluation is obtained through biological evaluations of long duration (rumen incubation lasting 240 or more hours) (Casali et al., 2008). This lengthy test makes it impossible to obtain quick estimates and restricts the evaluation according availability of fistulated animals.

Therefore, we adopted a chemical approach in which a sub-model for predicting the NDFpd was constructed based on a non-linear exponential relationship between lignin and NDF. This sub-model is based on Surface Law assumptions (Conrad et al., 1984; Weiss et al., 1992) whereby the protection factor for ruminal degradation of lignin over the NDF is considered a base parameter.

The protection factor for ruminal degradation of lignin was estimated using associations between levels of NDFi and lignin in tropical forages (Detmann et al., 2004a; n = 114). This association allowed the use of a chemical approach for equation (11a) as follows:

$$NDF_d = D \times \{(NDFap - L) \times [1 - (\frac{L}{NDFap})^{0.85}]\} \quad (12),$$

where NDF_d is the digestible NDF; *NDFap* is the dietary content of NDF, expressed with corrections for ash and protein; *L* is the lignin content; and 0.85 is the protection factor for ruminal degradation of lignin over the NDF. All terms are expressed as the percent of DM.

The digestibility coefficients of NDFpd were estimated from a meta-analysis of six experiments conducted under tropical conditions (Detmann et al., 2007; n = 156), as shown in Table 2.

Table 2 - Digestibility coefficients of potentially digestible neutral detergent fiber according to animal category and feeding level

	Animal Category	
Feeding Level	Dairy Cows	Growing and Finishing Cattle
Maintenance[1]	0.71	0.88
Production	0.67	0.84

[1] For maintenance conditions, we considered cows that were non-dairy and cattle from other categories under maintenance.

Sub-model for CP

Initially, the sub-model for evaluation of the CP digestible fraction was based on the same assumptions adopted for EE and NFC (Detmann et al., 2006b) and consistent with equations (1) to (8), resulting in:

$$CP_{td} = 0.78 \times CP \quad (13);$$

where CP_{td} is the truly digestible CP; and *CP* is the CP diet content. All terms are expressed as the percent of DM.

In this case, conversions to apparently digestible fractions were performed using corresponding estimates of metabolic fecal contributions based on different animal categories and feeding levels (Table 1).

However, subsequent observations showed that the CP could not be considered a homogeneous nutritional entity because of the great association of nitrogen compounds to insoluble fibrous fraction in tropical feeds (Detmann et al., 2008c).

Thus, a new sub-model using a chemical approach was developed considering two different sub-compartments for the CP (Detmann et al., 2008c), as follows:

$$CCCP \cong CP - NDIP \quad (14a),$$

$$CWCP \cong NDIP \quad (14b),$$

where *CCCP* is the cell contents CP; *CWCP* is the cell wall CP; and *NDIP* is the neutral detergent insoluble protein. All terms are expressed as the percent of DM.

According to derivations by Detmann et al. (2008c), the CCCP would present homogeneous digestive behavior similar to the other non-fibrous components (EE and NFC) (equation 8b). On the other hand, we assumed that the use of CWCP would be similar to that observed for the NDF (equation 12). Therefore, the apparently digestible fraction of CP can be expressed using the chemical approach under equation 14, as follows:

$$CP_{td} = D_{tCCCP} \times (CCCP) + D_{CWCPpd} \times (CWCP_{pd}) \quad (15a),$$

$$CP_{td} = D_{tCCCP} \times (CP - NDIP) + D_{CWCPpd} \times (NDIP - iNDIP) \quad (15b),$$

where CP_{td} is the truly digestible CP; D_{tCCCP} is the true digestibility coefficient of CCCP (g/g); $CWCP_{pd}$ is the potentially digestible CWCP; D_{CWCPpd} is the digestibility

coefficient of the $CWCP_{pd}$ (g/g); and *iNDIP* is the indigestible neutral detergent insoluble protein. All terms are expressed as the percent of DM.

In this case, the value of 0.98 g/g is assumed to be an estimate of D_{tCCCP} (Van Soest, 1994; Detmann et al., 2006c; 2008c). The D_{CWCPpd} estimates were assumed similar to those calculated for the fibrous portion of the feed/diet (Detmann et al., 2007) (Table 2).

