NATIONAL RESEARCH COUNCIL
NUTRIENT REQUIREMENTS OF BEEF CATTLE
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ERRATA

CORRECTED CHAPTER 10

PREDICTION EQUATIONS AND COMPUTER MODELS

The National Research Council's (NRC) Nutrient Requirement Series is used in many ways–teaching, research, and practical diet formulation. The level of solution needed depends on the intended use, information available, knowledge of the user and risk of use. As the complexity of the information desired and the completeness of prediction of animal responses increases, the information and knowledge needed also increases. A computer program containing two levels of equations was developed to (1) predict requirements and energy and protein allowable production from the dietary ingredients fed, and (2) allow use with widely varying objectives.

One of the primary purposes of developing and applying models such as the model presented in this revision of *Nutrient Requirements of Beef Cattle* is to improve nutrient management through refined animal feeding. Predicting nutrient requirements as accurately as possible for animals in a given production setting results in minimized overfeeding of nutrients, increased efficiency of nutrient utilization, maximized performance, and reduced excess nutrient excretion. Agricultural animal excretion of nitrogen, phosphorus, copper, and other minerals poses a risk for groundwater and soil contamination in areas of intensified animal production (U.S. Environmental Protection Agency, 1993). With the use of modeling techniques, however, to more accurately predict requirements and match them with dietary nutrients, producers have made significant strides to optimize performance while addressing environmental impacts. The application of a nutrition model to formulate dairy cattle diets in an area of Central New York State resulted in a 25 percent decrease in nitrogen excretion and a substantial reduction in feed costs (Fox et al., 1995). Food-producing animals are also often targeted as a source of atmospheric methane, which contributes to global warming. Cattle typically lose 6 percent of ingested energy as eructated methane, which is equivalent to approximately 300 L methane/day for an average steer (Johnson and Johnson, 1995). Development of management strategies, including modeling to predict nutrient requirements more precisely, can mitigate methane emissions from cattle by enhancing nutrient utilization and feed efficiency. Application of models in agricultural animal production thus has the potential to significantly reduce nutrient loading of the environment while providing economic benefits and tangible returns to those who implement these systems for improved animal feeding.

Both levels of the model introduced in this revision use the same cattle requirements equations presented in this publication, which the committee feels, can be used to compute requirements over wide variations in body sizes and cattle types, milk production levels and environmental conditions. Level 2 was designed to obtain additional information about ruminal carbohydrate and protein utilization and amino acid supply and requirements. To achieve these objectives, more mechanistic submodels published by Russell et al., 1992; Sniffen et al., 1992; Fox et al., 1992; and O'Connor et al., 1993 were included to predict microbial growth from feed carbohydrate and protein fractions and their digestion and passage rates. These submodels provide variable ME, MP, and amino acid supplies from feeds, based on variations in DMI, feed composition and feed fiber characteristics. In considering the level 2 model for use in this publication, other published models were reviewed (Institut National de la Recherche Agronomique, 1989; Commonwealth Scientific and Industrial Research Organization, 1990; Dikstra et al., 1992; Agricultural and Food Research Council, 1993; Baldwin, 1995). Major limitations of the more mechanistic models (Dikstra et al., 1992; Baldwin, 1995) were a lack of field available inputs to drive them, including feed libraries, and no improvement in predictability than the level 2 model chosen (Kohn et al, 1994; Tylutki et al., 1994; Pitt et al., 1996). Major limitations of the other more highly aggregated models (Institut National de la Recherche Agronomique, 1989; Commonwealth Scientific and Industrial Research Organization, 1990; Agricultural and Food Research Council, 1993) were inability to use inputs available in a specific production setting in North America to mechanistically predict feed net energy values and supply of amino acids.

Level 1 should be used when limited information on feed composition is available and the user is not familiar with how to use, interpret and apply the inputs and results from level 2. Potential uses of level 2 are (Fox et al., 1995):

- as a teaching tool to improve skills in evaluating the interactions of feed composition, feeding management and animal requirements in varying farm conditions;
- to develop tables of feed net energy and metabolizable protein values and adjustment factors that can extend and refine the use of conventional diet formulation programs;
- as a structure to estimate feed utilization for which no values have been determined and on which to design experiments to quantify those values;
- to predict requirements and balances for nutrients for which more detailed systems of accounting are needed, such as peptides, total rumen nitrogen, and amino acid balances;
- as a tool for extending research results to varying farm conditions; and
- as a diagnostic tool to evaluate feeding programs and to account for more of the variation in performance in a specific production setting.

The equations for each level are presented in "pseudo code" form for convenience of programming them into any language. The data on which the equations are based are discussed in the appropriate section of the text.

In this revision, much more emphasis is placed on predicting the supply of nutrients, because animal requirements and diet are interactive, including calculating feed digestibility under specific conditions, heat increment to compute lower critical temperature, calculation of efficiency of ME use for maintenance, growth and lactation, and adjusting microbial protein production for diet effective NDF content. Therefore, accuracy of prediction of nutrient requirements and performance under specific conditions depends on accuracy of description of feedstuff composition and DMI.

In developing more mechanistic models for determining the nutrient requirements of beef cattle, the subcommittee considered recent models that describe some of all aspects of postabsorptive metabolism (Oltjen et al., 1986; France et al., 1987). The France model is mechanistic in its approach to metabolism but has received no, or limited, validation with field data. The Oltjen model was considered by the subcommittee and compared with predictions of the proposed models with respect to growth (see Chapter 3). For further presentation on alternative techniques to modeling responses to nutrients in farm animals, the reader is referred to the report of the Agricultural and Food Research Council (AFRC) Technical Subcommittee on Responses to Nutrients (Agricultural and Food Research Council, 1991).

Requirements for Both Levels

The requirement section is subdivided into four main sections: maintenance, growth, lactation and pregnancy.

Maintenance

Maintenance requirements are computed by adjusting the base NEm requirement for breed, physiological state, activity and heat loss vs. heat production, which is computed as ME intake - retained energy. Heat loss is affected by animal insulation factors and environmental conditions.

Energy

$a1 = 0.077$

Adjustment for previous temperature:

$a2 = 0.0007 * (20-T_p)$

Adjustment for breed, lactation and previous plane of nutrition:

$NEm = SBW^{0.75} * ((a1 * BE * L * COMP) + a2)$

$COMP = 0.8 + ((CS-1) * 0.05)$

Adjustment for activity:

If on pasture:

$NE_{mact} = ((0.006*pI*(0.9 * (TDN_p/100)))+ (0.05*TERRAIN/((.002471*pAVAIL)+3)))*BW/4.184$

otherwise

$NE_{mact} = 0$

$I_m = (NE_m + NE_{mact})/(NE_{ma} * ADTV)$

for growing cattle (used to compute heat increment):

$RE = (DMI - I_m) * NE_{ga}$

$YE_n = 0$

$LE = 0$

for lactating cattle (used to compute heat increment):

$(RE+YE_n+NE_{preg}) = (DMI - I_m) * NE_{ma}$;

assumes $NE_{ma} = NE_{lactation}$,

adjustment for cold stress:

$SA = 0.09\ BW^{0.67}$

$HE = (MEI - (RE+YE_n+NE_{preg})) / SA$

$EI = (7.36 - 0.296 * WIND + 2.55 * HAIR) * MUD2 * HIDE$;

if $EI < 0$ then $EI = 0$

MUD2 code factor 1 = 1.0	HIDE code factor 1 = 0.8
MUD2 code factor 2 = 0.8	HIDE code factor 2 = 1.0
MUD2 code factor 3 = 0.5	HIDE code factor 3 = 1.2
MUD2 code factor 4 = 0.2	

if $t <= 30$ then $TI = 2.5$

if $t > 30$ and $<= 183$ $TI = 6.5$

if $t > 183$ and $<= 363$ $TI = 5.1875 + (0.3125 * CS)$

if $t > 363$ $TI = 5.25 + (0.75 * CS)$

$IN = TI + EI$

$LCT = 39 - (IN*(HE)*0.85)$

if $LCT > T_c$ $ME_{cs} = SA * (LCT - T_c) / IN$

otherwise, $ME_{cs} = 0$
$NE_{mcs} = k_m * ME_{cs}$
$NE_m total = (NE_m + NE_{mact} + NE_{mcs})$

or if heat stressed (panting):
$NE_m total = (NE_m * NE_{mhs}) + NE_{mact}$
$I_m total = NE_m total / NE_{ma}$

where
a1 is thermal neutral maintenance requirement (Mcal/day/SBW$^{0.75}$);
a2 is maintenance adjustment for previous ambient temperature, (Mcal/day/BW$^{0.75}$);
T_p is previous average monthly temperature, °C;
t is days of age;
NE_m is net energy required for maintenance adjusted for acclimatization;
BE is breed effect on NE_m requirement (Table 10-1);
L is lactation effect on NE_m requirement(1 if dry, 1.2 if lactating);
SEX is 1.15 if bulls, otherwise 1;
CS is condition score, 1-9 scale;
COMP is effect of previous plane of nutrition on NE_m requirement;
NE_{mact} is activity effect on NE_m requirement (Mcal/kg);
DMI is dry matter intake kg/day;
pI is pasture dry matter intake, kg/d;
TDN_p is total digestible nutrient content of the pasture, %;
TERRAIN is terrain factor, 1 = level land, 2 = hilly;
pAVAIL is pasture mass available for grazing, T/ha;
I_m is I for maintenance (no stress), kg DM/day;
$I_m$total is I for maintenance (with stress), kg DM/day;
RE is net energy available for production, Mcal/day;
NE_{ma} is net energy value of diet for maintenance, Mcal/kg;
ADTV is 1.12 for diets containing ionophores, otherwise, 1.0;
NE_{ga} is net energy value of diet for gain, Mcal/kg;
YE_n is net energy milk (Mcal/kg);
NE_{preg} is net energy retained as gravid uterus (Mcal/kg);
MEC is metabolizable energy content of diet, Mcal/kg;
SA is surface area, m^2;
HE is heat production, Mcal/day;
MEI is metabolizable energy intake, Mcal/day;
LCT is animal's lower critical temperature, °C;
T_{tnz} is temperature at thermal neutral zone, °C,
IN is insulation value, °C/Mcal/m^2/day;
TI is tissue (internal) insulation value, °C/Mcal/m^2/day;
EI is external insulation value, °C/Mcal/m^2/day;
WIND is wind speed, kph;
HAIR is effective hair depth, cm;
MUD2 is mud adjustment factor for external insulation;
1 = dry and clean, 2 = some mud on lower body,
3 = wet and matted, 4= covered with wet snow or mud;
HIDE is hide adjustment factor for external insulation;
1 = thin, 2 = average, 3 = thick;
T_c is current temperature, °C;
EAT_c is current effective ambient temperature, °C;
ME_{cs} is metabolizable energy required due to cold stress, Mcal/day;
k_m is diet NE_m / diet ME (assumed 0.576 in derivation);
NE_{mcs} is net energy required due to cold stress, Mcal/day;

NE_{mhs} is 1.07 for rapid shallow panting and 1.18 for open mouth panting if temperature >is 30°C;
NE_mtotal is net energy for maintenance required adjusted for breed, lactation, sex, grazing, acclimatization and stress effects, Mcal/d; and
FFM_{total} is feed for maintenance (adjusted for stress), kg DM/day.

