16 Model Evaluation and Prediction Equations

The evaluation of specific components of the model can be found in the relevant chapters. This chapter concerns the evaluation of the overall model relative to energy, protein, and intake. The model equations are also presented in this chapter for reference.

METHODOLOGY

Data from experiments published in the *Journal of Dairy Science* from 1992 through February 2000 were used to evaluate the model. Only data from continuous lactation experiments that lasted at least 6 weeks were used (data from cross-over type experiments were not used). Twenty-five papers representing 100 different diets were selected. The papers were selected so that a wide variety of ingredients and production levels of cows could be evaluated. The selection was made prior to diet evaluation; all selected diets are shown in the plots. Diets varied in:

1. Forage source (corn silage and alfalfa were used in most experiments)
2. Forage:concentrate ratio
3. Fat supplementation (without and with a wide variety of fat sources)
4. Nonforage fiber sources (without and with a wide variety of nonforage fiber sources)
5. Source of starch (mostly corn grain but sorghum and barley was also fed in some experiments)
6. Corn grain processing (dry and high moisture, grind size, steam-treatment)

Cows varied with respect to days in milk, milk yield, and milk composition. Twenty-three papers used Holstein cows, two papers used Jersey cows.

Diet composition (ingredients) was entered into the model. Published nutrient composition of the individual ingredients was used when available. When nutrient composition data were missing, values from the feed composition table (Table 15-1) were used. When nutrient composition of ingredients was not published but nutrient composition of the total diet was included, nutrient composition of individual ingredients (usually only the forages) were changed by no more than one standard deviation so that composition (NDF and CP) of the diet was the same as the published composition. Most studies did not include measured lignin, ash, and neutral and acid detergent insoluble crude protein. The protein fraction and digestion rate data in the composition tables (Tables 15-2a and b) were used in all evaluations. Few papers published data on mineral composition of the ingredients or diets, and because mean composition data on minerals (Table 15-3) has a large variance, provision of minerals was not evaluated. However, the concentration of mineral supplements was included in the diets.

Mean production data (days in milk, lactation number, body weight, and milk yield and composition) were entered into the model. Day of gestation usually was not published so a reasonable estimate was entered based on days in milk. Most papers did not include data on the age of the cows. Therefore, growth requirements were set to zero for all cows except those that were exclusively primiparous (for those cows, model generated growth requirements were used).

EVALUATION

After diet and cow data were entered into the model, predicted dry matter intake, net energy allowable milk, and metabolizable protein allowable milk were compared with actual intake and milk production. Predicted net energy balance was compared with actual net energy balance by including net energy provided by or needed for the measured body weight change. Sources of data used in the evaluation are shown in Table 16-1.

Dry Matter Intake

Mean observed dry matter intake was 22.3 kg/d and mean predicted intake was 22.1 kg/d. No evidence of a linear bias was found (Figure 16-1). Root mean square error (predicted minus observed) was 2.0 kg/d. Predicted intake was within ± 5 percent of observed intake in 41 percent of the observations and 73 percent of the predicted intakes were within ± 10 percent of observed intake.

Energy

To evaluate the energy portion of the model, intake of NE_L (based on actual DMI and model predicted NE_L concentration) was compared with NE_L utilization (model predicted NE_L for maintenance, based on actual body weight, model predicted NE_L for actual milk produced, and NE_L used for measured body weight change). The data set was as described above except two studies (4 treatment means) could not be used because body weight change was not reported. If the model is accurate, NE_L intake and NE_L use should be equal with no apparent bias. Overall, the accuracy of the model was acceptable (Figure 16-2). Intake of NE_L and NE_L use were highly correlated ($r^2 = 0.61$; $P<0.01$). Energy use was within ± 5 percent of NE_L intake for 46 percent of the observations and within 10 percent for 76 percent of the observations. Mean NE_L intake was 35.4 Mcal/d compared with mean NE_L use of 34.5, therefore, a small mean bias (0.9 Mcal of NE_L intake or 2.5 percent) was present. A linear bias is apparent (NE_L intake $= 7.8 + 0.8 \times NE_L$ Use); however, within the range of NE_L used for most lactating cows in the United States the bias will be small (at 20 Mcal of NE_L use, estimated mean NE_L intake is 23.8 Mcal/day; at 30 Mcal/d NE_L use, estimated mean NE_L intake is 31.8 Mcal/day; and at 45 Mcal of NE_L use, estimated mean NE_L intake is 43.8 Mcal/day).

