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Application of the Cornell Net Carbohydrate and Protein System for tropical conditions

INTRODUCTION

CATTLE ARE used to convert forages, feed grains, and food byproducts into human food under production conditions that vary in soil, climate, feed composition and types of cattle. To balance their diets, people in the tropics have used nutrient requirements and feed values developed in North America under standardized, controlled research conditions for all types of cattle, feeds, and environmental and management conditions. An analysis of our data base (Ainslie *et al.*, 1993) and our unpublished data with lactating dairy cows indicate cattle performance is restricted to the level allowed by the most limiting nutrient, and that energetic efficiency is influenced by amino acid balance. Our analysis indicate accurate prediction of requirements in each situation depends on the ability to predict cattle requirements and supply of ruminally degraded carbohydrates, protein, microbial growth, TDN, ME, NE, heat increment (HI), metabolizable protein (MP), net protein (NP), and essential amino acids (EAA). Formulating rations for varying cattle requirements requires an accounting system for the variables known to influence requirements

and dietary supply of energy, and absorbed amino acids.

The efficiency of tropical cattle production can be improved using models to account for performance variation by accurately predicting requirements and feed utilization in individual production settings. To be useful at the farm level, the model must use inputs that are typically available. Since the required data may not be available on every farm, these models must permit logical adjustment of the inputs from each situation until predicted and observed performance (daily gain, milk amount and composition, and body condition score changes) agree. The observed responses to changes in management and feeds then can be explained by predicted effects on ruminal fermentation, intestinal digestion, utilization of energy and amino acids, and amount and composition of end products. Nutrient excretion and often wasteful "safety factors" can be minimized when the improved feeding program designed for the specific situation is in place. The Cornell Net Carbohydrate and Protein System (CNCPS) as described and validated by Russell *et al.*, 1992, Sniffen *et al.*, 1992, Fox *et al.*, 1992, O'Connor *et al.*, 1993, Ainslie *et al.*, 1993, Ty-

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lutki *et al.*, 1994, Fox *et al.*, 1995, Pitt *et al.*, 1996, NRC, 2000, and Tedeschi *et al.*, 2000 was developed for that purpose. The CNCPS can be used as a teaching tool for students and consultants, to design and interpret experiments, to apply research results, to develop tables of nutrient requirements for any cattle type and production level, and to evaluate and improve feeding programs on farms. Although this paper is written from a nutritional perspective, it is important to remember that nutritional status has a significant effect on reproductive performance. The ability to predict energy balance is important for reproductive efficiency because ovulation usually does not occur until 10-14 days after the time when the energy demand most exceeds supply NRC, 2000. This paper summarizes the structure of the CNCPS and its application in predicting energy balance in cattle. Included is discussion of the additional adjustments made to adapt the CNCPS for cattle in the tropics (maintenance, expected mature size, and peak milk production of tropical breeds and feed carbohydrate and protein fractions of tropical feeds) as summarized by Lanna *et al.*, 1996 and a sample application for Mexico, based on the studies of Juarez Lagunes, 1998. The summary presented also applies to the NRC, 2000 model level 2, since its structure is similar to the CNCPS v 4.0. Fox *et al.*, 2000.

The Structure of the Cornell Net Carbohydrate and Protein System

To predict requirements and feed utilization in each production setting, we use models that integrate our knowledge of the effects of feed, intake, and digestion and passage rates on feed energy values, escape of dietary protein and microbial growth efficiency. We define a model in the context described by Gill *et al.*, 1989; an integrated set of equations and transfer coefficients that describe the various physiological functions of cattle. Included are predictions of tissue requirements (maintenance, growth, pregnancy, lactation and tissue reserves), and supply of nutrients to meet requirements (dry matter intake, feed carbohydrate and protein fraction pool sizes and their characteristic digestion and passage rates, microbial growth, intestinal digestion and metabolism of absorbed nutrients). The purpose of a model is to describe mathematically the response of each compartment or several connected compartments to a variable or combination of variables. A model is considered to be mechanistic when it simulates behavior of a function through elements at a lower level Gill *et al.*, 1989.

Most biological responses are dynam-

ic: they are integrated, nonlinear and change over time Sauvant 1991. A totally mechanistic model that will accurately simulate whole animal metabolism under all conditions with little risk of use does not exist, however Gill *et al.*, 1989; Bannik *et al.*, 1997 evaluated three mechanistic rumen models and detected inconsistencies among them and between predicted and observed outputs. They reported that none of the models seemed to predict all nutrient flows best and the models particularly differed in the representation of microbial metabolism. We do not have sufficient information available on all compartments of the model under the range of likely production conditions to develop such a model for ration formulation. This lack of information precludes development of a truly mechanistic model in the short-term. Adequate validation of a mechanistic model also presents problems because we do not have validation data at the appropriate level of aggregation. In most application systems (AFRC 1993, CSRIO 1990, INRA 1989, NRC 1985. NRC 1989, the prediction of nutrient metabolism is not as advanced as the prediction of ruminal fermentation because of the number and complexity of the metabolic pathways linking the tissue and metabolic compartments, the multiple nutrient interactions, and the sophisticated metabolic regulatory mechanisms which direct the use of the absorbed nutrients (homeorhesis and homeostasis) (Sauvant, 1991). Therefore, most systems use a combination of mechanistic and empirical approaches. These systems generally assume steady state kinetics and are static. They use statistical representations of data to describe the aggregated response of whole compartments.