Table 10-1. Breed Maintenance Requirement Multipliers, Birth Weights, Peak Milk Production[a]

Breed	Code	NE_m (BE)	Birth wt. kg (CBW)	Peak Milk Yield, kg/day (PKYD)
Angus	1	1.00	31	8.0
Braford	2	0.95	36	7.0
Brahman	3	0.90	31	8.0
Brangus	4	0.95	33	8.0
Braunvieh	5	1.20	39	12.0
Charolais	6	1.00	39	9.0
Chianina	7	1.00	41	6.0
Devon	8	1.00	32	8.0
Galloway	9	1.00	36	8.0
Gelbvieh	10	1.20	39	11.5
Hereford	11	1.00	36	7.0
Holstein	12	1.20	43	15.0
Jersey	13	1.20	31	12.0
Limousin	14	1.00	37	9.0
Longhorn	15	1.00	33	5.0
Maine Anjou	16	1.00	40	9.0
Nellore	17	0.90	33	7.0
Piedmontese	18	1.00	38	7.0
Pinzgauer	19	1.00	38	11.0
Polled Here.	20	1.00	33	7.0
Red Poll	21	1.00	36	10.0
Sahiwal	22	0.90	38	8.0
Salers	23	1.00	35	9.0
S.Gertudis	24	0.95	33	8.0
Shorthorn	25	1.00	37	8.5
Simmental	26	1.20	39	12.0
South Devon	27	1.00	33	8.0
Tarentaise	28	1.00	33	9.0

[a]Variable names (BE, CBW, PKYD) are used in various equations to predict cow requirements.

Maintenance Protein Requirement

$$MP_{maint} = 3.8 * SBW^{0.75}$$

where

MP_{maint} is metabolizable protein requirement for maintenance, g/day;
SBW is shrunk body weight.

Growth

Requirements for growth are calculated using body weight, shrunk weight gain, body composition, and relative body size.

Energy & protein requirements

$EBW = 0.891\ SBW$
$EBG = 0.956\ SWG$
SRW = 478 kg for animals finishing at small marbling (28% body fat),replacement heifers, and breeding bulls.
= 462 kg for animals finishing at slight marbling (27% body fat),
= 435 kg for animals finishing at trace marbling (25% body fat).
$EQSBW = SBW * (SRW)/(FSBW)$
$EQEBW = 0.891 * EQSBW$
$RE = 0.0635 * EQEBW^{0.75} * EBG^{1.097}$
$NP_g = SWG * (268 - (29.4\ (RE/SWG)))$
If $EQSBW <= 300$ kg,
$MP_g = NP_g/(0.834-(EQSBW * 0.00114))$
otherwise,
$MP_g = NP_g/0.492$

where

EQSBW is equivalent shrunk body weight, kg;
EBW is empty body weight, kg;
SBW is shrunk body weight, kg (typically 0.96*full weight);
EBG is empty body gain, kg;
SWG is shrunk weight gain, kg;
RE is retained energy, Mcal/day;
EQEBW is equivalent empty body weight, kg;
FSBW is actual final shrunk body weight at the body fat endpoint selected for feedlot steers and heifers, at maturity for breeding heifers or at mature weight * 0.6 for breeding bulls;
NP_g is net protein requirement, g/day;
MP_g is metabolizable protein requirement, g/day.

Prediction of average daily gain (ADG) when net energy available for gain (RE) is known:

$EBG = 12.341 * EQEBW^{-0.6837} * RE^{0.9116}$.
$SWG = 13.91 * RE^{0.9116} * EQSBW^{-0.6837}$.

Growth Requirements of Replacement Heifers

Coefficients for computing target breeding weights at puberty are based on the summary in chapter 3. Coefficients for computing target breeding weights after first calving are based on USMARC data summarized by Gregory et al. (1992).

Predicting target weights and rates of gain:

TPW = MW * (0.55 for dual purpose and dairy, 0.60 for Bos taurus and 0.65 for Bos indicus)
TCA = Target calving age in days
$TPA = TCA - 280$
$BPADG = (TPW - SBW) / (TPA - T_{AGE})$
$TCW1 = MW * 0.80$
$TCW2 = MW * 0.92$
$TCW3 = MW * 0.96$
$TCW4 = MW * 1.0$
$APADG = (TCW1 - TPW) / (280)$
$ACADG = (TCW_{xx} - TCW_x)/CI$

where:

MW is mature weight, kg;
SBW is shrunk body weight, kg;
TPW is target pregnant weight, kg;
TCW1 is target first calving weight, kg;
TCW2 is target second calving weight, kg;
TCW3 is target third calving weight, kg;
TCW4 is target fourth calving weight, kg;
TCWx is current target calving weight, kg;
TCWxx is next target calving weight, kg;
TCA is target calving age in days
TPA is target pregnant age in days
BPADG = prepregnant target ADG, kg/day;
APADG = postpregnant target ADG, kg/day;
ACADG = after calving target ADG, kg/day
T_{age} is heifer age, days;
CI is calving interval, days.

The equations in the growth section are used to compute requirements for the target ADG. For pregnant animals, gain due to gravid uterus growth should be added to predicted daily gain (SWG), as follows:

$$ADG_{preg} = CBW * (18.28*(0.02-0.0000286*t) * e^{(0.02*t-0.0000143*t*t)})$$

For pregnant heifers, weight of fetal and associated uterine tissue is deducted from EQEBW to compute growth requirements. The conceptus weight (CW) can be calculated as follows:

$$CW = (CBW * 0.01828) * e^{(0.02*t-0.0000143*t*t)})$$

where:

CBW is expected calf birth weight, kg,
CW is conceptus weight, g
t is days pregnant
e is the base of the natural logarithms.

Lactation

Lactation requirements are calculated using age of cow, time of lactation peak, peak milk yield, day of lactation, duration of lactation, milk fat content, milk solids not fat, and protein:

$k = 1 / T$
$a = 1 / (PKYD * k * e)$
$Yn = n / (a*e^{(kn)})$
$TotalY= -7 / (a * k) * ((D * e^{(-kD)}) + ((1/k)*e^{(-kD)}) - (1/k))$

if age = 2
$Yn = 0.74\ Yn$
$TotalY = 0.74\ TotalY$;

if age = 3
$Yn = 0.88\ Yn$
$TotalY = 0.88\ TotalY$.

$E = 0.092 * MF + 0.049 * SNF - 0.0569$
$YEn = E * Yn$
$YFatn = MF/100 * Yn$
$YProtn = Prot/100 * Yn$

TotalE = E * TotalY
TotalFat = MF/100 * TotalY
TotalProt = Prot/100 * TotalY
MP_{lact} = (YProtn / 0.65) * 1000

where:

age is age of cow, years;
W is current week of lactation;
PKYD is peak milk yield, kg/day (Table 10-1);
T is week of peak lactation;
D is duration of lactation, weeks;
MF is milk fat composition, %;
SNF is milk solids not fat composition, %;
Prot is milk protein composition, %;
k is intermediate rate constant;
a is intermediate rate constant;
e is the base of the natural logarithms;
Yn is daily milk yield at week of lactation, kg/d;
TotalY is total milk yield for lactation, kg;
E is energy content of milk, Mcal (NE_m) / kg;
YE_n is daily energy secretion in milk at current stage of lactation, Mcal (NE_m)/day;
Yfatn is daily milk fat yield at current stage of lactation, kg/day;
YProtn is daily milk protein yield at current stage of lactation, kg/day;
TotalE is total energy yield for lactation, kg;
TotalFat is total fat yield for lactation, kg;
TotalProt is total protein yield for lactation, kg;
Mp_{lact} is metabolizable protein requirement for lactation, g/day.

Pregnancy

Calf birthweight and day of gestation are used to calculate pregnancy requirements.

$$NE_m \text{ req, Kcal/d} = CBW * (k_m/0.13) * (0.05855-0.0000996t) * e^{((0.03233-.0000275t)t)}$$

$$Ypn \text{ g/d} = ((CBW * (0.001669 - (0.00000211 * t)) * e^{((0.0278 - 0.0000176t) * t)})) * 6.25$$

$$MP_{preq} \text{ g/d} = Ypn / 0.65$$

where

CBW is expected calf birth weight, kg;
t is day of pregnancy;
Ypn is net protein retained as conceptus, g/d;
MP_{preg} is MP for pregnancy, g/day;
e is the base of the natural logarithms.

km is 0.576 (see Chapter 4).