TABLE 16-1 Sources of Data Used in the Model Evaluation (see also Figures 16-1 to 16-5)

Aydin et al. (1999)	Knowlton et al. (1998)	Soder and Holden (1999)
Bertrand et al. (1998)	Kuehn et al. (1999)	Stegeman et al. (1992)
Coomer et al. (1993)	Messman et al. (1992)	Tackett et al. (1996)
Dann et al. (2000)	Mowrey et al. (1999)	Wattiaux et al. (1994)
Dhiman and Satter (1993)	Overton et al. (1998)	Weiss (1995)
Kalscheur et al. (1999)	Pereira et al. (1999)	Weiss and Shockey (1991)
Khorasani et al. (1993)	Santos et al. (1998)	Weiss and Wyatt (2000)
Khorasani et al. (1996)	Santos et al. (1999)	Wilkerson et al. (1997)
Kim et al. (1993)		

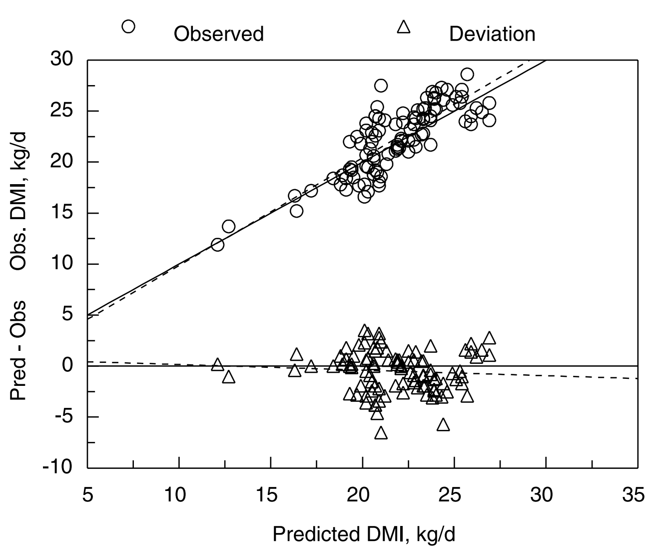

FIGURE 16-1 Model predicted vs. actual dry matter intake. Values from 100 published treatments means from 25 studies.

Protein

Evaluation of the protein portion of the model by comparing MP allowable milk with actual milk is equivocal. When MP allowable milk is greater than actual milk, milk production could be limited by the physiologic state or genetic potential of the cow or by a nutrient other than MP. Higher MP allowable milk than actual milk could also mean that the model underpredicted MP requirements of the cow. When MP allowable milk was compared with actual milk, MP allowable milk was less than actual milk in only 18 (18 percent) observations (Figure 16-3). Of those 18 observations, MP allowable milk for 5, 8, and 5 observations were within 10 to 17 percent, 5 to 10 percent, or less than 5 percent of actual milk. Eighty-two percent of all treatment groups in this data set produced less milk than the model predicted could be produced from the amount of MP available. In 67 percent of the observations, MP allowable milk was more than 10 percent greater than actual milk. Other than energy, the most likely nutrients

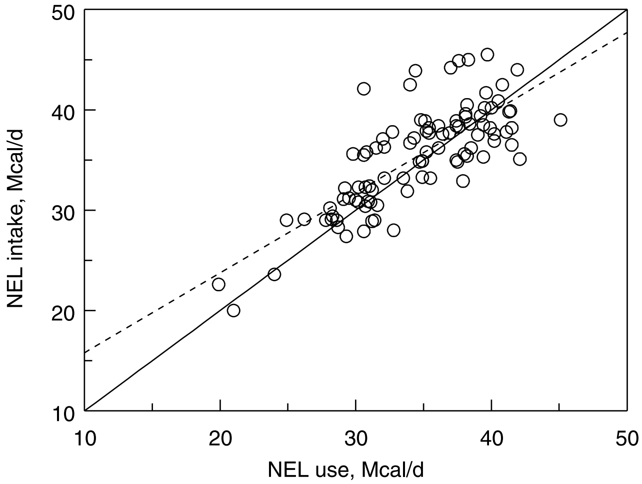

FIGURE 16-2 NEL intake (estimated from observed dry matter intake and model estimated NEL concentration) versus NEL use (estimated from model predicted maintenance and lactation requirement plus NEL needed to meet observed body weight change). Values from a data base of 96 published treatment means from 23 studies. The solid line represents y = x, the dashed line represents y = 7.8 + 0.8X.

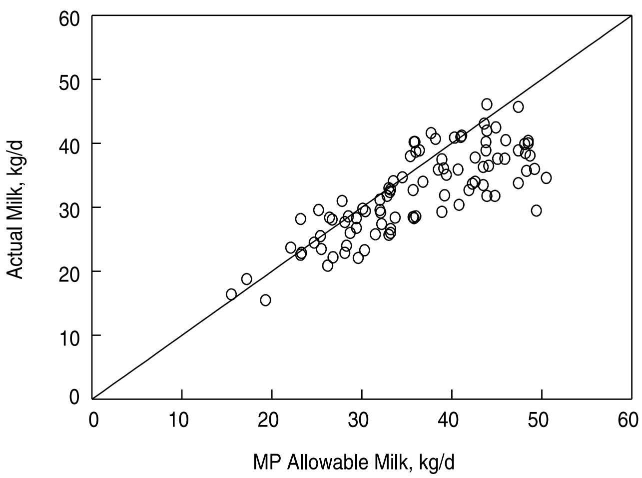

FIGURE 16-3 Actual milk production versus model predicted MP allowable milk production. Values from 100 published treatment means from 25 studies.