Because the development process of the CNCPS has been similar to the approaches used in the development of the other systems, there are similarities in the types of problems we have faced. The first issue that we encountered was in determining the appropriate level of aggregation of the equations: Are we attempting to model cellular function, whole animal performance or the whole farm system? Second, clear definition of the objective of the model is essential. Development of the equations to model physiological functions is the core of the modeling process. The important issues here involve deciding on the appropriate mix of empirical and mechanistic representations of physiological functions. These decisions are governed by the availability of development and validation data, the likelihood that needed input data will be available and the benefits and the risks

of use associated with increased sensitivity. In developing the CNCPS, one of our primary goals was that the program should be practical and useful at the farm level. Therefore, all of the inputs had to be available from the farm and the output from the model had to provide diagnostic information that would permit refinement of the feeding program on each farm. Another objective was to develop a flexible structure that could be continuously updated and refined as new knowledge becomes available.

The CNCPS thus contains a biologically based structure and hierarchy for evaluating diets for all classes of cattle over wide variations in cattle, feed, management and environmental conditions with the purpose of adjusting nutrient requirements and feed utilization. The structure and level of aggregation of the model were based on the experience of the authors in working with farmers and consultants applying knowledge to diagnose performance problems and to develop more accurate feeding programs. The CNCPS has been developed over 20 years, based on research on cattle requirements and feed utilization. Separate submodels of different physiological functions (feed intake and composition, rumen fermentation, intestinal digestion, metabolism, maintenance, growth, pregnancy, lactation and reserves) were developed so that new information could be incorporated into the appropriate submodels. The CNCPS uses information that can be universally obtained, understood and applied to describe cattle, and that can be easily used in program formulas to calculate responses. Although not universally available, most of the critical carbohydrate and protein fractions can be routinely determined by feed testing laboratories. The user must have some nutritional knowledge to use the program because background knowledge is assumed in choosing inputs. Because of the increased sensitivity of the program, the risk of use also is higher. For example, reducing the amount of protein fed may be of economic and environmental benefit to the producer, but, if intake is less than predicted, animal performance may be adversely affected because there is a slimmer safety margin. However, with experience, the CNCPS can be used to evaluate the interactions of animal type and production level, environment, feed composition and management factors. Changes in the ration needed to meet animal and rumen fermentation requirements under widely varying conditions can also be identified.

The following section summarizes the primary components in the CNCPS in-

cluding modifications for tropical cattle and feeds.

Maintenance requirement for energy and amino acids.

The maintenance energy requirement is determined by metabolic body size and rate and adjustments reflecting breed type, physiological state, previous nutritional treatment, activity, environment (temperature, wind velocity, and animal surface area and insulation) and heat gain or loss required to maintain normal body temperature. The proportion of the energy and protein intake and its composition needed for productive functions cannot be accurately determined until the proportion needed for maintenance is determined. To assess energy balance for a given animal, which requires prediction of NE, heat production from both the diet and from the animal must be determined. To predict the amino acid requirements for maintenance accurately, we must be able to predict the amount of metabolic fecal nitrogen and losses from net tissue turnover based on estimates of sloughed protein, urinary nitrogen loss, and scurf protein.

To adapt the CNCPS for use in the tropics, the maintenance requirement has been adjusted. The coefficients used to adjust maintenance requirements of fasting animals with an activity allowance of 10% in the tropics are as follows: 1. *Bos taurus*, beef, 0.077; 2 *Bos taurus*, dairy cows, 0.080; 3. *Bos taurus*, dairy heifers and steers, 0.086; 4. *Bos indicus*, 0.070; and dual purpose, 0.076. This base is adjusted for the effect of previous month's temperature, and body condition score to account for the effect of previous plane of nutrition.⁷ The NRC 2000 contains an excellent review of the factors affecting maintenance requirements. The CNCPS maintenance requirements were revised to more accurately account for the effects of activity and temperatures higher than 20°C (Fox, 1998).

Energy and amino acid requirements for tissue deposition and milk synthesis.

Growth requirements are based on empty body tissue composition of the gain expected, based on expected mature size for breeding herd replacements or expected weight at a particular final composition, considering body size, effect of dietary ingredients, and anabolic implants. The standard reference weight used to compute growth requirements is 467 kg for cattle in typical feeding situations in North America, as described by Tylutki *et al.*, 1994. This was modified by the NRC

2000 to three standard reference weights of 478, 462, and 435 kg for cattle fed to 28.2, 26.8, and 25.2% body fat associated with US and Canadian grades of standard or A, select or AA, and choice or AAA, respectively. In the tropical CNCPS, we use a standard reference weight of 400 kg when the tropical code is chosen because growing cattle are typically marketed at lower body fat endpoints (typically 18-22% body fat).

Pregnancy requirements are predicted from uterine and conceptus demand accounting for differences in expected birth weight and day of gestation. The ADG of the conceptus is computed separately from the optimum ADG of replacement heifers. The demands of pregnancy significantly affect animal requirements during the last 60 days of pregnancy.

Lactation requirements are computed based on the amount and composition of milk. For beef and dual-purpose cattle where daily milk production is not known, milk production is computed from a lactation curve using expected peak milk yield and day of lactation. For the tropical CNCPS, we have added the following peak milk values for tropical cattle breeds based on data from the Brazilian Universities of São Paulo and Viçosa: Nellore, 5; Guzerat, 5; Gir, 10; Canchim, 6; and Santa Gertudis, 5.