The analytical concept of iNDIP was defined by Detmann et al. (2004b) as an approximation to the parametric value of the non-degradable cell wall protein. This process consisted of evaluating the residual CP of the feed after 240 hours of *in situ*, ruminal incubations followed by neutral detergent treatment to remove microbial debris.

However, such analytical approximations may be an obstacle in some situations because fistulated animals may not be available. Thus, we developed an alternative equation to obtain the values of iNDIP, which involves using concentration of acid detergent insoluble protein (ADIP) and applying information from feeds produced under tropical conditions as follows (Detmann et al., 2010; n = 540):

$$iNDIP = NDIP \times e^{-(0.8188+0.1676\times ADIP)} \quad (16),$$

where ADIP is the acid detergent insoluble protein expressed as the percent of the DM.

To adopt the chemical approach for iNDIP, equation (15b) may be rewritten as:

$$CP_{td} = 0.98 \times (CP - NDIP) + D_{CWCP} \times \{NDIP \times [1 - e^{-(0.8188+1.1676\times ADIP)}]\} \quad (17),$$

It is important to note that the chemical approach for determining iNDIP from ADIP has limitations because iNDIP values represent a highly variable biological concept (Detmann et al., 2010). Therefore, this approach must be used with caution; it is preferable to estimate iNDIP by a biological method.

Detmann et al. (2008c) and Magalhães et al. (2010) both observed that the bi-compartmental concept produced more accurate estimates than the single compartment concept when calculating apparently digestible CP fractions from tropical forages. However, Azevêdo (2009) verified that the application of the single compartment concept provided more accurate estimates when some sub-products and agro-industrial residues were evaluated. Therefore, although the concept represented by equation 15 is recommended, the initial concept presented in equation 13 should not be completely discarded.

Summative system for TDN

The diet contents of TDN are obtained by the algebraic sum of the estimates produced by sub-models applied for each digestible fraction according to animal categories and feeding levels (production or maintenance) as follows:

$$TDN = CP_{ad} + NFC_{ad} + NDF_{d} + 2.25 \times EE_{ad} \quad (18a),$$

$$TDN = (CP_{td} - MC_{CP}) + (NFC_{td} - MC_{NFC}) + NDF_{d} + 2.25 \times (EE_{td} - MC_{EE}) \quad (18b),$$

$$TDN = CP_{td} + NFC_{td} + NDF_{d} + 2.25 \times EE_{td} - (MC_{CP} + MC_{NFC} + 2.25 \times MC_{EE}) \quad (18c),$$

$$TDN = CP_{td} + NFC_{td} + NDF_{d} + 2.25 \times EE_{td} - MF_{TDN} \quad (18d),$$

where *TDN* is the diet content of TDN; CP_{ad}, NFC_{ad} and EE_{ad} are apparently digestible fractions of CP, NFC and EE, respectively; CP_{td}, NFC_{td} and EE_{td} are true digestible fractions of CP, NFC and EE, respectively; NDF_d is the digestible fraction of NDF; MC_{CP}, MC_{NFC} and MC_{EE} are metabolic fecal contributions of CP, NFC and EE, respectively; MF_{TDN} is the total metabolic fecal fraction of TDN; and 2.25 is the Atwater's constant for equalization between lipids and carbohydrates. All terms are expressed as the percent of DM.

Recommendations of methods for chemical analysis

Table 3 summarizes the chemical methods of feed analysis suggested for evaluating the contents of DM, organic matter (OM), CP, EE, acid detergent fiber (ADF), NDIP, ADIP, NDFi, iNDIP and lignin.