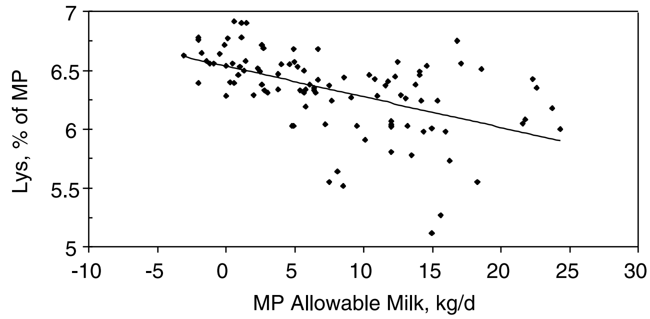

FIGURE 16-4 Difference between MP allowable milk and actual milk versus model predicted lysine concentration of MP. Values from 100 published treatment means from 25 studies. Regression line: y = 6.54 − 0.026x.

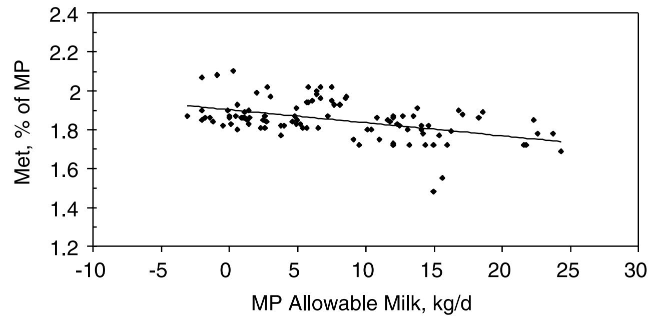

FIGURE 16-5 Difference between MP allowable milk and actual milk versus model predicted methionine concentration of MP. Values from 100 published treatment means from 25 studies. Regression line: y = 1.90 − 0.0067x.

limiting milk production and causing MP allowable milk to be greater than actual milk are specific amino acids. The difference between MP allowable milk and actual milk increased as the concentration of lysine decreased from 6.5 percent of MP (Figure 16-4) and as the concentration of methionine decreased from 1.9 percent of MP (Figure 16-5). This suggests that although supply of total MP was adequate in many of these experiments, the balance of absorbable amino acids may have been incorrect and limited milk production. Experiments specifically designed to test the MP requirements predicted by the model are needed.

MODEL PREDICTION EQUATIONS

Model Structure

The model is divided into two major components: prediction of requirements and supply of nutrients. Within this structure, there are submodels for young calves, maintenance, pregnancy, growth, lactation, dry matter intake, minerals, reserves, energy and protein supply, amino acids, and diet evaluation. A glossary of the terms used in the equations is included at the end of the chapter. Background information explaining the committee's rationale in choosing the approach and coefficients used in the model is presented in the appropriate chapters. A complete listing of all of the equations in the model is included in a file on the compact disk that contains the model itself. Note, MEng is used to denote metabolizable energy (ME) in the computer program and in the equations below because ME can not be used as a variable in the programming language that we used.

Animal Requirements

The requirements section is divided into four main sections based on physiological function: maintenance, growth, lactation, and pregnancy. Adjustments made for grazing activity are included in the maintenance section. There are four classes of animals in this model, lactating cow, dry cow, replacement heifer, and young calf. If different equations are used for heifers, lactating cows, or dry cows, they will be presented under the appropriate physiologic function. The equations used to predict the requirements and nutrient supply of the young calves are in a separate section.

Maintenance

MAINTENANCE ENERGY REQUIREMENTS

Maintenance requirements are computed by adjusting the NEm requirement for fasting metabolism for the effects of physiologic state, activity, and, in the case of heifers, heat and cold stress.

Lactating and Dry Cows The maintenance requirement for lactating cows is calculated using metabolic body size ($BW^{0.75}$), and calculated with the following equation which includes an adjustment for activity:

$$\text{NEmaint (Mcal/d)} = ((\text{BW} - \text{CW})^{0.75} \times \text{a1}) + \text{NEmact}$$

Where a1 = 0.08 for mature cows based on the requirement for NEm (80 kcal/kg $BW^{0.75}$) (NRC, 1989), CW is conceptus weight and NEmact is the variable to calculate the requirement for activity.

$$\text{NEmact} = ((((\text{Distance}/1000) \times \text{Trips}) \times (0.00045 \times \text{BW})) + (0.0012 \times (\text{BW}))$$

Where Distance is the distance from the pasture to the milking parlor (km), Trips is the number of times that animals go to and from the milking parlor daily, and Pasture is an adjustment for percent of the predicted dry matter intake supplied by grazing.

NEmact is adjusted for differences in topography for grazing animals. Topography may be either flat or hilly. No adjustment is made if the topography is flat.

If Topography = 'Hilly' Then NEmact = NEmact + (0.006 × BW)

The following equations are used to calculate the net energy concentration of the diet and the amount of feed that is required to meet the maintenance requirement.

$$\text{NEFP} = (\text{TotalDMFed} - \text{FeedMaint}) \times (\text{NEl\_Total} / \text{TotalDMFed}) \times 0.65$$

Where NEFP = Net energy for production, TotalDMFed = Total dry matter consumed, NEl_Total = total NE (in Mcals) and 0.65 is the assumed efficiency of conversion of metabolizable protein to net protein

Heifers The maintenance requirements for heifers without stress (NEmaintNS) are calculated with the following equation:

$$\text{NEmaintNS (Mcal/d)} = (((\text{SBW} - \text{CW})^{0.75}) \times ((\text{a1} \times \text{COMP}) + \text{a2})) + \text{NEmact}$$