Reserves are used to meet requirements when nutrient intake is inadequate. Reserves must be taken into account when evaluating the ability of a diet to meet animal requirements, especially under conditions of environmental stress, feed shortage or early lactation. Visual appraisal is used to assign a body condition score, which in turn is used to predict body fat and energy reserves. The cycle of reserve depletion and replenishment during lactation and the dry period is reflected by predicted condition score change.

Prediction of intake and ruminal degradation of feed carbohydrate and protein fractions, and microbial growth.

The absorbed energy and amino acids available to meet requirements depend on accurate determination of dry matter intake (DMI), and the pool sizes and digestion rates of each of the carbohydrate and protein fractions from all ingredients in the ration. Estimates of microbial growth are essential in predicting the amount of energy and protein available to the animal. These predictions are made based on substrate availability. Most important in the CNCPS is accurate determination of DMI.

We use predicted DMI as a benchmark for diagnostic purposes where intake is known, and to predict DMI where actual intake is not available, such as when cattle are grazing.

The CNCPS assumes that there is an interaction among DMI, digestion and passage. For example, as intake increases during early lactation, the rate of passage increases resulting in lower feed digestibility. This lower digestibility is more apparent in the fractions that are more slowly digested i.e. the cell wall fraction. The site of digestion also may be altered. For example, starch that is not digested in the rumen because of a rapid rate of passage is likely to be digested in the small intestine. This does not hold for cell wall because little cell wall digestion occurs post-ruminally. Second, the percentage of cell wall that escapes digestion changes depending on digestion and passage rates. The variable rates of digestion and passage have similar implications for extent and site of digestion of the protein fractions in feeds. The readily available fractions are degraded in the rumen, while those that are more slowly degraded are partially degraded in the rumen and partially degraded post-ruminally. The proportion digested in each compartment depends on the rates of digestion and passage of the protein fractions in the feeds.

Rumen microorganisms can be categorized according to the types of carbohydrate they ferment. In the CNCPS, they are categorized into those that ferment fiber carbohydrate (FC) and nonfiber carbohydrate (NFC), as described by Russell *et al.*, 1992. Generally, the slowly growing FC microorganisms ferment cellulose and hemicellulose and utilize ammonia as their primary nitrogen source for microbial protein synthesis. The rapidly growing NFC microorganisms, in contrast, ferment starch, pectin and sugars and can utilize ammonia and amino acids as nitrogen sources. The FC and NFC microorganisms have different maintenance requirements. The efficiency of growth of the NFC-digesting bacteria is optimized when peptide availability equals 14% of the NFC available. These conservative values are based on the observations of Russell *et al.*, 1992 that the maintenance requirement of, *Streptococcus bovis* a primary starch fermenter, is about 6 times greater than that of *Fibrobacter succinogenes*, a representative fiber digester. Thus the degradable protein requirement is to ensure that the two microbial populations can use NFC and FC efficiently and that microbial growth is optimized. The rate of microbial growth of

each class of bacteria is directly proportional to the rate of carbohydrate digestion, assuming that adequate nitrogen is available in a usable form. The extent of digestion thus depends on factors such as level of intake, particle size, rate of hydration, lignification, and characteristics of each carbohydrate and protein fraction.

Recently, we added a sub-model in the CNCPS prediction of fiber digestion and microbial mass production from ruminally-degraded carbohydrate to account for a ruminal N deficiency Tedeschi *et al.*, 2000. This adjustment was evaluated with five published studies containing adequate information to evaluate the response of animals to added dietary N. The adjustment decreased the CNCPS overprediction of ADG in these nitrogen deficient diets from 19.2 to 4.7%, mean bias declined from 0.16 to 0.04 kg/d, and the r^2 of the regression between observed and metabolizable energy or metabolizable protein allowable ADG was increased from 0.83 to 0.88 with the adjustment. These results indicated the adjustment for ruminal nitrogen deficiency increased the accuracy of the CNCPS model in evaluating diets when ruminally degraded N is deficient, which is frequently observed in tropical conditions.

The ME and MP derived in each situation primarily depends on the rates of digestion and passage of each of the feed carbohydrate and protein fractions. Digestion rates are feed specific, and are affected by type of starch and protein, degree of lignification, and processing. Extent of ruminal digestion is a function of competition between digestion and passage, and varies with feed type (forage versus grain) and particle size (eNDF). There are four nitrogen fraction requirements that must be met in evaluating a ration with the CNCPS; two microbial categories (ammonia for the FC and peptides and ammonia for the NFC microbial pools), and two animal pools (MP and essential amino acids). In evaluating a diet, one must be able to determine how well all four requirements are being met.

One of the critical factors affecting microbial growth is rumen pH. The CNCPS describes physical characteristics of feeds as related to their effectiveness in stimulating chewing and rumination. We use total cell wall content and particle size within classes of feeds to estimate effective NDF (eNDF), based on Mertens' definition Mertens, 1998. The eNDF value in the CNCPS is defined as the percent of the NDF retained on a 1.18 mm screen. Factors other than particle size that influence the eNDF value are degree of lignification of

the NDF, hydration, and bulk density. Beauchemin 1991, published an excellent review of the factors influencing buffer production and rumen pH in cattle. Pitt *et al.*, 1996 described the relationship between CNCPS eNDF values, rumen pH and FC digestion. Total microbial yield and growth rate of the FC degrading bacteria rapidly decline when pH is below 6.2. This usually occurs when dietary eNDF content is below 20%. The CNCPS reduces microbial yield 2.5 percentage units for each percentage drop in diet eNDF below 20%. Thus estimates of the diet eNDF must be correct to accurately predict microbial amino acid production and cell wall digestion.