Table 3 - Summary of suggested methods used to evaluate feed based on the new summative system for predicting the dietary content of 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 foods with urea content above 10%; b.105ºC/16 hours, for other materials; Equipments: non-ventilated oven, desiccator	1, 2
CP	Kjeldahl	Digestion in sulfuric acid (400ºC), distillation with sodium hydroxide, and titration with hydrochloric acid	1
EE	Goldfish	Extraction time is minimum of 3 hours; solvent rate is 5-6 drops/second; suggested extractor is petroleum ether	1, 3
Ash	Calcination	550-600ºC/2-4 hours; Equipment: furnace, desiccator	1, 3
Organic Matter	By difference	MO = 100 – Ash	-
ADF	Detergent system	Contents evaluated by conventional extractions (fibertech) or by micro-extraction in autoclave	4, 5
NDIP, ADIP	Detergent system	Evaluation by the Kjeldahl method after extraction with detergents	6
NDFi	Incubation *in situ*	Incubation *in situ* for 288 and 240 hours using F57 (Ankom®) or non-woven textile (TNT, 100 g/m²) bags, respectively. Sample mass: 20-25 mg DM/cm² of surface. Extract using neutral detergent	7, 8
iNDIP	Incubation *in situ*	Evaluation of the NDFi by the Kjeldahl method	9
Lignin	Sulfuric acid ou Potassium Permanganate	Solubilize cellulose by hydrolysis in H_2SO_4 (72% w/w) or oxidize lignin with permanganate, after treatment with an acid detergent	4

[1] Silva & Queiroz (2002). [2] Thiex & Richardson (2003). [3] AOAC (1990). [4] Van Soest & Robertson (1985). [5] Pell & Schofield (1993). [6] Licitra et al. (1996). [7] Casali et al. (2008). [8] Valente (2010). [9] Detmann et al. (2004b).

NDF content should be estimated according to Mertens (2002), using a heat-stable α-amylase and correcting for insoluble ash content. The use of sodium sulfite is not recommended. Corrections for the nitrogenous content of NDF are done as the estimation of NDIP content according to Licitra et al. (1996).

Therefore, the NDF content corrected for ash and protein (NDFap) is expressed as:

$$NDFap = NDF \times \frac{(100 - NDIP - NDIA)}{100} \quad (19),$$

where *NDFap* is the content of neutral detergent fiber corrected for ash and protein (% of DM); *NDF* is the content of neutral detergent fiber (% of DM); NDIP is the content of

neutral detergent insoluble protein (% of NDF) and NDIA is the content of neutral detergent insoluble ash (% of NDF).

It is important to note that correction of the NDF content should be conducted so that the total NFC content of the food is not underestimated and that the energetic contributions NDIP do not be computed in duplicate. Furthermore, this correction prevents the erroneous accounting of mineral matter (NDIA) as an energetic component of feed (Detmann et al., 2008b).

Thus, NFC contents are obtained by the equation (Detmann & Valadares Filho, 2010):

$$NFC = OM - [(CP - CPu + Ur) + EE + NDFap] \quad (20),$$

where *CPu* is the CP from urea; and *Ur* is the urea content in the food. All terms are expressed as the percent of DM.

DISCUSSION ON THE CHARACTERISTICS OF THE NEW MODEL

The main difference between the new sub-model to predict the apparently digestible EE and the NRC sub-model centers on methods to obtain the truly digestible fraction of EE.

For the NRC sub-model, the average level of non-fatty EE in ruminant diets is estimated to be approximately 10 g/kg of DM (Weiss et al., 1992). This estimate allowed estimation of fatty acids levels in the diet by a simple subtraction of a constant, assuming true digestibility of 1.0 g/g of the dietary fatty acids (Weiss et al., 1992).

In the new sub-model, the process to estimate the truly digestible EE content is conducted through a multiplicative coefficient using equation (9).

Previously obtained results under tropical conditions showed high divergence between observed values and those predicted by the NRC sub-model (Rocha Jr. et al., 2003; Silva, 2004; Campos, 2004; Oliveira, 2005).

Estimation of the content of truly digestible EE by subtracting a constant (Weiss et al., 1992; NRC, 2001) implies that any source of EE, except for oils and fats, present a common absolute fraction of non-insertable compounds in animal metabolism. This would represent the complement of fatty acids present in food, usually represented by waxes, carotenoids and other indigestible compounds (Van Soest, 1994).