Where:
SBW = shrunk body weight = 0.96 × BW, CW = conceptus weight (kg),
a1 = 0.086 (thermoneutral maintenance requirement (Mcal/day)),
a2 = 0.0007 × (20 − PrevTemp) (Adjustment for previous temperature effect),
COMP = 0.8 + ((CS9 − 1) × 0.05) (Adjustment for previous plane of nutrition) NEmact = energy required for activity

In the model, a 1–9 system for body condition scoring is used so the following equation is used to convert from the 1–5 system more commonly used in the dairy industry to the 1–9 system. The conversion to the 9-point condition score from the 5-point system is:

$$\text{CS9} = ((\text{CS} - 1) \times 2) + 1$$

The following equation is used to calculate the activity requirement for grazing heifers:

NEmact = ((0.0009 BW) + (0.0016 BW)) if the heifer is grazing, otherwise it is 0.
If Topography = 'Hilly' then NEmact = NEmact + (0.006 × BW)

For heifers, these requirements then are adjusted for the effects of temperature that are based on surface area, heat production, tissue and coat insulation, coat condition, and temperature. First surface area (SA) and heat production (HP) ($Mcal/m^2/day$) are calculated:

$$\text{SA} = 0.09 \times (\text{SBW}^{0.67})$$
$$\text{HP} = (\text{MEI} - \text{NEFP})/\text{SA}$$

Where NEFP = Net energy for production which equals NEGrowthDietNS (Net energy for growth available in the diet with no stress, Mcal/day), HP = Heat production ($Mcal/m^2/day$), MEI = Metabolizable energy intake (Mcal), and NEGrowthDietNS = (TotalDMFed − FeedMaint) × (NEg_Total / TotalDMFed)

The next step is to calculate tissue insulation (TI, $Mcal/m^2/°C/day$). For younger animals, these factors are based on age alone but, for older animals, body condition score is also considered. These factors are:

Age (days)	*TI Factor*
≤ 30	2.5
31 to 183	6.5
184 to 362	5.1875 × (0.3125 × CS9)
≥ 363	5.25 × (0.75 × CS9)

The insulation is further affected by coat condition (Coat):

Coat condition	*Factor*
Clean/dry	1.0
Some mud	0.8
Wet/matted	0.5
Coated with snow/mud	0.2

The external insulation value, EI (°C/Mcal/m^2/day) is:

$$EI = ((7.36 - (0.296 \times WindSpeed) + (2.55 \times HairDepth)) \times Coat) \times 0.8$$

Where WindSpeed (kph) is the average wind speed and typical HairDepth values for animals in summer are 0.63 cm (0.25 inches) and for winter 1.27 cm (0.5 inches) and Coat is the coat condition factor.

The total insulation (INS, Mcal/m^2/°C/day) is INS = TI + EI

The effects of heat and cold stress are based on lower and upper critical temperatures.
The animal's lower critical temperature (LCT, °C) is:

$$LCT = 39 - (INS \times HP \times 0.85)$$

If the LCT > ambient temperature (Temp), then

$$MEcs = SA \times (LCT - Temp)/INS$$

Where MEcs is Metabolizable energy required for cold stress (Mcal/day).
Otherwise, there is no cold stress.

$$ColdStr = (((NEDietConc/MEng\_Total/TotalDMFed)) \times MEcs)$$

Where NEDietConc is the concentration of net energy in the diet (kg DM/day), MEng_Total is Total ME intake (Mcal/day), and TotalDMFed is total dry matter fed (kg).
To calculate the effects of heat, the HeatStress variable is used. An index based on visible changes in breathing in response to heat based on breathing is used:

If HeatStress = 'None' or Temp < 30 then HeatStr = 1
If HeatStress = 'Rapid/Shallow' then HeatStr = 1.07
If HeatStress = 'Open Mouth' then HeatStr = 1.18

The final equation to calculate the maintenance requirement for replacement heifers is:

$$NEMaint = ((NEMaintNS + ColdStr) \times HeatStr) + NEmact$$

Maintenance Protein Requirement

LACTATING AND DRY COWS AND REPLACEMENT HEIFERS

The protein requirements for maintenance for all classes of cattle except for the young calves are calculated with the following equation:

$$MPMaint = (0.3 \times (BW - CW)^{0.6}) + (4.1 \times (BW - CW)^{0.5}) + (TotalDMFed \times 1000 \times 0.03 - 0.5 \times ((MPBact / 0.8) - MPBact) + MPEndoReq$$

Where MPMaint = Metabolizable protein required for maintenance (g/day)
CW = conceptus weight
Scurf Requirement = $(0.3 \times (BW - CW)^{0.6})$;
Urinary Requirement = $(4.1 \times (BW - CW)^{0.5})$;
Metabolic Fecal Protein Requirement = (TotalDMFed × 1000 × 0.03 − 0.5 × ((MPBact / 0.8) − MPBact));
MP required for Endogenous Protein (MPEndoReq) = MPEndo/0.67;
MPBact = Metabolizable protein supplied by microbial protein (g/day);
MPEndo = Endogenous metabolizable protein (g/day) = 0.4 × EndCP and
EndCP = Endogenous crude protein (g/day) = 11.8 × TotalDMFed.