Feeds are subdivided into 4 carbohydrate and 5 protein fractions in the CNCPS. The size and digestion rate of each of these fractions are used to compute the amount of FC and NFC available for each of the two microbial pools. Pool sizes, digestion and passage rates have been published for feeds common to North America, based on data in the literature NRC 2000, Sniffen *et al.*, 1992. A tropical feed library has been developed and evaluated by Tedeschi *et al.*, 2000a. Nearly all of the critical carbohydrate and protein fractions can be routinely determined by feed testing laboratories, using the Van Soest system (Van Soest *et al.*, 1991) of feed analysis (NDF, CP, soluble protein, neutral and acid detergent insoluble protein).

Establishing pool sizes and digestion rates for tropical forages for use in the CNCPS.

Table 1 summarizes carbohydrate and protein fractions and digestion rates determined in forages that were grown in tropical regions. All of the carbohydrate and protein fractions were measured, and the carbohydrate digestion rates of the first 4 grasses were determined using the gas production procedure of Pell and Schofield (Pell *et al.*, 1993). These analyses and the evaluations were done by Juarez Lagunes 1998, 99, in a collaborative project with the National Institute of Agroforestry and Animal Science Research (INIFAP), Veracruz, Mexico.

This experiment station is located on the southeastern coast of Mexico at 19 02' latitude and 96 08' longitude at an altitude of 12 m above sea level. This region is characterized as tropical subhumid Aw following Köppen's classification of tropical climates (Lal, 1987) with an average rainfall of 1728 mm/year and rainy season from June to November. The maximum temper-

ature is around 35°C, minimum 15°C, and average 25°C, with a seasonal change of about 3°C. The relative humidity averages 81 %. The soil is classified as Oxisol, a predominantly sandy loam with > 15 % Clay. The soil pH is between 5.3 - 5.6. The grasses were grown in pure stands. Each grass plot was fertilized with 100 Kg/ha of N at the beginning of the rainy season. Prior to the start of the experiment, all plots were cut to a height of 5 cm. After 35 and 42 d of re-growth, grass samples were clipped at a height of 10 cm. The first cutting was collected on July 25th and the second on August 1st. About 2 kg of green material was clipped from each plot at each sampling time. About 500 g were frozen immediately at -15°C, and 500 g were put at 100°C in a forced air oven for 24 h, for DM determination. At the end of the sampling collection period, the frozen samples were freeze dried, placed in 30 x 25 cm heavy duty freezer bags, and sent to Cornell University for laboratory analyses. All samples were ground through a 1-mm screen in a Wiley mill (Model 4, Arthur H. Thomas Co. Philadelphia, PA). As in AOAC 1990, dry matter by direct oven-drying at 100°C overnight, crude protein (N 6.25) by macro Kjeldahl procedure, ash, and solvent-soluble fat, were performed. Neutral detergent fiber (NDF) (without sodium sulfite), Acid detergent fiber (ADF), Permanganate lignin, and NFC were determined as in Van Soest *et al.*, 1991.

Table 1 shows the chemically determined fractions; the second section shows the digestion rates (kd) for carbohydrates (CHO) A (sugars), B1 (starch and pectin) and B2 (available NDF) and fast (B1), intermediate (B2) and slow (B3) protein. Total carbohydrates are computed as 100 - (protein + fat + ash), using tabular or analytical values. Then carbohydrates are partitioned into fiber (FC) and nonfiber (NFC) by subtracting NDF from total carbohydrates. The available cell wall is calculated using the equation: $NDF_{available} = NDF - NDF_{protein} - (Lignin - NDF) \cdot 2.4$. Traxler *et al.*, 1998 recently examined whether Lignin 2.4 accurately predicted the size of the indigestible fraction. This equation was adequate although an alternative more mechanistic equation was developed. Data from the literature are used to establish the distribution of sugars and starch in the NFC fraction. The protein fractions are expressed as a percentage of the CP (Licitra *et al.*, 1996). The "A" protein fraction is NPN and the "B1" fraction is true protein that is almost completely degraded in the rumen. Both of these pools are included in

Table 1. Carbohydrate and protein fractions and digestion rates of some tropical forages^a

Item	Unit	Tropical Forages ^b							
		1	2	3	4	5	6	7	8
Concentrations of carbohydrate and protein fractions, fat and ash									
NDF	% of DM	74.7	69.3	70.2	66.1	69.6	72.4	68.3	71.0
Lignin	% of NDF	7.5	6.2	6.1	5.6	6.3	5.7	4.7	6.0
CP	% of DM	8.0	7.4	8.6	8.9	7.8	6.3	9.3	10.5
Solubility	% of CP	35.6	31.0	20.4	42.5	44.1	41.2	29.6	19.7
NPN	% of SolP	34.9	61.9	82.4	69.7	67.0	58.4	74.8	58.4
NDIP	% of CP	39.3	34.7	48.6	13.6	13.7	21.9	25.6	43.2
ADIP	% of CP	9.7	8.6	6.7	3.5	4.4	7.2	4.8	8.3
Fat	% of DM	1.3	2.5	2.0	2.3	1.8	1.5	1.8	1.4
Ash	% of DM	9.0	11.0	8.0	9.3	8.8	9.4	12.3	10.7
Unavail. NDF	% of DM	13.4	13.3	10.3	8.9	10.5	9.9	7.7	10.2
Available NDF	% of DM	58.1	56.4	55.7	56.0	58.0	61.1	58.2	56.2
NFC ^c	% of DM	10.1	12.4	15.4	14.6	13.1	11.8	10.7	10.9