<u>Energy and protein reserves</u>

Body condition score, body weight, and body composition are used to calculate energy and protein reserves. The equations were developed from data on chemical body composition and visual appraisal of condition scores on 106 mature cows of diverse breed types and body sizes and were validated on an independent data set of 65 mature cows(data from C.L. Ferrell, USMARC, personal communication, 1995).

(1) Body composition is computed for the current CS:

$$AF = 0.037683 * CS$$
$$AP = 0.200886 - 0.0066762 * CS;$$
$$AW = 0.766637 - 0.034506 * CS;$$
$$AA = 0.078982 - 0.00438 * CS;$$
$$EBW = 0.851 * SBW$$
$$TA = AA * EBW$$

where:

AF is proportion of empty body fat;
AP is proportion of empty body protein;
AW is proportion of empty body water;
AA is proportion of empty body ash;
SBW is shrunk body weight, kg;
EBW is empty body weight, kg;
TA is total ash, kg;

(2) For CS = 1, ash, fat, and protein composition are as follows:

$$AA1 = 0.074602$$
$$AF1 = 0.037683$$
$$AP1 = 0.194208$$

where:

AA1 is proportion of empty body ash @ CS of 1
AF1 is proportion of empty body fat @ CS of 1
AP1 is proportion of empty body protein @ CS of 1

(3) Assuming that ash mass does not vary with condition score, EBW and component body mass at condition score 1 is calculated:

$$EBW1 = TA/AA1$$
$$TF = AF * EBW$$
$$TP = AP * EBW$$
$$TF1 = EBW1 * AF1$$
$$TP1 = EBW1 * AP1$$

where:

EBW1 is calculated empty body weight at CS is 1, kg;
TF is total body fat, kg;
TP is total body protein, kg;
TF1 is Total body fat @ CS of 1, kg;
TP1 is Total body protein @ CS of 1, kg.

(4) Mobilizable energy and protein are computed:

$$FM = (TF-TF1)$$
$$PM = (TP-TP1)$$
$$ER = 9.4FM + 5.7PM$$

where:

FM is mobilizable fat, kg;
PM is mobilizable protein, kg;

ER is energy reserves, Mcal.

(5) EBW, AF and AP are computed for the next CS to compute energy and protein gain or loss to reach the next CS:

EBWN= TA/AAN

where:

EBWN is EBW at the next score;
TA is total kg ash at the current score;
AAN is proportion of ash at the next score.

AF, AP, TF and TP are computed as in steps 1 and 3 for the next CS and FM, PM, and ER are computed as the difference between the next and current scores.

During mobilization, 1 Mcal of RE will substitute for 0.80 Mcal of diet NE_m; during repletion, 1 Mcal diet NE_m will provide 1 Mcal of RE.

Mineral and Vitamin Requirements

Mineral and vitamin requirements are summarized in Tables 10-2 and 10-3. Requirements are identified for maintenance, growth, lactation, and pregnancy.

Table 10-2 Calcium and Phosphorus Requirements

	Requirements, g/day		Pregnancy		Maximum
Mineral	Maintenance	Growth	Lactation	last 90 d)	Tolerable
Ca	.0154*SBW/0.5	NP_g*0.071/0.5	Milk*1.23/0.5	CBW*(13.7/90)/0.5	0.2 * DMI
P	.016*SBW/0.68	NP_g*0.045/0.68	Milk*0.95/0.68	CBW*(7.6/90)/0.68	0.1 * DMI

Note: SWB is shrunk body weight, kg; DMI, dry matter intake, kg; NPg is retained protein, g; Milk, milk production, kg; CBW, expected birth weight, kg.

Table 10-3 Other Mineral Requirements and Maximum Tolerable Concentrations and Vitamin Requirements

Mineral/ Vitamin	Unit	Growing and Finishing[a]	Cows: Gestation	Cows: Early Lactation	Maximum Tolerable Level
Magnesium	%	0.10	0.12	0.20	0.40
Potassium	%	0.60	0.60	0.70	3.00
Sodium	%	0.06-0.08	0.06-0.08	0.10	--
Sulfur	%	0.15	0.15	0.15	0.40
Cobalt	mg/kg	0.10	0.10	0.10	10.00
Copper	mg/kg	10.00	10.00	10.00	100.00
Iodine	mg/kg	0.50	0.50	0.50	50.00
Iron	mg/kg	50.00	50.00	50.00	1000.00
Manganese	mg/kg	20.00--	40.00	40.00	1000.00
Selenium	mg/kg	0.10	0.10	0.10	2.00
Zinc	mg/kg	30.00--	30.00	30.00	500.00
Vitamin A	IU/kg	2200	2800	3900	--
Vitamin D	IU/kg	275	275	275	--

[a]Also for breeding bulls.

Predicting Dry Matter Intake

The following equations are used to predict intake for various cattle types; adjustments for various factors are given in Table 10-4 and can be used with these or other intake estimates.

For growing calves:

$$DMI = ((SBW^{0.75} * (0.2435NE_m - 0.0466NE_{ma}^2 - 0.1128))/NE_{ma}) * ((BFAF) * (BI) * (ADTV) * (TEMP1) * (MUD1)).$$

For diets with a $NE_m < 1.0$ Mcal/kg, NE_{ma} (divisor) = 0.95.

For growing yearlings:

$$DMI = ((SBW^{0.75} * (0.2435NE_{ma} - 0.0466NE_{ma}^2 - 0.0869))/NE_{ma}) * ((BFAF) * (BI) * (ADTV) * (TEMP1) * (MUD1)).$$

For diets with a $NE_m < 1.0$ Mcal/kg, NE_{ma} (divisor) = 0.95.

For non-pregnant beef cows:

$$DMI = (((SBW^{0.75} * (0.04997 * NE_{ma}^2 + 0.03840)/NE_{ma}) * (TEMP1) * (MUD1) + 0.2 * Yn)$$

For diets with a $NE_m < 1.0$ Mcal/kg, NE_{ma} (divisor) = 0.95.

For pregnant cows (last two-thirds of pregnancy):

$$DMI = ((SBW^{0.75} * (0.04997\ NE_m^2 + .04631)/NE_{ma}) * (TEMP1) * (MUD1) + 0.2 * Yn)$$

For diets with a $NE_m < 1.0$ Mcal/kg, NE_{ma} (divisor) = 0.95.

where

DMI is dry matter intake, kg/d;
SBW is shrunk body weight, kg;
NE_{ma} is net energy value of diet for maintenance, Mcal/kg;
Yn is milk production, kg/d;
BI is breed adjustment factor for DMI (Table 10-4);
BFAF is body fat adjustment factor (Table 10-4);
ADTV is feed additive adjustment factor for DMI (Table 10-4);
TEMP1 is temperature adjustment factor for DMI (Table 10-4);
MUD1 is mud adjustment factor for DMI (Table 10-4).

The same environmental adjustments (Table 10-4) are used to adjust intake for all cattle types.

Adjustment of Dry Matter Intake relative to forage allowance for animals grazing:

$$pI = GRAZE * DMI;$$
$$FA = 1000*GU*IPM/(SBW*N*DOP)$$

IF FA > (DMI * 4) **or** IPM > 1150 kg/ha,

$$GRAZE = 1.0$$

otherwise:

$$GRAZE = ((0.17 * IPM) - (0.000074*IPM^2) + 2.4)/100$$

where

DMI is g predicted dry matter intake per kg SBW using previous equations;
pI is kg predicted dry matter intake adjusted for grazing situations;
FA is daily forage allowance, g/kg SBW/day;
GRAZE is forage availability factor if grazing, %;
IPM is initial pasture mass (kg DM/ha);
GU is grazing unit size (ha);
SBW is shrunk body weight;
N is number of animals; and
DOP is days on pasture.

TABLE 10-4 Adjustment Factors for Dry Matter Intake for Cattle[a]

Adjustment factor	Multiplier
Breed (BI)	
Holstein	1.08
Holstein x Beef	1.04
Empty body fat effect (BFAF)	
21.3 (to 350 kg EQW)	1.00
23.8 (400 kg EQW)	0.97
26.5 (450 kg EQW)	0.90
29.0 (500 kg EQW)	0.82
31.5 (550 kg EQW)	0.73
Anabolic implant (ADTV)	1.00
No anabolic stimulant	0.94
Temperature, C (TEMP1)	
> 35, no night cooling	0.65
> 35, with night cooling	0.90
25 to 35	0.90
15 to 25	1.00
5 to 15	1.03
- 5 to 5	1.05
- 15 to – 5	1.07
< - 15	1.16
Mud (MUD1)	
None	1.00
Mild (10 - 20 cm)	0.85
Severe (30 - 60 cm)	0.70

[a]National Research Council, 1987.

Supply of Nutrients

Amounts are computed from actual dry matter intake when available or from predicted intake equation. Risk of use increases when predicted intakes are used versus actual DMI.

Level One

Energy

Ration energy values are computed by summing the energy contribution of each feed to arrive at a total energy content of the ration, using tabular energy values. Tabular energy values used include % TDN, ME (Mcal/kg), NE_{ma} (Mcal/kg), and NE_{ga} (Mcal/kg).

Protein

Supply of metabolizable protein (MP) is the sum of digested ruminally undegraded feed protein and digested microbial protein. Feed composition parameters used include percentage CP, percentage UIP, and percentage DIP.

Undegraded available feed protein is assumed to be 80 percent digestible. Hence,

$$MP_{feed} = UIP_{intake} * 0.8.$$

The contribution of microbial protein to the MP supply is estimated from the microbial crude protein yield.

$$MCP = 0.13 * TDN * eNDF_{adj}$$

where

MCP is microbial crude protein, g/d;
$eNDF_{adj}$ is 1.0 if the effective NDF (eNDF) of the ration is > 20% ;
$eNDF_{adj}$ is (1.0 - ((20-eNDF)*0.025)) when eNDF <= 20%;
TDN is total digestible nutrients, g/d;
MCP is assumed to be 80% true protein and 80% digestible, hence,

$$MP_{bact} = MCP * 0.64$$
$$MP_{tot} = MP_{bact} + MP_{feed}$$

Level Two

Level 2 computes amino acid requirements and predicts energy and protein supply from feed physical and chemical properties. All energy and protein requirements are the same as level 1.)