Growth

ENERGY REQUIREMENTS FOR GROWTH

Replacement Heifers, Lactating and Dry Cows (1st and 2nd Lactation only)

In this section of the model, requirements for growth are calculated from shrunk body weight, SBW (0.96 × BW) and empty body weight (EBW) (see Chapter 11 for rationale). The user may choose to enter a desired rate of gain or may use the model-generated target gains. For both options, a size-scaling approach is used which requires information on mature body weight (MBW) and mature shrunk body weight (MSBW). The user may use data on mature weights from his/her herd or may rely on default values generated in the program. Accurate estimates of mature weight are needed for accurate predictions of requirements. Representative weights of mature culls cows with average body condition scores may be used to estimate mature weights (MW).

MSBW = Mature shrunk body weight = 0.96 × MW
SBW = Shrunk body weight = 0.96 × BW
EBW = Empty body weight = 0.891 × SBW
EBG = Empty body weight gain = 0.956 × SWG

The following calculation is used to calculate the ratio of the standard reference weight to mature shrunk body weight (SRW_to_MSBW).

$$SRW\_to\_MSBW = 478 / MSBW$$

$$EQSBW = (SBW - CW) \times SRW\_to\_MSBW$$

Where EQSBW = Equivalent shrunk body weight (kg) and CW = Conceptus weight (kg).

The equation is used to compute shrunk weight gain (SWG):

$SWG = 13.91 \times (NEGrowthDiet^{0.9116}) \times (EQSBW^{-0.6837})$

Where SWG = shrunk weight gain (kg), NEGrowthDiet = NEg in the diet (Mcal)

If the animal is a replacement heifer, then WG (weight gain) = SWG (shrunk weight gain),
Otherwise, WG = ADG (Average daily gain)

The following equations are conversions to equivalent (size-scaled) weights:

$EQEBW$ = Size-scaled empty body weight $= 0.891 \times EQSBW$
$EQEBG$ = Size-scaled empty body weight gain $= 0.956 \times WG$

Retained energy (RE) is calculated with the following equation:

$RE = 0.0635 \times (EQEBW^{0.75}) \times (EQEBG^{1.097})$

Protein Requirements for Growth

REPLACEMENT HEIFERS, LACTATING AND DRY COWS (1ST AND 2ND LACTATION ONLY)

Net protein for growth (NPg) is calculated as follows:

$NPg = WG \times (268 - (29.4 \times (RE / WG)))$

Where WG = weight gain (kg) (always positive) and RE = retained energy (Mcal).

The efficiency with which net protein is used for gain (EffMP_NPg) is then computed:

If $EQSBW \leq 478$ then $EffMP\_NPg = (83.4 - (0.114 \times EQSBW)) / 100$
Otherwise $EffMP\_NPg = 0.28908$

The next step is to calculate the metabolizable protein required for growth (MPGrowth) by dividing NPg by the efficiency with which MP is converted to NP:

$MPGrowth = NPg / EffMP\_NPg$

If the animal is a replacement heifer,
DMIAvailGrowth = TotalDMFed − DMIMaint − DMIPreg
Otherwise
DMIAvailGrowth = TotalDMFed − DMIMaint − DMIPreg − DMILact

Where DMIAvailGrowth is the dry matter intake for growth.

If Age < FirstCalf, then ADGwPreg = SWG + (ADGPreg / 1000)
Otherwise, ADGwPreg = (EQEBG / 0.956) + (ADGPreg/ 1000)

For replacement heifers only,
If NEfOverMEng > 0, then MEGrowth = NEGrowth / NEgOverMEng

Calculation of Target Weights and Average Daily Gain for Replacement Heifers and Animals in 1st and 2nd Lactations

The following set of calculations is used to compute the gain required to achieve specified target weights at first breeding, calving, and maturity which is assumed to occur at the beginning of the third lactation. It is important to ensure that appropriate mature weights, age at first calving, and calving interval data are entered or the predictions for target gain will be unrealistic.

The following equations are used to calculate age at different calvings:

Age1st = FirstCalf
Age2nd = Age1st + CalfInt
Age3rd = Age2nd + CalfInt
Age1stBred = Age1st − (280 / 30.4)

It is assumed that heifers will achieve 0.55 of their mature shrunk body weight at first breeding, 0.82 at first calving, and 0.92 at 2nd calving. At the onset of their third lactation, they are assumed to have reached their mature weight.

Wt1stBred = MSBW × 0.55
Wt1st = MSBW × 0.82
Wt2nd = MSBW × 0.92
Wt3rd = MSBW

ADG1stBred = (Wt1st − Wt1stBred) / ((Age1st − Age1stBred) × 30.4)
ADG1st = (Wt2nd − Wt1st) / (CI × 30.4)
ADG2nd = (Wt3rd − Wt2nd) / (CI × 30.4)

If AnimalType = "Replacement Heifer" and Age < Age1stBred Then ADGNonBred = (Wt1stBred − SBW) / ((Age1stBred − Age) × 30.4)
Otherwise, ADGNonBred = 0

If AnimalType ≠ "Replacement Heifer", then ADGNonBred = 0

If AnimalType = "Replacement Heifer" and is pregnant then
ADG = ADG1stBred
Otherwise, ADG = ADGNonBred

Pregnancy

PREGNANT REPLACEMENT HEIFERS AND MATURE COWS

Constants used in pregnancy calculations are:

Km = conversion of ME to NE = 0.64
EffMEPreg = The efficiency with which ME is used for pregnancy = 0.14
EffMPPreg = The efficiency with which MP is used for pregnancy = 0.33

Until day 190 of pregnancy, no requirements for pregnancy are computed in the model. The maximum number of days that a cow can be pregnant is assumed to be 279.