Digestion rates of carbohydrate and protein fractions

NFC ^c	%/hr	13.2	8.6	13.8	27.4	25.7	24.4	22.2	18.4
Available NDF	%/hr	3.8	6.8	7.3	8.4	8.1	8.1	7.5	5.5
Available NDF protein	%/hr	5.2	9.5	8.0	5.7	3.4	3.3	8.6	0.1

^a Values in bold are from Juarez Lagunes *et al.*, 1999.^b Feedstuffs: (1) Estrella (*Cynodon plectostachyus*); (2) Guinea (*Panicum maximum* Var. guinea); (3) Llanero (*Andropogon gayanus*); (4) *Brachiaria brizantha*; (5) *Brachiaria decumbens*; (6) *Brachiaria humidicola*; (7) Aleman (*Echinochloa polystachya*); and (8) Remolino (*Paspalum notatum*).^c NFC – nonfiber carbohydrate.

measures of soluble protein. The “C” protein fraction is measured as acid detergent insoluble protein (ADIP) and is assumed to be unavailable. The “B₃” or slowly degraded protein fraction can be determined by subtracting the value determined for ADIP from the value determined for neutral detergent insoluble protein (NDIP). The “B₂” fraction, which is partly degraded in the rumen, depends on digestion and passage rates, can be then estimated using the following equation:

$$B_2 = CP - (\text{Soluble CP} + B_3 + C)$$

The growth of two microbial pools (FC and NFC) is predicted, based on the integration of the rates of digestion and passage. This information then is used to determine the nitrogen requirements of each pool, the amount of microbial protein produced and MP available, carbohydrates available for intestinal digestion and ME derived from the diet. Microbial growth is adjusted for effective NDF (eNDF), using the values shown in the second section of Table 1. Passage rates are a function of level of intake, percent forage, and effective NDF value. The prediction of the ruminally available protein is used to determine nitrogen balance for the FC and

NFC bacteria. The MP from undegraded feed protein (excluding the microbial protein) is calculated from the amount of feed protein that is digested post-ruminally minus the indigestible protein fraction.

Feed amino acid content is described by amino acid concentration in the undegraded protein, as described by O'Connor *et al.*, 1993. Intestinal digestibility of the amino acids (Table 1) is assumed to be 100% of the B₁ and B₂, and 80% of the B₃ protein fractions escaping ruminal degradation.

This table demonstrates the importance of measuring pool sizes and digestion rates of tropical feeds; they are very different from feeds grown in a temperate climate. The importance of measuring these protein and carbohydrate fractions will be demonstrated later in the case study in Mexico with dual-purpose cattle.

Prediction of intestinal digestion.

Coefficients empirically derived are used to predict intestinal digestibilities and fecal losses based on summaries of data in the literature. A more mechanistic approach is needed that incorporates the integration of digestion and passage to predict intestinal digestion. However, the accuracy of prediction of pool sizes digested depends on the accurate knowledge of ruminal flows. For most feeds, 75% of the digestion occurs in

the rumen so it is more important to ensure that our estimates of ruminal fermentation are robust than to refine the intestinal model. Until the information on the carbohydrate and protein fractions is available routinely and their digestion and passage rates can be accurately predicted, the use of a more complex intestinal submodel could result in a multiplication of errors.

Prediction of metabolism of absorbed energy and aminoacids and feed biological values.

A metabolic submodel must predict heat increment and efficiency of use of absorbed carbohydrates, VFA, lipid and amino acids for various physiological functions based on changes in productive states.

Our inability to predict end products of ruminal fermentation and the complexity of the metabolic pathways of the animal dictate that we must use simple transfer coefficients to predict nutrient absorption if our model is to function well under a variety of field conditions. Pitt *et al.*, 1996 described the prediction of ruminal fermentation end products within the CNCPS structure as a first step.

The equations used to predict ME from

DE reflect the variation in methane produced across a wide range of diets. The equations used for lactating dairy cows to predict NEL from ME reflect the energetic efficiency associated with a typical mix of metabolites in the ME, based on respiration chamber data (Moe, 1981), and validated reasonably well on independent data (Roseler 1994). The equations used for growing cattle to predict NEm and NEg reflect the wide variation in metabolites used by growing cattle and dry cows, and validated with little bias over a wide range of ME contents (NRC 2000).

Predicting Dry Matter Intake

The use of actual dry matter intake (DMI) values when they are available is the utmost importance for an accurate prediction of animal performance. However, few producers know DMI under most tropical conditions, except in confinement dairy and beef feedlot conditions. Dry matter intake is driven primarily by demand (maintenance requirements, growth rate and milk production) up to the limits of rumen capacity with high cell wall diets, or chemostatic controls with high concentrate diets (NRC 1989).

In tropical conditions where diets are based on high cell wall forages, predictions of intake must reflect the effects of cell wall concentration. Traxler 1997 recently developed a composite model using the equation of NRC 1984, beef breeding female plus a linear component for milk yield to predict DMI ($BW^{0.75} \times (0.1462 \times NE_m - 0.0517 NE_m^2 - 0.0074) + 0.305 \times FCM$). For cows in the tropics yielding >15 kg/day of 4% fat corrected milk (FCM) and consuming high forage diets containing more than 55% NDF, we suggest adding 1.7 kg (the amount of mean bias) to the predicted intake value. No adjustment is likely to be needed for substantially lower daily milk yields. This equation as well as those in the CNCPS and in the NRC 2000 models for growing cattle accounts for both demand and physical fill effects. For tropical breeds of beef cattle, we begin reducing DMI when the diet contains approximately 2/3 concentrate; data from the University of São Paulo indicate that tropical breeds are less tolerant of high concentrate diets. Adjustments are made to the base intake for temperature and forage availability.