Amino acid requirements for maintenance

$$MPAA_i = AATISS_i * 0.01 * MP_{maint}$$

where

MP_{maint} is metabolizable protein required for maintenance, g/d;
$MPAA_i$ is metabolizable requirement for the i^{th} absorbed amino acid, g/day;
$AATISS_i$ is amino acid composition of tissue, Table 10-5.

Amino acid requirements for growth

$$RPN = PB * .01 * EBG$$
$$RPAA_i = AATISS_i * RPN / EAAG_i$$

where

PB is protein content of empty body gain, g/100g;
EBG is empty body gain, g/d;
RPN is net protein required for growth, g/d;
$RPAA_i$ = growth requirement for the i^{th} absorbed amino acid, g/d.
$AATISS_i$ is amino acid composition of tissue (Table 10-5);
$EAAG_i$ is efficiency of use of the i^{th} amino acid for growth (Table 10-6), g/g, and

Amino acid requirements for lactation

$$LPAA_i = AALACT_i * .01 * YProtn / EAAL_i$$

where

$AALACT_i$ is the i^{th} amino acid content of milk true protein, g/100g (Table 10-6);
$EAAL_i$ is efficiency of use of the i^{th} amino acid for milk protein formation, g/g (Table 10-5), and
$LPAA_i$ is metabolizable requirement for lactation for the i^{th} absorbed amino acid, g/d.

Amino acid pregnancy requirements:

$$MPAA_i = AATISS_i * YPN / EAAP_i$$

where

$MPAA_i$ is metabolizable requirement for gestation for the i^{th} absorbed amino acid, g/day.

$AATISS_i$ is amino acid composition of tissue (Table 10-5);
YPN is net protein required for gestation, g/day;
$EAAP_i$ is efficiency of use of the i^{th} amino acid for gestation, g/g (Table 10.6).

Table 10-5 Amino Acid Composition of Tissue and Milk Protein (g/100 g of protein)

Amino acid	Tissue[a]	Milk[b]
Methionine	2.0	2.71
Lysine	6.4	7.62
Histidine	2.5	2.74
Phenylalanine	3.5	4.75
Tryptophan	0.6	1.51
Threonine	3.9	3.72
Leucine	6.7	9.18
Isoleucine	2.8	5.79
Valine	4.0	5.89
Arginine	3.3	3.40

[a]Average of three studies summarized by whole empty body values of Ainslie et al., 1993.
[b]Waghorn and Baldwin, 1984.
[C]Based on hindlimb uptake studies (Robinson et al., 1995).

Table 10-6 Utilization of Individual Absorbed Amino Acids for Physiological Functions (g/g)[a]

Amino acid	Gestation	Lactation
Methionine	0.85	0.98
Lysine	0.85	0.88
Histidine	0.85	0.90
Phenylalanine	0.85	1.00
Tryptophan	0.85	0.85
Threonine	0.85	0.83
Leucine	0.66	0.72
Isoleucine	0.66	0.62
Valine	0.66	0.72
Arginine	0.66	0.85

[a]Requirement for growth varies with stage of growth as determined by Ainslie et al.(1993): if SBW < 300 kg, EAAG = 0.834 - (0.00114EBW), otherwise 0.492; EAAG is efficiency factor and EQSBW is equivalent shrunk body weight as described by Fox et al. (1992). Other values are from Evans and Patterson (1985).

Supply of energy, protein and amino acids.

Predicting the energy content of the ration is accomplished by estimating apparent TDN of each feed and for the total ration and utilizing equations and conversion factors to estimate ME, NE_m, NE_g, and NE_l values. To calculate apparent TDN, apparent digestibilities for carbohydrates, proteins and fats are estimated. These apparent digestibilities are determined by simulating the degradation, passage, and digestion of feedstuffs in the rumen and small intestine. Also, microbial yields and fecal composition are estimated. Feed composition values used include: NDF, lignin, CP, Fat, Ash, NDFIP, as a percent of the diet DM and starch and sugar expressed as a percentage of non-fiber carbohydrates.

Intake Carbohydrate:

Based upon chemical analyses (Appendix Table 1), equations used to calculate carbohydrate composition of the j^{th} feedstuff are listed below:

$CHO_j = 100 - CP_j(\%DM) - FAT_j(\%DM) - ASH_j(\%DM)$

$CC_j = NDF_j(\%DM) * 0.01*LIGNIN_j(\%NDF)*2.4$

$$CB2_j = NDF_j(\%DM) - (NDFIP_j(\%CP) * 0.01 * CP_j(\%DM)) - CC_j$$
$$NFC_j = CHO - CB2_j - CC_j$$
$$CB1_j = STARCH_j(\%NFC) * (NFC_j)/100$$
$$CA_j = (NFC_j - CBI_j)$$

where

$CP_j(\%DM)$ is percentage of crude protein of the j^{th} feedstuff;
$CHO_j(\%DM)$ is percentage of carbohydrate of the j^{th} feedstuff;
$FAT_j(\%DM)$ is percentage of fat of the j^{th} feedstuff;
$ASH_j(\%DM)$ is percentage of ash of the j^{th} feedstuff;
$NDF_j(\%DM)$ is percentage of the j^{th} feedstuff that is neutral detergent fiber;
$NDFIP_j(\%CP)$ is the percentage of neutral detergent insoluble protein in the crude protein of the j^{th} feedstuff;
$LIGNIN_j(\%NDF)$ is percentage of lignin of the j^{th} feedstuff's NDF;
$STARCH_j(\%NFC)$ is percentage of starch in the non-structural carbohydrate of the j^{th} feedstuff;
$CA_j(\%DM)$ is percentage of DM of the j^{th} feedstuff that is sugar;
$CB1_j(\%DM)$ is percentage of DM of the j^{th} feedstuff that is starch;
$CB2_j(\%DM)$ is percentage of DM of the j^{th} feedstuff that is available fiber, and
$CC_j(\%DM)$ is percentage of DM in the j^{th} feedstuff that is unavailable fiber.
$NFC_j(\%DM)$ is percentage of the DM in the j^{th} feedstuff that is
nonfiber carbohydates.

Intake Protein:

The *Ruminant Nitrogen Usage* (National Research Council, 1985) equation is used to predict recycled nitrogen:

$$U = 121.7 - 12.01X + 0.3235 X^2$$

where

U is urea N recycled (percent of N intake), and
X is diet CP, as a percent of diet dry matter.

The following equations are be used to calculate the five protein fractions contained in the j^{th} feedstuff from percent of crude protein, percent of protein solubility, percent of NDFIP, and percent of ADFIP:

$$PA_j (\%DM) = NPN_j * 0.0001 * SOLP_j * CP$$
$$PB1_j(\%DM) = SOLP_j * CP * 0.01 - PA_j$$
$$PC_j(\%DM) = ADFIP_j * CP * 0.01$$
$$PB3_j(\%DM) = (NDFIP_j - ADFIP_j) * CP * 0.01$$
$$PB2_j(\%DM) = CP - PA_j - PB1_j - PB3_j - PC_j$$

where

$CP_j(\%DM)$ is percentage of crude protein of the $_j{}^{th}$ feedstuff;
$NPN_j(\%soluble\ protein)$ is percentage of soluble protein in the crude protein of the $_j{}^{th}$ feedstuff that is non-protein nitrogen times 6.25;
$SOLP_j(\%CP)$ is percentage of the crude protein of the $_j{}^{th}$ feedstuff that is soluble protein;
$NDFIP_j(\%CP)$ is percentage of the crude protein of the $_j{}^{th}$ feedstuff that is neutral detergent insoluble protein;
$ADFIP_j(\%CP)$ is percentage of the $_j{}^{th}$ feedstuff that is acid detergent insoluble protein;
$PA_j(\%DM)$ is percentage of crude protein in the $_j{}^{th}$ feedstuff that is non-protein nitrogen;
$PB1_j(\%DM)$ is percentage of crude protein in the $_j{}^{th}$ feedstuff that is rapidly degraded protein;
$PB2_j(\%DM)$ is percentage of crude protein in the $_j{}^{th}$ feedstuff that is intermediately degraded protein;
$PB3_j(\%DM)$ is percentage of crude protein in the $_j{}^{th}$ feedstuff that is slowly degraded protein, and
$PC_j(\%DM)$ is percentage of crude protein in the $_j{}^{th}$ feedstuff that is bound protein.

Adjusting Degradation Rates of Available Fiber for the Effect of pH

(1) Predict rumen pH (Pitt et al., 1996) if
eNDF < 24.5%, pH = 5.425 + 0.04229 eNDF;

otherwise pH = 6.46

2) Compute original yield for each feed:
$Y = 1 / ((0.05/(Kd - .02)) + (2.5))$

3) Compute relative yield adjustment:
$relY = (1 - e^{(-5.624 * ((pH - 5.7)^{\wedge}0.909))})/0.9968$

4) Compute new yield for each feed:
$Y' = relY * Y$

5) Compute new Kd for each feed:
if pH < 5.7,
Kd' = 0;
otherwise
$A = (-0.01490722 + (0.012024 * pH) - (0.0010152 * pH^2))$

$Kd' = A * ((Y' / ((-0.1058 + (0.0752 * pH)) - Y')) + 1)$

where
eNDF is % effective NDF in ration;
e is the base of the natural logarithms;
Kd is feed specific degradation rate of available fiber fraction (decimal form), which must be $\geq 0.02h^{-1}$;
Kd'is pH adjusted feed specific degradation rate of available fiber fraction (decimal form).