CBW (calf birth weight) = MW × 0.06275
CW (conceptus weight) = (18 + ((DaysPreg − 190) × 0.665)) × (CBW / 45)
ADGPreg (ADG of the conceptus) = 665 × (CBW / 45)
MEPreg (ME required for pregnancy) = ((2 × 0.00159 × DaysPreg − 0.0352) × (CBW / 45)) / EffMEPreg
MPPreg (MP required for pregnancy) = ((0.69 × DaysPreg − 69.2) × (CBW / 45)) / EffMPPreg
NEPreg = Net energy required for pregnancy = MEPreg × Km

Lactation

If lactose content of milk is not available,

MilkEn (energy content of milk) = (0.0929 × MilkFat) + (0.0547 × MilkTrueProtein / 0.93) + 0.192

If lactose content is known,

MilkEn = (0.0929 × MilkFat) + (0.0547 × MilkTrueProtein / 0.93) + (0.0395 × Lactose)

The amounts of energy, protein, and fat in milk then are computed:

YEn = NElact (energy in milk daily, Mcal/day) = MilkEn × MilkProd
YProtn (daily protein yield in milk, kg/day) = MilkProd × (MilkTrueProtein / 100)
Yfatn (daily fat yield in milk, kg/day) = MilkProd × (MilkFat / 100)

MPLact (Metabolizable protein required for lactation) = (Yprotn / 0.67) × 1000

The following equation is used to convert to fat-corrected milk (FCM):

FCM = 0.4 × MilkProd + 15 × (MilkFat / 100) × MilkProd

Reserves

The factors used to adjust weight at the current CS to expected weight at CS3.

CS_F_1 = 0.726	CS_F_6 = 1.069
CS_F_2 = 0.794	CS_F_7 = 1.137
CS_F_3 = 0.863	CS_F_8 = 1.206
CS_F_4 = 0.931	CS_F_9 = 1.274
CS_F_5 = 1.000	

CS5EBW = (SBW × 0.851) / (CS_F_X)

Where CS5EBW = Empty body weight at CS5 using the 1 to 9 scale and CS_F = factor to calculate reserves at CS1 to 9.

EBW_X (Empty body weight at CS_X) = CS_F_X × CS5EBW
AF_X (Proportion of fat at CS_X) = 0.037683 × X
TF_X (Weight of fat at CS_X) = AF_X × EBW_X
AP_X (Proportion of protein at CS_X) = 0.200886 − (0.0066762 × X)
TP_X (Weight of protein at CS_X) = AP_X × EBW_X
ER_X (Energy reserves at CS_X) = (9.4 × TF_X) + (5.55 × TP_X)

Where X varies from 1 to 9.

If CS9 ≥ 3, then Lose1CS = $ER_{CS9} - ER_{CS9-2}$,
Otherwise, Lose1CS = 1000000

If CS9 ≥ 3, then NElSub = 0.82 × Lose1CS
Otherwise, NElSub = 0.82 × ($ER_{CS9} - ER_1$)

If CS9 ≤ 7, then Gain1CS = $ER_{CS9+2} - ER_{CS9}$
Otherwise, Gain1CS = 1000000

If CS9 ≤ 7, then NElReq = (0.644 / 0.75) × Gain1CS
Otherwise, NElReq = (0.644 / 0.75) × ($ER_9 - ER_{CS9}$)

If EnergyBal > 0, then deltaER = NElReq
Otherwise, deltaER = NElSub

Days to change condition score is calculated only for cows:

If AnimalType = "Replacement Heifer", then DaysToChange = 0.
Otherwise, DaysToChange = deltaER / EnergyBal

Energy balance is calculated in the following equations.

For Dry Cows and Lactating Cows:
NEBalance = NEl_Total − (NEMaint + NEPreg + NELact + NEGrowth)
(These groups of animals use an NE-based system.)

For Replacement Heifers:
MEBalance = (MEng_Total − (MEMaint + MEPreg + MEGrowth))
(Heifers use an ME-based system).

Weight change in cows due to energy balance is computed in the following equations:

For Lactating Cows:

If NEBalance < 0, Then kg weight change = NEBalance / 4.92
If NEBalance > 0, Then kg weight change = NEBalance / 5.12

For Dry Cows:
If NEBalance < 0, Then kg weight change = NEBalance / 4.92
If NEBalance > 0, Then kg weight change = NEBalance / 6.40

If the animal is gaining weight, the protein requirement for this gain must be computed.

If NEBalance > 0 Then
MPReqReserves = (Reserves_WG × ProteinInGain) / 0.492
MPProvReserves = 0
RUPReqReserves = MPReqReserves / DietRUPDigest

If NEBalance < 0 Then
MPReqReserves = 0

If the animal is losing weight, the protein provided by catabolism is computed.