Case Study using Mexico Data

We developed a case study with data with 50 dual-purpose lactating cows from the Experiment Station “La Posta” (INI-

FAP), Veracruz, Mexico. The mature cow data used as CNCPS inputs were:

3/4 Holstein x 1/4 Zebu cow in the middle of the 5th lactation in August (rainy season). Body weight was 511 kg, milk production was 10 kg of milk/day, and the animal gained 0.5 kg of body weight daily. This cow is representative of a herd that was evaluated for 15 years. The herd was rotationally grazing Pangola grass (*Digitaria decumbens*). Cows were milked mechanically twice a day and supplemented with 3.5 kg/d of concentrate.

The CNCPS version 4.0 (Fox *et al.*, 2000), which contains all of the modifications for tropical conditions that have

been discussed, was used to compute the feed required to support the observed milk production, using feed composition values from the feed library or from the actual values determined in this experiment. The animal, management and environmental inputs are summarized in Table 2 and the feed composition values used are in Table 3. Because the intake of the pasture was unknown we computed pasture DMI required by changing the pasture intake until the observed milk production was met (Table 4).

Table 4 shows the predicted voluntary DMI was similar to the amount of DMI needed to support the observed animal per-

Table 2. Animal and environment descriptions used to predict feed requirements

Animal Description	
Animal Type	2 - Lactating Dairy Cow
Age	66 months
Sex	4 – Cow
Body Weight	511 kg
Breed Type	2 - Beef x Dairy
Mature Weight	550 kg
Condition Score	3 (1 = thin – 5 = fleshy)
Breeding System	2 way cross
Dam’s Breed	17 – Brahman
Bull’s Breed	15 – Holstein
Days Pregnant	55 days
Days since Calving	174 days
Lactation #	5
Rolling Herd Average	2866 kg
Milk Production	10 kg
Milk Fat	3.6 kg
Milk Protein	3.2 kg
Relative Milk Prod.	5 (1 – 9)
Exp. calf birth weight	38 kg
Management Description	
Additive	1 - None
Grazing Unit Size	27 hectares
Daily Pasture Allow.	1 DMI _{Actual} /DMI _{Potential}
Initial Pasture Mass	3000 kg/Hectare
Feeding Frequency	24 # Times Daily
Feeding Method	1 - For. and Gr. separate
Environment Description	
Wind Speed	16 kph
Previous Temperature	27 °C
Current Temperature	28 °C
Storm Exposure	1 - Yes
Night Cooling	1 - No cooling
Hair Depth	0.6 cm
Hide	1 - Thin
Hair Coat	1 - No Mud
Cattle Panting	1 - None

formance (12.8 vs 12.0 kg) when actual forage composition and measured digestion rates were used. We conclude that the CNCPS predicted animal requirements, nutritive values of the feeds, and forage DMI required accurately in this situation when measured feed composition values were used.

Table 5 shows that milk production was limited to the MP supply (10 kg MP allowable milk vs. 10.1 kg actual milk/day); ruminal nitrogen balance was positive; this is important for maximizing fiber digestion as well as microbial yield (the model adjusts both when N is deficient). The peptide balance was positive, indicating maximum microbial yield is obtained from bacteria that ferment NFC. Table 5 also shows the use of tabular values would have resulted in under predicting milk production from the forage and overfeeding the concentrate mix for 10 kg milk production (6.7 kg of concentrate mix were required for 10 kg ME allowable milk) with a higher cost. Although measured and tabular NDF values were nearly identical, the lower concentration of lignin and the higher measured rate of available fiber di-

gestion resulted in a higher predicted ruminal degradation of fiber which results in higher microbial yield and higher ME value for the grass.

Table 6 summarizes the ranges in forage composition measured in 15 species of tropical forages at 35 to 42 days re-growth in the study of Juarez Lagunes *et al.*, 1999. Tables 7 and 8 show the impact of these ranges on energy and protein allowable milk production when substituted one at a time for the forage composition values shown in Table 3.

Neutral Detergent Fiber and Lignin.

The impact of NDF and lignin concentrations are summarized in Table 7. The reduced milk production predicted as NDF increased was due to the replacement of NFC with FC. The MP from bacteria decreased because there was less rumen degradation of carbohydrates resulting in less microbial growth; this reduced predicted MP allowable milk. Ruminal N balance was positive because of reduced microbial growth. The CNCPS calculates unavailable NDF by multiplying the lignin concentration by 2.4 (recently evaluated

by Traxler *et al.*, 1998 so higher levels of lignin decreased NDF availability. The impact of increased lignin was to reduce available cell wall, which reduced ME available for milk production and microbial yield from cell wall, which reduced MP from bacteria and MP allowable milk. Rumen N balance was positive because of lower microbial growth. Because NDF provides most of the energy in tropical grasses and NDF digestibility is highly variable, it is important to have accurate values for NDF and lignin in tropical forages when fed as a high proportion of the diet to lactating dual-purpose cows.