However, inspection of data from the literature (Sukhija & Palmiquist, 1988; Van Soest, 1994) indicated high variability between fatty and non-fatty EE content in cattle feeds. This variability may cause distortions of estimates of truly digestible EE from subtraction of a constant (Detmann et al., 2006a). Thus, the assumption of proportionality between truly digestible and indigestible material would lead to some compensation between sources with different EE levels. This compensation is the probable cause of increased prediction efficiency in the new sub-model, which is based on a multiplicative factor (Figure 1).

Both sub-models used to predict apparently digestible NFC are based on the Lucas test (Weiss et al., 1992; Detmann et al., 2006c). These sub-models have similar true digestibility coefficients (Detmann et al., 2006c) thereby providing similar estimates of truly digestible NFC (Detmann et al., 2006c; 2008b).

Thus, discrepancies between the NRC sub-model and the new sub-model can be attributed to variations in metabolic fecal fractions (Detmann et al., 2008b).

The metabolic fraction of NFC established by Weiss et al. (1992) and used by the NRC (2001) was based on average fecal compositions evaluated in cattle and sheep under non-tropical conditions (Weiss et al., 1992).

However, the metabolic fecal fraction is influenced by nutrient flow to the large intestine and alterations in cecal microbial activity (Ørskov, 1988). This fraction is also influenced by levels of fibrous components in the diet (Arroyo-Aguilu & Evans, 1972). These factors may vary across animals fed under tropical and non-tropical conditions.

Differences in the metabolic fecal fraction may be directly applied to compare the sub-models used for NFC because they present similar coefficients of true digestibility (Detmann et al., 2006c). However, the increased prediction efficiency of the new EE and CP sub-models may be partly a result of more accurate estimates of metabolic fecal fractions (Detmann et al., 2006a; 2006b; 2008b).

According to the basic assumptions for the non-fibrous components submodels, the metabolic fecal fraction differs as a function of feed intake level (Table 1). Under tropical conditions, changes in feed intake observed for lactating cows or growing and finishing cattle fed at production level are not sufficient to cause large discrepancies in the estimates of apparent digestibility obtained in the same animal category. However, divergences between categories are observed as a function of large differences in feed intake and in the composition of the diets used for each category (Detmann et al., 2008c).