MPProvReserves = (−1 × Reserves_WG) × ProteinInGain × 0.67
RUPReqReserves = MPProvReserves /DietRUPDigest

Where MPReqReserves = metabolizable protein required for reserves, MPProvReserves = metabolizable protein provided by mobilization of reserves, RUPReqReserves = RUP required for repletion of reserves and RUPProvReserves = RUP provided by mobilization of reserves.

Mineral Requirements

In most cases, the requirements for minerals are determined for each physiologic function, maintenance, growth, lactation, and pregnancy, but for some minerals this approach has not been followed. The maintenance component of the mineral requirement includes fecal, urinary, sweat, and miscellaneous losses. Because the bioavailability of minerals from various sources differs, the amount of the total mineral in the diet that is absorbable is determined. Growth requirements for minerals are calculated for heifers during their first lactation, but not during their first dry period or during the second lactation.

All calculations for milk mineral requirements are done on a 4 percent fat corrected milk basis (FCM). The equation to convert to FCM is:

FCM = (0.4 × MilkProd) + (15 × (MilkFat / 100) × MilkProd)

CALCIUM (g/d)

Fecal
If DaysInMilk > 0, then Fecal = 3.1 × (BW / 100)
If DaysInMilk = 0, then Fecal = 1.54 × (BW / 100)

Urinary
Urine = 0.08 × (BW / 100)

Miscellaneous
Misc = 0

Sweat
Sweat = 0

Pregnancy
If DaysPreg > 190, then
Fetal = 0.02456 × Exp((0.05581 − (0.00007 × DaysPreg)) × DaysPreg) − 0.02456 × Exp((0.05581 − (0.00007 × (DaysPreg − 1))) × (DaysPreg − 1))

If DaysPreg ≤ 190, then Fetal = 0

Lactation
If DaysInMilk > 0, then
If breed = Holstein or Milking Shorthorn, then
Milk = 1.22 × Milk Prod
If breed = Jersey, then
Milk = 1.45 × Milk Prod
Otherwise, Milk = 1.37 × Milk Prod

Growth
If BW > 0 and WG > 0, Then
Growth = $(9.83 \times (MW^{0.22}) \times (BW^{-0.22})) \times (WG / 0.96)$

PHOSPHORUS (g/d)

Fecal
If AnimalType = Cow, then Fecal = 1 × TotalDMFed
Otherwise, Fecal = 0.8 × TotalDMFed

Urine
Urine = 0.002 × BW

Miscellaneous
Misc = 0

Sweat
Sweat = 0

Pregnancy
If DaysPreg ≥ 190 Then
Fetal = 0.02743 × Exp(((0.05527 − (0.000075 × DaysPreg)) × DaysPreg)) − 0.02743 ×

Exp(((0.05527 − (0.000075 × (DaysPreg − 1))) × (DaysPreg − 1)))
Otherwise, Fetal = 0

Lactation
If DaysInMilk > 0, then Milk phosphorus = 0.9 × MilkProd

Growth
If BW > 0 and WG > 0, then
Growth = (1.2 + (4.635 × ($MW^{0.22}$) × ($BW^{-0.22}$))) × (WG / 0.96)

MAGNESIUM (g/day)

Fecal
Fecal = 0.003 × BW

Urine
Urine = 0

Miscellaneous
Misc = 0

Sweat
Sweat = 0

Pregnancy
If DaysPreg > 190 Then Fetal = 0.33 g/day
Otherwise, Fetal = 0

Lactation
If DaysInMilk > 0, Then Milk = 0.15 × MilkProd

Growth
Growth = 0.45 × (WG / 0.96)

CHLORINE (g/day)

Fecal
Fecal = 2.25 × (BW / 100)

Urine
Urine = 0

Miscellaneous
Misc = 0

Sweat
Sweat = 0

Pregnancy
If DaysPreg > 190 Then Fetal = 1
Otherwise, Fetal = 0

Lactation
Milk = 1.15 × MilkProd

Growth
Growth = 1 × (WG / 0.96)

POTASSIUM (g/day)

Fecal
If AnimalType = Lactating cow
Fecal = 6.1 × TotalDMFed
Otherwise Fecal = 2.6 × TotalDMFed

Urine
Urine = 0.038 × BW

Sweat
If Temp < 25, then Sweat = 0
If Temp 25 to 30, then Sweat = 0.04 × (BW / 100)
If Temp > 30, then Sweat = 0.4 × (BW / 100)

Miscellaneous
Misc = 0

Pregnancy
If DaysPreg > 190 Then Fetal = 1.027
Otherwise, Fetal = 0

Lactation
Milk = 1.5 × MilkProd

Growth
Growth = 1.6 × (WG / 0.96)

SODIUM (g/day)

Fecal
For lactating cows, Fecal = 0.038 × BW
Otherwise, Fecal = 0.015 × BW

Urine
Urine = 0

Miscellaneous
Misc = 0

Sweat
If Temp < 25, then Sweat = 0
If Temp 25 to 30, then Sweat = 0.1 × (BW / 100)
If Temp > 30, then Sweat = 0.5 × (BW / 100)

Pregnancy
If DaysPreg > 190, then Fetal = 1.39
If DaysPreg ≤ 190, then Fetal = 0

Lactation
Milk = 0.63 × MilkProd

Growth
Growth = 1.4 × (WG / 0.96)

SULFUR (g/day)

A non-factorial approach is used to determine the sulfur requirement.