Computing Ruminal Escape of Carbohydrate and Protein

Ruminal degradation and escape of carbohydrate and protein fractions are determined by the following formulas, using digestion rates for each carbohydrate and protein fraction, and the passage rate equation which uses % forage and % effective NDF:

$RD = Kd / (Kd + Kp)$
$RESC = Kp / (Kd + Kp)$

where
RD is a proportion of component of a feedstuff degraded in the rumen
RESC is a proportion of component of feedstuff escaping ruminal degradation
Kd is degradation rate of feedstuff component
Kp is passage rate of feedstuff

Passage Rate Equation:

$Kp[forages] = (0.388 + (0.022 * DMI/SBW^{0.75}) + 2.0 * FORAGE^2)/100$
$Kp\{conc\} = -0.424 + (1.45Kp[forages])$

where
DMI is dry matter intake, g/d;
SBW is shrunk body weight, kg/d;
FORAGE is forage concentration in the diet, %;

Kp is adjusted for individual feeds using a multiplicative adjustment factor (Af) for particle size using diet effective NDF (eNDF):

$$Af[forages] = 100/(eNDF + 70)$$
$$Af[conc] = 100/(eNDF + 90).$$

where

eNDF is effective NDF concentration of individual feedstuff, percent The following equations calculate the amounts of protein fractions that are ruminally degraded.

$$RDPA_j = I_j * Pa_j$$
$$RDPB1_j = I_j * PB1_j * (Kd_{1j} / (Kd_{1j} + Kp_j))$$
$$RDPB2_j = I_j * PB2_j * (Kd_{2j} / (Kd_{2j} + Kp_j))$$
$$RDPB3_j = I_j * PB3_j * (Kd_{3j} / (Kd_{3j} + Kp_j))$$
$$RDPEP_j = RDPB1_j + RDPB2_j + RDPB3_j$$

where

I_j is intake of the j^{th} feedstuff g/day;
Kd_{1j} is the rumen rate of digestion of the rapidly degraded protein fraction of the j^{th} feedstuff, h^{-1};
Kd_{2j} is the rumen rate of digestion of the intermediately degraded protein fraction of the j^{th} feedstuff, h^{-1};
Kd_{3j} is the rumen rate of digestion of the slowly degraded protein fraction of the j^{th} feedstuff, h^{-1};
Kp_j is the rate of passage from the rumen of the j^{th} feedstuff, h^{-1};
$RDPA_j$ is the amount of ruminally degraded NPN in the j^{th} feedstuff, g/day;
$RDPB1_j$ is the amount of ruminally degraded B1 true protein in the j^{th} feedstuff, g/day;
$RDPB2_j$ is the amount of ruminally degraded B2 true protein in the j^{th} feedstuff, g/day;
$RDPB3_j$ is the amount of ruminally degraded B3 true protein in the j^{th} feedstuff, g/day, and
$RDPEP_j$ is the amount of rumen degraded peptides from the j^{th} feedstuff, g/day.

The undegraded protein is passed to the small intestine and the following equations calculate the amount of each protein fraction that escapes rumen degradation:

$$REPB1_j = I_j * PB1_j * (Kp_j / (Kd1_j + Kp_j))$$
$$REPB2_j = I_j * PB2_j * (Kp_j / (Kd2_j + Kp_j))$$
$$REPB3_j = I_j * PB3_j * (Kp_j / (Kd3_j + Kp_j))$$
$$REPC_j = I_j * PC_j$$

where

$REPB1_j$ is the amount of ruminally escaped B1 true protein in the j^{th} feedstuff, g/day;
$REPB2_j$ is the amount of ruminally escaped B2 true protein in the j^{th} feedstuff, g/day;
$REPB3_j$ is the amount of ruminally escaped B3 true protein in the j^{th} feedstuff, g/day, and
$REPC_j$ is the amount of rumen escaped bound C protein from the j^{th} feedstuff, g/day.

The following equations are used to calculate the amounts of each of the carbohydrate fractions of the j^{th} feedstuff that are ruminally digested:

$$RDCA_j = I_j * CA_j * (Kd_{4j} / (Kd_{4j} + Kp_j))$$
$$RDCB1_j = I_j * CB1_j * (Kd_{5j} / (Kd_{5j} + Kp_j))$$
$$RDCB2_j = I_j * CB2_j * (Kd_{6j} / (Kd_{6j} + Kp_j))$$

where

Kd_{4j} is the rumen rate of sugar digestion of the j^{th} feedstuff, h^{-1};
Kd_{5j} is the rumen rate of starch digestion of the j^{th} feedstuff,
h^{-1};
Kd_{6j} is the rumen rate of available fiber digestion of the j^{th} feedstuff, h^{-1};
$RDCA_j$ is the amount of ruminally degraded sugar from the j^{th} feedstuff, g/day;
$RDCB1_j$ is the amount of ruminally degraded starch from the j^{th} feedstuff, g/day, and
$RDCB2_j$ is the amount of ruminally degraded available fiber from the j^{th} feedstuff, g/day.

The following equations are used to calculate the amounts of each of the carbohydrate fractions of the j^{th} feedstuff that escape the rumen:

$$RECA_j = I_j * CA_j * (Kp_j / (Kd_{4j} + Kp_j))$$
$$RECB1_j = I_j * CB1_j * (Kp_j / (Kd_{5j} + Kp_j))$$
$$RECB2_j = I_j * CB2_j * (Kp_j / (Kd_{6j} + Kp_j))$$
$$RECC_j = I_j * CC_j$$

where

$RECA_j$ is the amount of ruminally escaped sugar from the j^{th} feedstuff, g/day;
$RECB1_j$ is the amount of ruminally escaped starch from the j^{th} feedstuff, g/day;
$RECB2_j$ is the amount of ruminally escaped available fiber from the j^{th} feedstuff, g/day, and
$RECC_j$ is the amount of ruminally escaped unavailable fiber from the j^{th} feedstuff, g/day.

Calculation of Microbial Yield

Bacterial yields for structural and non-structural carbohydrate fermenting bacteria are given by the following:

$$\text{if } eNDF<20, \text{ then } YG_1 = YG_1 * (1 - ((20 - eNDF) * 0.025))$$
$$\text{if } eNDF<20 \text{ then } YG_2 = YG_2 * (1 - ((20 - eNDF) * 0.025))$$
$$1/Y_{1j} = (KM_1/Kd_{6j}) + (1/YG_1)$$
$$1/Y_{2j} = (KM_2/Kd_{4j}) + (1/YG_2)$$
$$1/Y_{3j} = (KM_2/Kd_{5j}) + (1/YG_2)$$

$$RATIO_j = RDPEP_j/(RDCA_j + RDCB1_j + RDPEP_j)$$
$$\text{if } RATIO > 0.18 \; RATIO = 0.18$$
$$IMP_j = e(0.404 * Ln(RATIO_j * 100) + 1.942)$$
$$FCBACT_j = Y_{1j} * RDCB2_j$$
$$Y_{2j} = Y_{2j} * (1 + IMP_j * 0.01)$$
$$Y_{3j} = Y_{3j} * (1 + IMP_j * 0.01)$$

$$NFCBACT_j = (Y_{2j} * RDCA_j) + (Y_{3j} * RDCB1_j)$$
$$BACT_j = NFCBACT_j + FCBACT_j$$
$$BACTN_j = 0.10 * BACT_j$$
$$NFCBACTN_j = 0.10 * NFCBACT_j$$
$$FCBACTN_j = 0.10 * FCBACT_j$$

$$PEPUP_j = RDPEP_j$$
$$PEPUPN_j = PEPUP_j/6.25$$
$$EN = PEPUPN + RDPA/6.25 + ((MP_a - MP_{req})/6.25) - BACTN$$
$$PEPBAL = (PEPUP/6.25) - 2/3 * NFCBACTN$$
$$BACTNBAL = (((PEPUP + RDPA)/6.25) + U) - BACTN$$

where

Y_{1j} is yield efficiency of FC bacteria from the available fiber fraction of the j^{th} feedstuff, g FC bacteria/g FC digested;
Y_{2j} is yield efficiency of NFC bacteria from the sugar fraction of the j^{th} feedstuff, g NFC bacteria/g NFC digested;
Y_{3j} is yield efficiency of NFC bacteria from the starch fraction of the j^{th} feedstuff, g NFC bacteria/g NFC digested;

KM_1 is the maintenance rate of the fiber carbohydrate bacteria, 0.05 g FC/g bacteria/h;
KM_2 is the maintenance rate of the non-fiber carbohydrate bacteria, 0.15 g NFC/g bacteria/h;
YG_1 is the theoretical maximum yield of the fiber carbohydrate bacteria, 0.4 g bacteria/g FC/h;
YG_2 is the theoretical maximum yield of the non-fiber carbohydrate bacteria, 0.4 g bacteria/g NFC/h;
$Ratio_j$ is the ratio of peptides to peptide plus NFC in the j^{th} feedstuff;

$RDPEP_j$ is the peptides in the j^{th} feedstuff;
$RDCA_j$ is the g NFC in the A (sugar) fraction of the j^{th} feedstuff ruminally degraded;
$RDCB1_j$ is the g NFC in the B1 (starch and pectins) fraction of the j^{th} feedstuff ruminally degraded;
$RDCB2_j$ is the g FC in the B2 (available fiber) fraction in the j^{th} feedstuff ruminally degraded;

KD_{4j} is growth rate of the sugar fermenting carbohydrate bacteria, h^{-1};
KD_5j is growth rate of the starch fermenting carbohydrate bacteria, h^{-1};
KD_{6j} is growth rate of the fiber carbohydrate bacteria, h^{-1};

IMP_j is percent improvement in bacterial yield, %, due to the ratio of peptides to peptides plus non-structural CHO in j^{th} feedstuff;
e is the base of the natural logarithms;
Ln is the natural logarithm;

$FCBACT_j$ is yield of fiber carbohydrate bacteria from the j^{th} feedstuff g/day;
$NFCBACT_j$ is yield of non-fiber carbohydrate bacteria from the j^{th} feedstuff, g/day;

$BACT_j$ is yield of bacteria from the j^{th} feedstuff g/day;
$BACTN_j$ is bacterial nitrogen, g/day;
FCBACTNj is fiber carbohydrate bacterial nitrogen, g/day;
$NFCBACTN_j$ is non-fiber carbohydrate bacterial nitrogen, g/day;

PEPUPj is bacterial peptide from the j^{th} feedstuff, g/day;
$PEPUPN_j$ is bacterial peptide nitrogen from the j^{th} feedstuff, g/day;
MP_a is metabolizable protein supplied, g/day;
MP_{req} is metabolizable protein required, g/day;

EN is nitrogen in excess of rumen bacterial nitrogen and tissue needs, g/day;
PEPBAL is peptide balance, g nitrogen/day;
BACTNBAL is bacterial nitrogen balance, g/day;

U is recycled nitrogen, g/day.