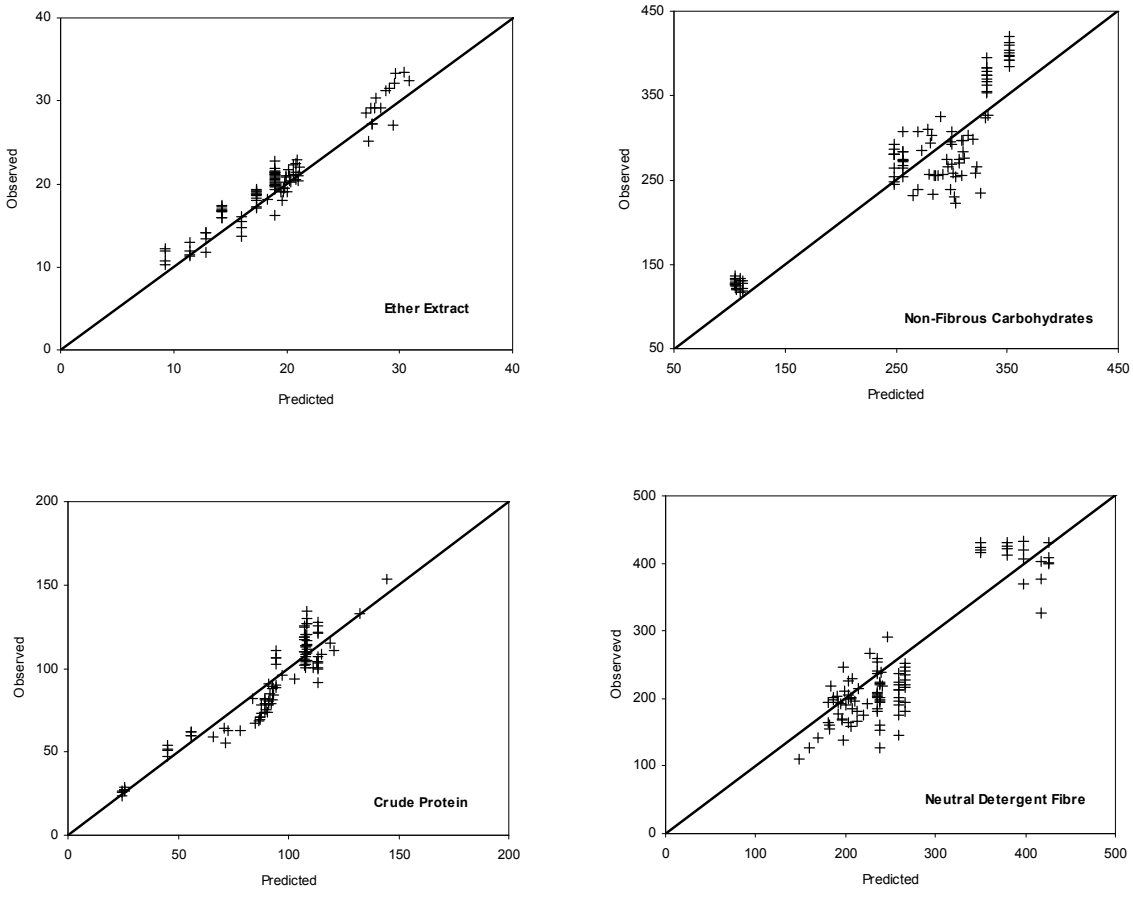


Figure 1 - Relationship between the apparently digestible fractions observed and predicted by the new model (g/kg of the DM; n = 107) (the continuous line represents the equality relationship) (Detmann et al., 2008b).

It should be emphasized that the NRC sub-models did not include corrections for differences in metabolic fecal fraction across animal categories, which appears to contribute to lower predicted efficiency under tropical conditions (Detmann et al., 2008b; Figure 2).

It is also important to highlight that the TDN content of cattle feed constitutes a summative system. Thereby, estimates of total energetic levels are comprised of the sum of its parts, which are determined by their apparent digestibility coefficients. Therefore, the accuracy and precision of each individual metabolic fraction (e.g., EE, CP and NFC) enhances the accuracy and precision of the TDN content, even if the total metabolic fecal fractions appear similar across categories (Table 1).

Total metabolic fecal fraction differences between animals managed in tropical and non-tropical regions becomes evident by considering estimates obtained for animals fed *ad libitum* (production feeding levels) (Table 1). These are similar to those suggested by Weiss et al. (1992) and adopted by the NRC (2001) for maintenance feeding levels (70 g/kg or 7%).

The prediction of the truly digestible CP by the NRC sub-model is based on the action of ADIP on the total digestibility of CP (Weiss et al., 1992). This argument is considered to be valid assuming that the ADIP is constantly unavailable for all feeds, taking into account only particularities between concentrates and forages.

However, Henriques et al. (2007) observed that the non-degradable CP fraction may not be fully represented by the ADIP. They also note high variability among feeds as it relates to nitrogenous compounds associated with plant cell walls and the availability of CP under tropical conditions. These factors seem to be a main limitation of applying the NRC sub-model to tropical regions.

The theoretical bi-compartmental concept applied to the evaluation of CP (Equation 15) allows for different explanations of nitrogen use because of its association (or non-association) with plant cell wall. This association involves differentiation in the rate and extent of microbial action. It is a valid assumption under tropical conditions because significant portions of nitrogenous compounds are associated with insoluble fibrous fraction of the feeds.

The theoretical concept of the sub-model applied to CP provides breakdowns by biological pathways associated with cell walls in potentially degradable and non-degradable fractions. The non-degradable fraction is analytically represented by the concept of iNDIP (Detmann et al., 2004b; 2008c; 2010). However, we acknowledge that laboratory evaluations of the NDIIP are an obstacle for fast and practical energy prediction (Detmann et al., 2008c).