CP and soluble protein

Table 7 also summarizes the results when CP and soluble protein are changed. At the measured protein solubility, as CP increased, the estimated MP allowable milk increased because of an increase in the MP from undegraded feed protein. At the measured forage CP, MP allowable milk production was reduced when the soluble protein percentage was increased. The decrease in MP allowable milk as a result of increased protein solubility resulted from a decrease in MP from unde-

Table 3. Feed analysis used for evaluating cattle performance with the CNCPS

Item	Pangola grass ¹		Sorghum	Soybean	Sugarcane
	FeedLibrary ²	MeasuredValues ³	Grain ³	Meal ³	Molasses ³
Cost, \$/ton as-fed	3.0	3.0	250.0	60.0	40.0
DM, %	21.0	26.8	87.4	89.0	85.8
NDF, % of DM	70.0	69.5	10.3	11.4	0.0
Lignin, % of NDF	11.4	7.5	12.8	0.9	0.0
CP, % of DM	9.1	8.9	10.4	52.6	4.2
Solubility, % of CP	42.0	41.9	14.9	16.0	98.0
NPN, % of SolP	4.8	36.3	33.0	55.0	100.0
NDIP ⁴ , % of CP	24.0	32.5	33.9	5.5	0.0
ADIP ⁵ , % of CP	2.2	5.4	5.0	2.0	0.0
Fat, % of DM	2.3	2.4	3.6	2.0	2.2
Ash, % of DM	7.6	8.6	3.0	7.0	11.6
Unavail. NDF, % of DM ⁶	19.2	12.5	3.2	0.3	0.0
Avail. NDF, % of DM ⁷	48.7	54.1	3.6	8.3	0.0
NFC, % of DM ⁸	13.2	13.5	76.2	29.9	82.0
Digestion rates, %/hr					
NFC (CHO A + B1)	30.0	19.7	14.3	7.9	17.5
Available NDF (CHO B2)	3.0	5.3	6.0	5.7	-
B1 protein	135.0	135.0	135.0 ²	230.0 ²	350.0 ²
B2 protein	11.0	11.0	6.0 ²	11.0 ²	11.0 ²
Available NDF protein ⁹	0.09	5.3	0.12 ²	0.20 ²	0.25 ²

¹ *Digitaria decumbens*.

² Tabular values from NRC, (2000).

³ Laboratory measurements except where noted.

⁴ Neutral detergent insoluble protein.

⁵ Acid detergent insoluble protein.

⁶ Unavailable NDF = NDF - (NDF x lignin (% of NDF) x 2.4).

⁷ Available NDF = NDF - (CP x (NDIP/100)) - unavailable NDF.

⁸ NFC = nonfiber carbohydrate, and is 100 -

CP - fat - ash - unavailable NDF - available NDF.

⁹ Available NDF protein = NDIP - ADIP.

graded feed protein. However, as more feed protein escapes the rumen undegraded, less degradable protein is available to meet microbial growth requirements. If degradable protein equals or exceeds requirement for the carbohydrate allowable microbial growth, additional soluble protein would not be beneficial. An excess of soluble protein will increase energy requirement to excrete excess N (urea cost), which increases maintenance requirement and reduces energy allowable milk production.

Digestion rates of carbohydrates.

Table 8 summarizes the results with changing digestion rates. Predicted ME allowable milk was insensitive to changes in digestion rates of the NFC (A and B₁ ruminal carbohydrate fractions), due to the high intestinal digestibility (75%) assumed for these fractions. The predicted MP allowable milk increased as the digestion rate of the A and B₁ fraction increased because more microbial protein is produced when more NFC is digested in the rumen. With all other values set to those measured (Table 3) the ME allowable milk was very sensitive to change in the rate of digestion of the B₂ carbohydrate fraction. The ME allowable milk increased when

Table 4. Feed intake of case study cows

Diet ingredient	Intake, kg/d
Sorghum grain	2.24
Soybean meal	0.77
Sugarcane molasses	0.35
Minerals	0.10
Urea	0.04
Pangola grass ¹	9.3
Total DMI, kg/d	12.8
Predicted DMI, kg/d	12.0

¹ DMI required to support observed performance.

Table 5. Expected milk production responses with measured or tabular values

Item	Measured	Library ¹	Library, ME balanced ²
Actual Milk production, kg/d	10.0	—	10.0
ME allowable milk, kg/d	10.0	2.8	10.0
MP allowable milk, kg/d	10.1	7.2	12.7
Rumen N Balance, g/d	55.0	59	93
Peptide Balance, g/d	66.0	58	75
MP balance, g/d	4.0	200	125
MP from Bacteria, g/d	662.0	476	589
MP from undegraded feed, g/d	397.0	380	568
Predicted DMI, kg/day	12.0	10.1	11.9
DMI required, kg/day	12.8	10.1	12.7
Cost per day, \$.	0.52	0.51	0.85

¹ Forage intake and milk production reduced to level predicted for the tabular forage quality.

² Concentrate mix was substituted for forage until ME allowable milk matched actual milk.

Table 6. Ranges in forage carbohydrate and Protein fractions at 35 to 42 days re-growth¹

Variable	Minimum	Maximum
Feed fraction		
NDF, % of DM	60	80
Lignin, % of NDF	4	8
Crude protein (CP), % of DM	4	12
Soluble protein, % of CP	20	50
Digestion rate, %/hr		
CHO A + B ₁ (NDF Soluble)	6	26
CHO B ₂ (Available NDF)	3	9
Protein B ₃ (NDIP)	4	10

¹ Values were rounded for simplicity of use in this case study.