Microbial Composition:

Bacterial fractions escaping the rumen are:

$REBTP_j = 0.60 * 0.625 * BACT_j$
$REBCW_j = 0.25 * 0.625 * BACT_j$
$REBNA_j = 0.15 * 0.625 * BACT_j$
$REBCHO_j = 0.21 * BACT_j$
$REBFAT_j = 0.12 * BACT_j$
$REBASH_j = 0.044 * BACT_j$

where

$REBTP_j$ is the amount of bacterial true protein passed to the intestine by the j^{th} feedstuff, g/day;
$REBCW_j$ is the amount of bacterial cell wall protein passed to the intestine by the j^{th} feedstuff, g/day;
$REBNA_j$ is the amount of bacterial nucleic acids passed to the intestine by the j^{th} feedstuff, g/day;
$REBCHO_j$ is the amount of bacterial carbohydrate passed to the intestine by the j^{th} feedstuff, g/day;
$REBFAT_j$ is the amount of bacterial fat passed to the intestine by the j^{th} feedstuff, g/day, and
$REBASH_j$ is the amount of bacterial ash passed to the intestine by the j^{th} feedstuff, g/day.

Intestinal Digestibilities and Absorption

Equations for calculating digested protein from feed and bacterial sources are listed below:

$DIGPB1_j = REPB1_j$
$DIGPB2_j = REPB2_j$
$DIGPB3_j = 0.80 * REPB3_j$
$DIGFP_j = DIGPB1_j + DIGPB2_j + DIGPB3_j$
$DIGBTP_j = REBTP_j$
$DIGBNA_j = REBNA_j$
$DIGP_j = DIGFP_j + DIGBTP_j + DIGBNA_j$

where

$DIGPB1_j$ is the digestible B1 protein from the j^{th} feedstuff, g/day;
$DIGPB2_j$ is the digestible B2 protein from the j^{th} feedstuff, g/day;
$DIGPB3_j$ is the digestible B3 protein from the j^{th} feedstuff, g/day;
$DIGFP_j$ is the digestible feed protein from the j^{th} feedstuff, g/day;
$DIGBTP_j$ is the digestible bacterial true protein produced from the j^{th} feedstuff, g/day;
$DIGBNA_j$ is the digestible bacterial nucleic acids produced from the j^{th} feedstuff, g/day, and
$DIGP_j$ is the digestible protein from the j^{th} feedstuff, g/day.

The equations for calculating digested carbohydrate due to the j^{th} feedstuff are listed below:

$DIGFC_j = RECA_j + stdig * RECB1_j + 0.20 * RECB2_j$
$DIGBC_j = 0.95 * REBCHO_j$
$DIGC_j = DIGFC_j + DIGBC_j$

where

stdig is postruminal starch digestibility, g/g,
$DIGFC_j$ is intestinally digested feed carbohydrate from the j^{th} feedstuff, g/day,
$DIGBC_j$ is digested bacterial carbohydrate produced from the j^{th} feedstuff, g/day, and
$DIGC_j$ is digestible carbohydrate from the j^{th} feedstuff, g/day.

The following equation is used to calculate ruminally escaped fat from the j^{th} feedstuff:

$$REFAT_j = I_j * FAT_j$$

where

$REFAT_j$ is the amount of ruminally escaped fat from the j^{th} feedstuff, g/day;
FAT is fat composition of the j^{th} feedstuff, g/day.

Equations for calculating digestible fat from feed and bacterial sources are listed below:

$$DIGFF_j = 0.95 * REFAT_j$$
$$DIGBF_j = 0.95 * REBFAT_j$$
$$DIGF_j = DIGFF_j + DIGBF_j$$

where

$DIGFF_j$ is digestible feed fat from the j^{th} feedstuff, g/day;
$DIGBF_j$ is digestible bacterial fat from the j^{th} feedstuff, g/day;
$DIGF_j$ is digestible fat from the j^{th} feedstuff, g/day.

Fecal Output

The following equations calculate undigested feed residues appearing in the feces from NDFIP, ADFIP, starch, fiber, fat and ash fractions, based on data summarized by Van Soest (1994):

$$FEPB3_j = (1 - 0.80) * REPB3_j$$
$$FEPC_j = REPC_j$$
$$FEFP_j = FEPB3_j + FEPC_j$$
$$FECB1_j = (1 - stdig) * RECB1_j$$
$$FECB2_j = (1 - 0.20) * RECB2_j$$
$$FECC_j = RECC_j$$
$$FEFC_j = FECB1_j + FECB2_j + FECC_j$$
$$FEFA_j = I_j * ASH_j * 0.5$$
$$FEFF_j = REFAT_j * (1-0.95)$$

where

$FEPB3_j$ is the amount of feed B3 protein fraction in feces from the j^{th} feedstuff, g/day;
$FEPC_j$ is the amount of feed C protein fraction in feces from the j^{th} feedstuff, g/day;
$FEFP_j$ is the amount of feed protein in feces from the j^{th} feedstuff, g/day;
$FECB1_j$ is the amount of feed starch in feces from the j^{th} feedstuff, g/day;
$FECB2_j$ is the amount of feed available fiber in feces from the j^{th} feedstuff, g/day;
$FECC_j$ is the amount of feed unavailable fiber in feces from the j^{th} feedstuff, g/day;
$FEFC_j$ is the amount of feed carbohydrate in feces from the j^{th}

feedstuff, g/day;
$FEFA_j$ is the amount of undigested feed ash in feces from the j^{th} feedstuff, g/day;
FEFF is the amount of undigested feed fat in feces from the j^{th} feedstuff, g/day;.
$REFAT_j$ is the amount of ruminally escaped fat form the jth feedstuff, g/day, and.
ASHj is the ash composition of the jth feedstuff, g/day.

Microbial matter in the feces is composed of indigestible bacterial cell walls, bacterial carbohydrate, fat and ash (Van Soest, 1994):

$$FEBCW_j = REBCW_j$$
$$FEBCP_j = FEBCW_j$$
$$FEBC_j = (1 - 0.95) * REBCHO_j$$
$$FEBF_j = (1 - 0.95) * REBFAT_j$$
$$FEBASH_j = (1 - 0.95) * REBASH_j$$
$$FEBACT_j = FEBCP_j + FEBC_j + FEBF_j + FEBASH_j$$

where

$FEBCW_j$ is the amount of fecal bacterial cell wall protein from the j^{th} feedstuff, g/day;
$FEBCP_j$ is the amount of fecal bacterial protein from the j^{th} feedstuff, g/day;
$FEBC_j$ is the amount of bacterial carbohydrate in feces from the j^{th} feedstuff, g/day;
$FEBF_j$ is the amount of bacterial fat in feces from the j^{th} feedstuff, g/day;
$FEBASH_j$ is the amount of bacterial ash in feces from the j^{th} feedstuff, g/day, and
$FEBACT_j$ is the amount of bacteria in feces from the j^{th} feedstuff, g/day.

Endogenous protein, carbohydrate and ash are:

$FEENGP_j = 0.09 * IDM_j$ (National Research Council, 1989)
$FEENGF_j = 0.0119 * DMI$ (Lucas et al., 1961)
$FEENGA_j = 0.017 * DMI$ (Lucas et al., 1961)

where

DMI is feed DM consumed, g/day;
$FEENGP_j$ is the amount of endogenous protein in feces from the j^{th} feedstuff, g/day;
$FEENGF_j$ is the amount of endogenous fat in feces from the j^{th} feedstuff, g/day;
$FEENGA_j$ is the amount of endogenous ash in feces from the j^{th} feedstuff, g/day, and
IDM_j is the indigestible dry matter, g/day.

Total fecal DM is calculated by summing protein, carbohydrate, fat and ash DM contributions from undigested feed residues, microbial matter, and endogenous matter:

$$FEPROT_j = FEFP_j + FEBCP_j + FEENGP_j$$
$$FECHO_j = FEFC_j + FEBC_j$$
$$FEFAT_j = FEBF_j + FEFF_j + FEENGF_j$$
$$FEASH_j = FEFA_j + FEBASH_j + FEENGA_j$$
$$FEDM_j = (FEFP_j + FEBCP_j) + FECHO_j + FEFAT_j + FEASH_j) / 0.91$$

where

$FEPROT_j$ is the amount of fecal protein from the j^{th} feedstuff, g/day;
$FECHO_j$ is the amount of carbohydrate in feces from the j^{th} feedstuff, g/day;
$FEFAT_j$ is the amount of fat in feces from the j^{th} feedstuff, g/day;
$FEASH_j$ is the amount of ash in feces from the j^{th} feedstuff, g/day, and
$FEDM_j$ is the amount of fecal DM from the j^{th} feedstuff, g/day.