Estimates of iNDIP from ADIP were proposed as an alternative to expedite the prediction process (Detmann et al., 2008c). However, safeguards must be maintained because relationships between iNDIP (biological concept) and ADIP (chemical concept) are not very precise due to high biological variability in the availability of nitrogen compounds associated with fiber (Detmann et al., 2010). In this context, ADIP use as a predictive element should be understood as a chemical approach that is not biologically grounded.

Although the mathematical structures of both sub-models for predicting NDF digestible fraction are similar, we found remarkable differences in parameter estimates across the sub-models.

The protection factor for ruminal degradation of lignin adopted by the NRC (2001) is theoretically based on the Surface Law (Conrad et al., 1984). According to this geometric principle, the surface of a solid is proportional to its mass raised to the 0.667 power. From this, one may assume that the digestible surface is determined by the fact that non-lignified tissues and lignin are physically located surface-by-surface in plant cell wall. Therefore, the portion of NDF unavailable to microorganisms is proportional to the surface area of the lignin mass and inversely proportional to the surface area of the NDF mass (Detmann et al., 2004a).

However, the lignin constraint on NDF determined by the Surface Law does not correspond to the relationship between the lignin and NDFi under tropical conditions

(Detmann et al., 2004a). According to Detmann et al. (2004a), the exponent 0.667 is not able to accurately express the NDFi fraction from the levels of the lignin under tropical conditions. Nevertheless, the relationship between these variables assumed a similar form to that of the non-linear structure by the Surface Law, which allowed empirical adjustment of the exponent to 0.85 (Equation 12).

That empirical correction showed that the constraint caused by lignin in the cell wall degradation of tropical feeds is less intense than that initially proposed by the Surface Law (Detmann et al., 2004a).

A distinction between the two sub-models is that the new sub-model we propose considers differences among animal categories in relation to digestibility coefficient of potentially digestible fraction of NDF (Table 2). The greater digestibility obtained for growing and finishing animals appears to be supported by higher intake and concentrate levels in diets typically observed for dairy cows. Higher feed intake directly implies a higher passage rate that reduces the time of exposure to microbial degradation and, consequently, total digestibility. Moreover, the increased concentrate levels in the diet imply lower values of rumen pH and changes in nutrient competition and in the priority of substrate utilization by ruminal microorganisms, thus reducing the degradation of fibrous components (Mould et al, 1983; Arroquy et al., 2005).

Even in the presence of differences between categories, the estimates of the digestibility coefficient of potentially digestible NDF applied to the new submodel under maintenance feeding differ from that used in the NRC sub-model (Detmann et al., 2007; 2008b).

Feeds produced under tropical conditions may present degradation and ruminal transit that are different from those of feeds produced under non-tropical conditions. In this context, the assumption of first-order asymptotic models used by Weiss et al. (1992) to derive coefficients of digestibility of potentially digestible NDF could not represent the best alternative under tropical conditions (Detmann et al., 2009).

The digestibility coefficient of the potentially digestible NDF is a result of integration between degradation and transit in the gastrointestinal tract of ruminants. Therefore, obtaining estimates *in vivo* allows the consideration of differences between feeds in regard to how these processes occur. Thus, since the estimates adopted for the new submodels were obtained *in vivo*, it is expected that the processes cited above are conveniently integrated, with the estimates becoming more accurate, at least under tropical conditions, compared to values produced with dynamic models approach.

However, further refinements may be obtained for the digestibility coefficients shown in Table 2, since the data initially used for their estimation are limited (n = 156). Accuracy may be improved by incorporating more data from different production systems.