Table 7. Expected milk production responses to changes in feed carbohydrate and protein fractions¹

Item	Base	MinNDF	MaxNDF	MinLignin	MaxLignin	MinCP	MaxCP	MinSP	MaxSP
ME allow. milk, kg/d	10.0	11.5	8.1	11.4	9.7	9.8	9.6	9.9	10.0
MP balance, g/d	4	72	-85	70	-11	-49	38	51	-14
MP allow. milk, kg/d	10.1	11.5	8.1	11.5	9.9	8.9	10.8	11.1	9.7
Rumen N Balance, g/d	55	46	70	47	57	8	84	48	58
Peptide Balance, g/d	66	50	85	66	66	19	96	69	65
MP from Bacteria, g/d	662	696	604	695	657	704	634	662	662
MP Undegr. feed, g/d	397	397	403	398	398	308	458	444	380

¹ Base is the original base values from Table 5.

Table 8. Expected milk production responses to changes in forage digestion rates

Item	Base	MinCHOA+B1	MaxCHOA+B1	MinCHOB2	MaxCHOB2	MinProteinB3	MaxProteinB3
ME allowable milk, kg/d	10.0	9.8	9.9	7.2	11.8	9.9	10.0
MP balance, g/d	4	-67	18	-164	152	15	-20
MP allowable milk, kg/d	10.1	8.5	10.4	6.4	13.5	10.3	9.6
Rumen N Balance, g/d	55	75	51	87	25	53	60
Peptide Balance, g/d	66	79	64	66	66	64	71
MP from Bacteria, g/d	662	584	678	545	777	662	662
MP from undegraded feed, g/d	397	403	397	398	398	410	373

the rate increased, due to a greater extent of degradation in the rumen. The predicted MP allowable milk increased as the B2 rate increased due to greater microbial yield from the cell wall as the extent of ruminal digestion increased.

B₃ protein rates of degradation

Table 8 also shows that increases in the degradation rates of the B₃ protein fraction for grasses decreased predicted MP allowable because less MP was obtained from undegraded feed. Because the rate of digestion of the B₃ protein approximated the passage rate, small changes in either the digestion rate of the B₃ protein or the predicted passage rate had a pronounced effect on the rumen degradability of the B₃ protein fraction. The B₃ protein fraction rates in the original CNCPS library rates were much lower (generally less than 0.1%/h) than the measured rates. The original rates result in rumen escape of most of the B₃ protein fraction.

Conclusions

The results presented show variations in feed carbohydrate and protein fractions and their digestion rates in tropical grasses can have a large effect on milk production of dual-purpose cattle. The case study indicates accurate prediction of energy and absorbed protein supply depended on prediction of the pool sizes of the NDF, starch, CP and soluble protein, and their digestion and passage rates as well as microbial amino acid composition. In these evaluations, we assumed the CNCPS accurately predicted animal requirements and responses to these variations in feed composition, based on previous studies (Lanna *et al.*, 1996). In those studies, the CNCPS was evaluated at the University of São Paulo at Piracicaba (Brazil) for accuracy of predictions in tropical conditions with actual DM intake of tropical feeds fed to cattle types typical of those used in the tropics (Lanna *et al.*, 1996). Feeds were characterized for their content of carbo-

hydrate and protein fractions and their digestion rates. The energy and protein content of empty BW gain (growing animals) and milk production (dual-purpose lactating cows) were measured. The growing cattle data set included 943 Nellore (the most common Zebu breed in Brazil) bulls and steers fed 96 different diets, with a subset of approximately 200 head used to determine composition of weight gain. Average live weight and live weight gain were 337 kg and 0.923 kg/d, respectively. The CNCPS accounted for 72% of the variation in live weight gain with only a 2% bias.

The lactating cow data set included 18 different diets fed to 178 Zebu crossbred cows representing the wide range in genotypes used for milk production in tropical conditions. The CNCPS accounted for 71% of the variation in milk production with a 10% bias. The 10% bias for the lactating cows is believed to be due to difficulty establishing the maintenance requirements of the animals because of the wide variation in their percentage of Holstein and Zebu. The authors observed that accounting for more of the variation in performance with the CNCPS would be difficult, because of the lack of uniformity in genotype within Zebu cattle. They also concluded that the CNCPS was more accurate than the NRC under tropical conditions when the feeds and cattle types could be characterized adequately to provide accurate inputs into the CNCPS.

In evaluating animal performance data, Tedeschi *et al.*, 2000 showed the NRC 2000 tabular feed energy values (TDN) were less accurate than those predicted by the CNCPS model or by an alternative equation (Weiss *et al.*, 1992) that also predicts TDN from feed composition. The tabular system overpredicted ME and MP allowable ADG by 11 and 4%, respectively, while Weiss equation and CNCPS biases were less than 2%. The authors reported

that the CNCPS model accounted for 83% of the variation in tabular values with no bias and 96% of the variation in values predicted by Weiss equation with only a –1% bias.

Based on these evaluations, we conclude the CNCPS can be used to describe animal requirements and the biological values of tropical feeds for cattle typical of those kept in the tropics for developing feeding recommendations in specific production situations, if adequate forage analysis information is available. With tropical grasses, predictions of animal responses are highly dependent on accurate values for NDF, lignin, CP and soluble protein and rates of digestion for the B₂ carbohydrate and B₃ protein fractions. The animal, environmental and feed compositional factors must be described as accurately and completely as possible. However, because many of the factors (body size, environmental conditions, feed digestion rates, particle size, etc.) depend on field observation, the input factors must be adjusted in a logical way until the model predicts the performance that is being observed before alternatives can accurately be evaluated. This approach allows requirements to be computed for the specific animal, environmental, DMI and feed compositional conditions.

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