Total Digestible Nutrients and Energy Values of Feedstuffs

Apparent TDN is potentially digestible nutrient intake minus indigestible bacterial and feed components appearing in the feces:

$$TDNAPP_j = (DIET\ PROT_j - FEPROT_j) + (DIET\ CHO_j - FECHO_j) + (2.25 * (DIET\ FAT_j - FEFAT_j))$$

where

$TDNAPP_j$ is apparent TDN from the j^{th} feedstuff, g/day.

The ME values for each feed are based on assuming 1 kg of TDN is equal to 4.409 Mcal of DE and 1 Mcal of DE is equal to 0.82 Mcal of ME (NRC, 1976):

$$ME_{aj} = 0.001 * TDNAPP_j * 4.409 * 0.82$$
$$MEC_j = ME_{aj} / I_j$$
$$MEI = \sum_{j=1}^{n} ME_{aj}$$
$$MEC = MEI / DMI$$

where

ME_{aj} is metabolizable energy available from the j^{th} feedstuff, Mcal/day;
MEC_j is metabolizable energy concentration of the j^{th} feedstuff, Mcal/kg;
MEI is metabolizable energy supplied by the diet, Mcal/day, and
MEC is metabolizable energy concentration of the diet, Mcal/kg.

Calculation of Net Energy Values

$$NEga_j = (1.42 * MEC_j - 0.174 * MEC_j^2 + 0.0122 * MEC_j^3 - 1.65)$$ (National Research Council, 1984);

$$NEma_j = (1.37 * MEC_j - 0.138 * MEC_j^2 + .0105 * MEC_j^3 - 1.12)$$(National Research Council, 1984);

where

$NEga_j$ is net energy for gain content of the j^{th} feedstuff, Mcal/kg;
$NEma_j$ is net energy for maintenance content of the j^{th} feedstuff, Mcal/kg;

Metabolizable Protein

Total feed MP is the sum of each feed MP:

$$MP_{aj} = DIGP_j - DIGBNA_j$$
$$MP_a = \sum_{j=1}^{n} MP_{aj}$$

where

MP_{aj} is metabolizable protein from the j^{th} feedstuff, g/day, and
MP_a is metabolizable protein available in the diet, g/day.

Amino Acid Supply

Essential amino acid composition of the undegradable protein of each feedstuff is used to calculate supply of amino acids from the feeds. Microbial composition of essential amino acids are used to calculate the supply of amino acids from bacteria.

Bacterial Amino Acid Supply to the Duodenum

$$REBAAi = \sum_{j=1}^{n} (AABCW_i * 0.01 * REBCW_j) + (AABNCW_i * 0.01 * REBTP_j)$$

where

AABCWi is the i^{th} amino acid content of rumen bacteria cell wall protein, g/100g (Table 10-7);
AABNCWi is the i^{th} amino acid content of rumen bacteria non-cell wall protein, g/100g (Table 10-7);
$REBCW_j$ is the bacterial cell wall protein appearing at the duodenum as a result of fermentation of the j^{th} feedstuff, g/day;
$REBTP_j$ is the bacterial non-cell wall protein appearing at the duodenum as a result of fermentation of the j^{th} feedstuff, g/day, and
$REBAA_i$ is the amount of the i^{th} bacterial amino acid appearing at the duodenum, g/day.

Bacterial Amino Acid Digestion

$$DIGBAA_i = \sum_{j=1}^{n} AABNCWi * 0.01 * REBTP_j$$

where

$DIGBAA_i$ is the amount of the i^{th} absorbed bacterial amino acid, g/day;

Feed Amino Acid Supply

$$REFAA_i = \sum_{j=1}^{n} AAINSP_{ij} * 0.01 * (REPB1_j + REPB2_j + REPB3_j + REPC_j)$$

where

$AAINSP_{ij}$ is the i^{th} amino acid content of the insoluble protein for the j^{th} feedstuff, g/100g;
$REPB1_j$ is the rumen escaped B1 protein from the j^{th} feedstuff, g/day;
$REPB2_j$ is the rumen escaped B2 protein from the j^{th} feedstuff, g/day;
$REPB3_j$ is the rumen escaped B3 protein from the j^{th} feedstuff, g/day;
$REPC_j$ is the rumen escaped C protein from the j^{th} feedstuff, g/day, and
$REFAA_i$ is the amount of i^{th} dietary amino acid appearing at the duodenum, g/day.

Total Duodenal Amino Acid Supply

$$REAA_i = REBAA_i + REFAA_i$$

where

$REAA_i$ is the total amount of the i^{th} amino acid appearing at the duodenum, g/day.

Feed Amino Acid Digestion

$$DIGFAA_i = \sum_{j=1}^{n} AAINSP_{ij} * 0.01 * (REPB1_j + REPB2_j + 0.8 * REPB3_j)$$

where

$DIGFAA_i$ is the amount of the i^{th} absorbed amino acid from dietary protein escaping rumen degradation, g/day.

Total Metabolizable Amino Acid Supply

$$AAA_{si} = DIGBAA_i + DIGFAA_i$$

where

AAA_{si} is the total amount of the i^{th} absorbed amino acid supplied by dietary and bacterial sources, g/day.

Table 10-7 Amino Acid Composition of Rumen Microbial Cell Wall and Noncell Wall Protein (g/100 g of protein)

			Ruminal Bacteria[a]	
Amino acid	Cell wall	Noncell wall	Mean	SD
Methionine	2.40	2.68	2.60	0.7
Lysine	5.60	8.20	7.90	0.9
Histidine	1.74	2.69	2.00	0.4
Phenylalanine	4.20	5.16	5.10	0.3
Tryptophan	1.63[b]	1.63	-	-
Threonine	3.30	5.59	5.80	0.5
Leucine	5.90	7.51	8.10	0.8
Isoleucine	4.00	5.88	5.70	0.4
Valine	4.70	6.16	6.20	0.6
Arginine	3.82	6.96	5.10	0.7

[a]Average composition and SD of 441 bacterial samples from animals fed 61 dietary treatments in 35 experiments (Clark et al., 1992). Included for comparison to the cell wall and noncell wall values used in this model.
[b]Data were not available, therefore, content of cell wall protein was assumed to be same as noncell wall protein (O'Connor et al., 1993).

FEED COMPOSITION VALUES FOR USE IN THE NRC MODELS

A feed library developed for use with the computer models(Appendix Table 1) contains feed composition values that are needed to predict the supply of nutrients available to meet animal requirements. In this library, feeds are described by their chemical, physical and biological characteristics. Level 1 uses the tabular net energy and protein values, which are consistent where possible with those published in Chapter 11. Level 2 uses the feed carbohydrate and protein fractions and their digestion and passage rates to predict net energy and metabolizable protein values for each feed based on the interaction of these variables. For ease of use, the feed composition table (Appendix Table 1) is organized to make it easy to find and compare feeds of the same type and to find all values for a feed in the same column. It is arranged with feed names listed alphabetically within feed classes of forages-legumes, forages-grasses, forages-cereal grains, high energy concentrates, high protein plant concentrates, plant by-products and animal byproducts. All of the chemical, physical and biological values for each feed are in the column below the feed name. The international feed number (IFN) is given for each feed where appropriate for comparison with previous feed composition tables.

Chemical composition of feeds is described by feed carbohydrate and protein fractions that are used to predict microbial protein production, ruminal degradation and escape of carbohydrates and proteins and ME and MP in level 2. Feed library values for carbohydrate and protein fractions are based on Sniffen et al. (1992), and Van Soest (1994).

Feedstuffs are composed of chemically measurable carbohydrate, protein, fat, ash and water. The Weende system for proximate analysis has been used for more than 150 years to measure these components as crude fiber, ether extract, dry matter, and total nitrogen, with nitrogen free extract (NFE) being calculated by difference. However, this system cannot be used to mechanistically predict microbial growth because crude fiber does not represent all of the fiber, NFE does not accurately represent the nonfiber carbohydrates, and protein must be described by fractions related to its ruminal degradation characteristics.

The level 2 model was developed to mechanistically predict microbial growth and ruminal degradation and escape of carbohydrate and protein to more dynamically predict ME and MP feed values. To accomplish this objective, the detergent fiber system of feed analysis is used to compute carbohydrate (fiber carbohydrates, CHO FC and nonfiber carbohydrates, CHO NFC) and protein fractions according to their fermentation characteristics (A = fast, B = intermediate and slow and C = not fermented and unavailable to the animal), as described by Sniffen et al.(1992).

Validations of the system implemented in level 2 for predicting feed biological values from feed analysis of carbohydrate and protein fractions have been published (Ainslie et al., 1993; O'Connor et al., 1993; and Fox et al., 1995). However, the subcommittee recognizes that considerable research is needed to refine this structure. The decision to implement the second level was based on the need to identify a system that will allow for implementing accumulated knowledge that can lead to accounting for more of the variation in performance. It is then assumed that further research between this revision and the next one will result in refinement of sensitive coefficients to improve the accuracy of its use under specific conditions.

The procedures used to determine each fraction are described as follows (Sniffen et al., 1992); the methods of crude protein fractionation have been recently standardized (Licitra et al., 1996).

1. Residual from neutral detergent fiber (NDF) procedure is total insoluble matrix fiber (cellulose, hemicellulose and lignin) (Van Soest et al.,1991).

2. Lignin procedure is an indicator of indigestible fiber (Van Soest et al., 1991). Then the unavailable fiber is estimated as lignin * 2.4. The factor 2.4 is not constant across feeds. It may overestimate the CHO C fraction feeds that are of low lignification. However, it appears to be of sufficient accuracy for the current state of the model.

3. Available fiber (CHO fraction B2) is NDF - (NDFN * 6.25) - CHO fraction C, and is used to predict ruminal fiber digestion and microbial protein production on fiber. Intestinal digestibility of the B2 fraction that escapes the rumen is assumed to be 20%.

4. Total nitrogen is measured by Kjeldahl (Association of Official Analytical Chemists, 1980).

5. Soluble nitrogen (NPN + soluble true protein) is measured to identify total N rapidly degraded in the rumen (Krishnamoorthy et al., 1983).