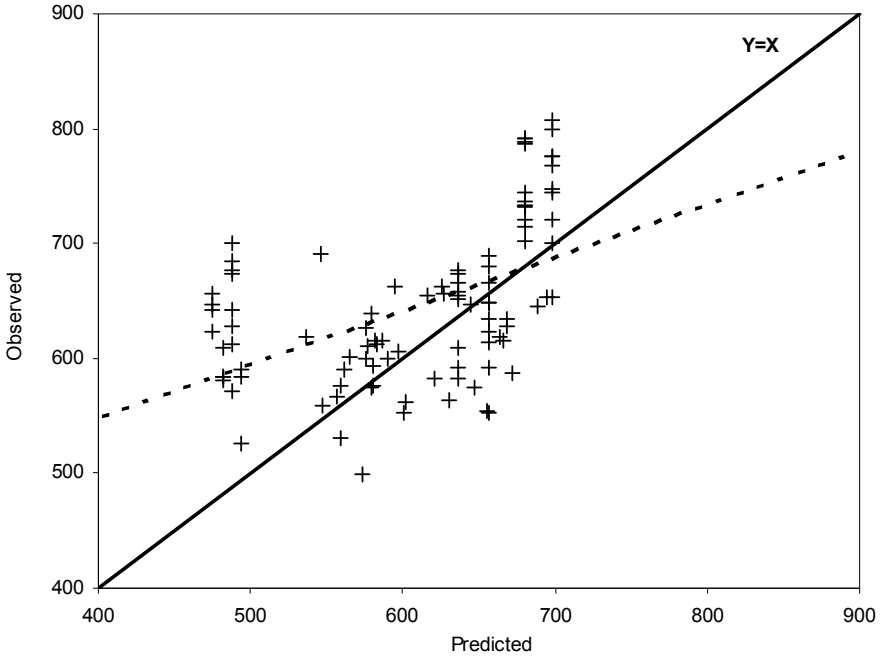
The empirical correction for the lignin constraint factor on NDF degradation increases the accuracy of the relationship between lignin and indigestible NDF contents (Detmann et al., 2004a). However, limitations are still observed in the precision of the new sub-model (Detmann et al., 2007; 2008b; Azevêdo, 2009).

Studies conducted under tropical conditions indicated weak to moderate correlations between the levels of lignin and those of NDFi (Detmann et al., 2007). This implies that gravimetric estimates of lignin content in feeds fail to precisely predict the dimensions of the potentially digestible (or indigestible) fraction of the NDF. Several environmental effects influence the chemical structure and arrangement of the lignin complex in plant cell wall (Van Soest, 1994). Thus, a simple gravimetric estimate would not accurately estimate the true inhibitory action of lignin on NDF.

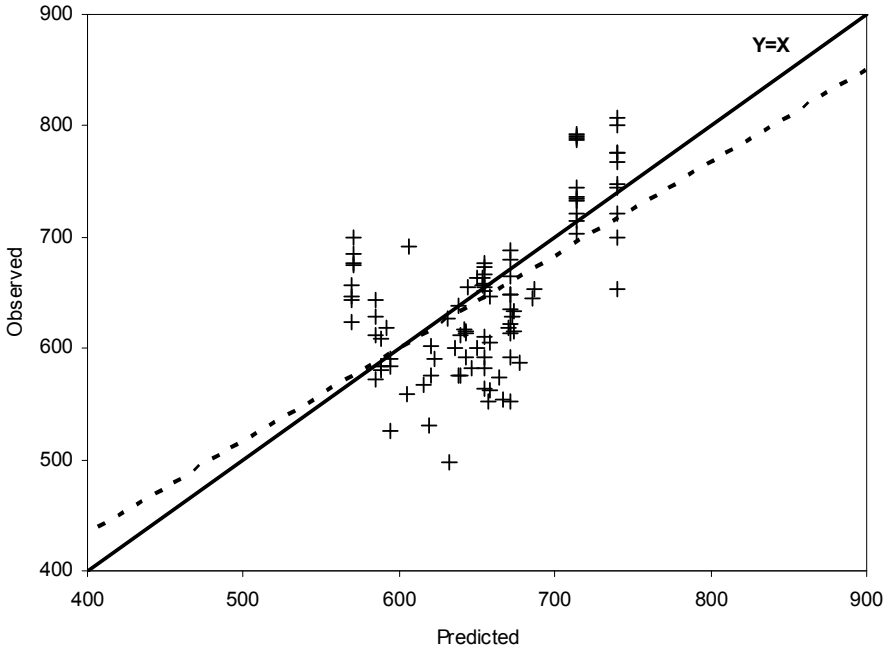
To change this situation, obtaining estimates of the potentially digestible fraction of the NDF may be performed by means of biological methods (e.g.: by *in situ*

procedures) (Detmann et al., 2007). These could be incorporated in routine of laboratory feed analysis, amplifying the efficiency of the prediction process.

However, despite the limitations in the sub-model with regard to NDF estimates, the implementation of the new summative system allows to obtain accurate estimates of dietary levels of TDN under tropical conditions, which has not been observed with the NRC sub-model (Detmann et al., 2008b; Azevêdo, 2009; Magalhães et al., 2010) (Figure 2).



(a)



(b)

Figure 2 - Relationship between TDN content (g/kg of DM) observed and predicted by the NRC (2001) (a) and new summetive (b) systems. (The solid line represents the equality relationship and the dashed line represents the least squares relationship; n = 107; Detmann et al., 2008b).

In conclusion, the new sub-models presented here provide accurate estimates of digestible fractions of EE, CP, NFC and NDF. Therefore, the summative system constructed from these new sub-models constitutes an alternative to the model adopted by the NRC (2001) to estimate the TDN content in cattle feeds and diets under tropical conditions.

APPLICATION EXAMPLE

Productive situation – Dairy Cows
Diet: forage:concentrate ratio of 60:40 based on dry matter.
Forage: Corn silage.
Concentrate: Mixture of corn grain (67.74% of the DM), soybean meal (28.76% of the DM), urea:ammonium sulphate (U:AS; 9:1; 1.5% of the DM) and mineral mix (MM; 2.0% of the DM).

Table 4 - Chemical composition of feeds and total diet (% of the DM)

Item[1]	Silage[1]	Corn grain[1]	Soybean meal[1]	U:AS	MM	Concentrate	Diet
DM	30.92	87.64	88.61	100	100	88.35	53.89
OM	94.74	97.60	92.85	100	0	94.32	94.57
CP	7.26	9.11	48.78	260	-	24.10	14.00
Ur	-	-	-	100	-	1.50	0.60
PBu	-	-	-	260	-	3.90	1.56
EE	3.16	4.07	1.71	-	-	3.25	3.20
NDFcp	51.77	10.19	10.72	-	-	9.99	35.06
Lignin	4.97	1.16	1.33	-	-	1.17	3.45
NFC	32.55	74.23	31.64	-	-	59.38	43.28
NDIP	1.14	0.87	2.38	-	-	1.27	1.19
ADIP	0.57	0.35	1.34	-	-	0.62	0.59

[1] Valadares Filho et al. (2006).

Calculation of the truly digestible EE (Equation 9)

$$EE_{vd} = 086 \times EE = 0.8596 \times 3.20 = 2.75\%$$

Calculation of the truly digestible NFC (Equation 10)

$$NFC_{vd} = 0.95 \times NFC = 0.95 \times 43.28 = 41.11\%$$

Calculation of the digestible NDF (Equation 12; Table 2)

$$NDF_d = D_v \times \{(NDFap - L) \times [1 - (\frac{L}{NDFap})^{0.85}]\}$$

$$NDF_d = 0.67 \times \{(35.06 - 3.45) \times [1 - (\frac{3.45}{35.06})^{0.85}]\} = 18.23\%$$

Calculation of the truly digestible CP (Equation 17; Table 2)

$$CP_{vd} = D_{tCCCP} \times (CP - NDIP) + D_{CWCPpd} \times \{NDIP \times [1 - e^{-(0.8188+1.1676 \times ADIP)}]\}$$

$$CP_{vd} = 0.98 \times (14.00 - 1.19) + 0.67 \times \{1.19 \times [1 - e^{-(0.8188+1.1676 \times 0.59)}]\}$$

$$CP_{vd} = 0.98 \times 12.81 + 0.67 \times (1.19 \times 0.7786)$$

$$CP_{vd} = 12.55 + 0.62 = 13.17\%$$

Calculation of the TDN (Equation 18; Table 1)

$$TDN = CP_{vd} + NFC_{vd} + NDF_{d} + 2.25 \times EE_{vd} - FM_{TDN}$$
$$TDN = 13.17 + 41.11 + 18.23 + 2.25 \times 2.75 - 7.16$$
$$TDN = 78.70 - 7.16$$
$$TDN = 71.54\%$$

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