6. True protein is precipitated from the soluble fraction to separate the NPN (protein fraction A) from true rapidly degraded protein (protein fraction B1). Protein fraction B1 typically contains albumin and globulin proteins and provides peptides for meeting NFC microbial requirements for maximum efficiency of growth. A small amount of this fraction escapes ruminal degradation and 100% is assumed to be digested intestinally. Protein fraction A provides ammonia for both FC and NFC growth.

7. The detergent analysis systems (Van Soest et al, 1991) was designed to analyze for carbohydrate and protein fractions in forages. It has limitations in the analysis of other feedstuffs, particularly in the case of animal byproducts and treated plant protein sources. Nitrogen that is insoluble in neutral detergent (without sodium sulfite) and acid detergent (Van Soest et al., 1991) measures slowly degraded plus unavailable protein. Animal proteins do not contain fiber. However, because of filtering problems, analysis with this procedure will yield unrealistic values for ADF and NDF pools. To correct for this problem, all animal

proteins have been assigned ADFIP values that reflect average unavailable protein due to heat damage and keratins. The residual protein fraction (B2) has been assigned rates reflecting their relatively slower rates.

8. Acid detergent insoluble protein (ADFIP) (Van Soest et al., 1991) is used to identify unavailable protein (protein fraction C), and is assumed to have 0 ruminal and intestinal digestibility, realizing some studies have shown digestive disappearance of ADFIP. The levels of ADFIP can be adjusted where appropriate.

9. NDFIP - ADFIP identifies slowly degraded available protein (protein fraction B3). This fraction typically contains prolamin and extensin type proteins and nearly all escapes degradation in the rumen, and is assumed to have an intestinal digestibility of 80 percent.

10. (Total nitrogen * 6.25) - A - B1 - B3 - C = protein intermediate in degradation rate (protein fraction B2), except for animal protein as described above. This fraction typically contains glutelin protein and extent of ruminal degradation and escape is variable, depending on individual feed characteristics and level of intake. The ruminally escaped B2 is assumed to have an intestinal digestibility of 100 percent.

11. Ash (Association of Official Analytical Chemists, 1980).

12. Solvent-soluble fat (Association of Official Analytical Chemists, 1980). All of this fraction is assumed to escape ruminal degradation and is assumed to have an intestinal digestibility of 95 percent. Only the glycerol and galactolipid are fermented and the fatty acids escape rumen digestion.

13. Non-fiber carbohydrates (sugar, starch, NFC) are computed as 100 - CP - [(NDF - NDF protein) - fat - ash). Pectins are included in this fraction. Pectins are more rapidly degraded than starches but do not give rise to lactic acid.

14. CHO fraction A is nonfiber CHO - starch. It is assumed that these nonstarch polysaccharides are more rapidly degradable than most starches. Nearly all of this fraction is degraded in the rumen, but the small amount that escapes is assumed to have an intestinal digestibility of 100 percent.

15. CHO fraction B1 is nonfiber CHO - sugar. This fraction has a variable ruminal degradability, depending on level of intake, type of grain, degree of hydration and type of processing. Microbial protein production is most sensitive to ruminal starch degradation in the level 2 model. The B1 fraction that escapes is assumed to have a variable digestibility, depending on type of grain and type of processing. Feed physical characteristics are described as effective NDF (eNDF) as published by Sniffen et al. (1992). The basic eNDF is described as the percent of the NDF remaining on a 1.18 mm screen after dry sieving (Smith and Waldo, 1969, Mertens, 1985). This value was then adjusted for density, hydration and degree of lignification of the NDF within classes of feeds (Appendix Table 1). The eNDF was found to be an accurate predictor of rumen pH (Pitt et al., 1996);

Rumen pH = 5.425 + 0.04229 * %eNDF for %eNDF<35% in DM; ($R^2 = 0.52$).

The rumen pH is directly related to microbial protein yield (Russell et al., 1992) and FC microbial growth (Pitt et al., 1996). In level l, the microbial yield multiplier = 1 if eNDF>20 percent and is reduced 2.5 percent for each percentage unit reduction in eNDF below 20 percent. Level 2 adjusts microbial protein yield for rumen pH using this same approach but with a more mechanistic adjustment based on predicted microbial growth rates. Adjustment to FC digestion rate is made in level 2, based on the predicted rumen pH.

"Effective NDF" is the percentage of the NDF effective in stimulating chewing and salivation, rumination, and rumen motility. The data of Russell et al. (1992) and Pitt et al. (1996) show that rumen pH below 6.2 results in linear reductions in microbial protein production and FC digestion. Using data in the literature, Pitt et al. (1996) evaluated several approaches to predict rumen pH: diet content of forage, NDF, a mechanistic model of rumen fermentation or the effective NDF values published by Sniffen et al, 1992. Effective NDF gave predictions of rumen pH similar to the mechanistic model, and has the advantage of simplicity and flexibility in application. The tabular values for eNDF can be used as a guide, with adjustments based on field observations and experience. The importance of stimulating salivary flow in buffering the rumen is well documented (Beauchemin, 1991). Additional factors not accounted for in the eNDF system that can influence rumen pH are total grain intake and its digestion rate, and form of grain (whole corn will stimulate rumination but processed corn may not; a higher proportion of the starch in whole corn will escape ruminal fermentation compared to processed corn and other grains). Therefore adjustments or functional equivalents of eNDF must be assigned to feeds in these cases to make the system reflect these conditions. Ionophores will inhibit the growth of *Streptococcis bovis (S. bovis*), which produces lactic acid, which is 10 times stronger than the normal Volatile fatty acids produced in the rumen. Highly digestible feeds that are high in pectins (soybean hulls, beet pulp, etc.) will not produce the drop in pH as grains do.

Estimated eNDF requirements are provided in Table 10-8 and are based on the data of Pitt et al. (1996).

Table 10-8 Estimated eNDF Requirements

Diet Type	Minimum eNDF Required, % of DM
High concentrate to maximize gain/feed fed mixed diet, good bunk mgt, and ionophores	5 to 8[a]
Fed mixed diet, variable bunk mgt, or no ionophore fed	20
High concentrate to maximize NFC use and microbial protein yield	20[b]

[a] To keep rumen pH more than 5.6 to 5.7, the threshold below which cattle stop eating, based on the data of Britton et al. (1989).
[b] To keep rumen pH above 6.2 to maximum cell wall digestion and/or microbial protein yield.

Feed Biological Values.

Level 1 uses tabular energy and protein values for use in traditional approaches to ration formulation; level 2 permits the user to integrate intake, digestion and passage rates of carbohydrate and protein fractions to predict metabolizable energy and protein values of feeds for each unique situation.

The tabular TDN values are from summaries of digestion trial data (National Research Council, 1989; Van Soest, 1994), experimental data of subcommittee members, and represent 1 times maintenance, which is appropriate for gestating beef cows. Level 2 computes a TDN value that reflects the integration of level of intake and ruminal digestion and passage rates. Tabular net energy values are based on NRC (1984) equations. Tabular DIP/UIP values are based on Van Soest (1994), NRC (1989), data in the literature, experimental data of subcommittee members, or generated from the level 2 model.

Tabular Net Energy Values

The net energy system implemented by the 1976 Subcommittee on Beef Cattle Nutrition (National Research Council, 1976) for growing cattle has been successfully used since then to adjust for methane, urinary and heat increment losses in meeting net energy requirements for maintenance and tissue deposition. This system accounts for differences in usefulness of absorbed energy depending on source of energy and physiological function (National Research Council, 1984). However, these values are not directly measurable in feeds and do not account for the variation in ME and MP derived from feeds with varying levels of intake and extent of ruminal and intestinal digestion. Level 2 allows the prediction of NE values with these variables accounted for.

Both use the 1984 NRC equations to predict NE_m and NE_g values as shown in the equations section. These equations are mechanistic in predicting NE values from the standpoint of reducing the efficiency of use of ME for maintenance and growth (with a relatively greater effect on NE_g) as ME value of the feed declines (National Research Council, 1984). Diet NE_m and NE_g values determined in the body composition data base described by Fox et al.(1992) were regressed against NE_m and NE_g predicted with the 1984 NRC equations. Diet NE_g concentrations varied from approximately 0.90 to 1.50 Mcal/kg. There was no bias in either NE_m or NE_g predicted values, and the R^2 was 0.89 and 0.58, respectively. The lower R^2 for NE_g prediction is the result of feed for gain reflecting all cumulative errors in predicting requirements in this system, because NE_m requirement and feed for maintenance is computed using a fixed 0.077 Mcal/$BW^{0.75}$. Thus, it is likely that this is a "worst-case" scenario for predicted feed NE_g because maintenance requirement can be highly variable (Fox et al., 1992).

Tabular UIP/DIP Values

The system of UIP/DIP values was introduced in *Ruminant Nitrogen Usage* (National Research Council, 1985) and was implemented in the dairy cattle revision (National Research Council, 1989) to more accurately predict protein available to meet rumen microbial requirements and to supplement microbial protein in meeting animal requirements. Level 2 allows the determination of these values mechanistically, based on the integration of feed carbohydrate and protein fractions and microbial growth. The tabluar values for use in level 1 are from various sources and represent determinations by various methods. Analytically, DIP and UIP tabular values are determined by either in vitro or in situ methods, which have limitations in predicting ruminal degradation and escape of protein because of the limitations of the procedures and not accounting for variation in effects of digestion and passage rates.

Model Predicted Net Energy and Metabolizable Protein Values

Level 2 permits the user to integrate intake, digestion and passage rates of carbohydrate and protein fractions to predict metabolizable energy and protein values of feeds for each unique situation. Digestion rates have been assigned to each feed as described by Sniffen et al. (1992). The equations describe how these are used to predict metabolizable energy and protein values. Essential amino acid values have been assigned to feeds to represent their concentration in the undegraded protein fraction, based on O'Connor et al. (1993).

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