Total = 2 × TotalDMFed

COBALT (mg/day)

A non-factorial approach is used to determine the cobalt requirement.

Total = 0.11 × TotalDMFed

COPPER (mg/day)

Fecal
Fecal = (0.0071 × BW)

Urine
Urine = 0

Sweat
Sweat = 0

Miscellaneous
Misc = 0

Pregnancy
If DaysPreg < 100, then Fetal = 0.5 mg/day
If 100 ≤ DaysPreg ≤ 225, then Fetal = 1.5 mg/day
If DaysPreg > 225, then Fetal = 2 mg/day

Lactation
Milk = 0.15 × MilkProd

Growth
Growth = 1.15 × (WG / 0.96)

IODINE (mg/day)

Fecal
Fecal = 0

Urine
Urine = 0

Sweat
Sweat = 0

Miscellaneous
Misc = 0

Fetal
Fetal = 0

Lactation
If DaysInMilk > 0, then Milk = 1.5 × (BW / 100)
If DaysInMilk = 0, then Misc = 0.6 × (BW / 100)

Growth
Growth = 0

IRON (mg/day)

Fecal
Fecal = 0

Urine
Urine = 0

Sweat
Sweat = 0

Miscellaneous
Misc = 0

Pregnancy
If DaysPreg > 190, then Fetal = 18
Otherwise, Fetal = 0

Lactation
Milk = 1 × MilkProd

Growth
Growth = 34 × (WG / 0.96)

MANGANESE (mg/day)

Fecal
Fecal = 0.002 × BW

Urine
Urine = 0

Sweat
Sweat = 0

Miscellaneous
Misc = 0

Pregnancy
If DaysPreg > 190, then Fetal = 0.3
Otherwise, Fetal = 0

Lactation
If DaysInMilk > 0, then Milk = 0.03 × MilkProd

Growth
Growth = 0.7 × (WG / 0.96)

SELENIUM (mg/d)

A non-factorial approach is used to determine the selenium requirement.

Total = 0.3 × TotalDMFed

ZINC (mg/day)

Fecal
Fecal = 0.033 × BW

Urine
Urine = 0.012 × BW

Sweat
Sweat = 0

Miscellaneous
Misc = 0

Pregnancy
If DaysPreg > 190, then Fetal = 12
Otherwise, Fetal = 0

Lactation
Milk = 4 × MilkProd

Growth
Growth = 24 × (WG / 0.96)

VITAMIN A (1000 IU/kg)

A non-factorial approach is used to determine the Vitamin A requirement.

If AnimalType = Lactating Cow, Dry Cow, or Replacement Heifer with DaysPreg > 259, then Total = 0.11 × BW
If AnimalType = Replacement Heifer with DaysPreg ≤ 259, then Total = 0.08 × BW

VITAMIN D (1000 IU/kg)

A non-factorial approach is used to determine the Vitamin D requirement.

The requirement is 0.03 × BW.

VITAMIN E (IU/kg)

A non-factorial approach is used to determine the Vitamin E requirement.

If the animal is grazing and the AnimalType = Dry Cow, then Vit E required = 0.5 × BW
If the animal is grazing and the AnimalType = Lactating Cow or Replacement Heifer,
Then Vit E required = 0.26 × BW
If the animal is not grazing and the AnimalType = Dry Cow, then Total = 1.6 × BW
If the animal is not grazing and the AnimalType = Lactating Cow or Replacement Heifer, then Vit E required = 0.8 × BW

Dry Matter Intake Predictions

LACTATING AND DRY COWS

The equation to predict intake for lactating cows (DMILact) is:

$$DMILact = (((BW^{0.75}) \times 0.0968) + (0.372 \times FCM) - 0.293) \times Lag$$

Low intake in early lactation is adjusted using the Lag variable for lactating cows:

$$Lag = 1 - e^{(-1 \times 0.192 \times (WOL + 3.67))}$$

The equation for predicting the dry matter intake of dry cows (DMIDry) in the last 21 days of pregnancy is:

$$DMIDry = ((1.97 - (0.75 \times e^{(0.16 \times (DaysPreg - 280))})) / 100) \times BW$$

REPLACEMENT HEIFERS

Heifer intakes are adjusted for environmental temperature and conditions using the coat condition (CoatCond) variable to calculate CCFact, the adjustment factor. In the following section, we describe how the environmental adjustments are made and then provide the equation for heifer intake (DMI_RH).

If CoatCond = Clean/Dry, then CCFact = 1
If CoatCond = Some Mud, then CCFact = 1
If CoatCond = Wet/Matted, then CCFact = 0.85
If CoatCond = Covered with Snow/Mud, then CCFact = 0.7

Heifer intake also is adjusted for temperature effects (TempFact). At temperatures > 35, night cooling also affects intake:

If Temp < -15, then TempFact = 1.16
If -15 ≤ Temp ≤ -5, then TempFact = 1.07
If -5 ≤ Temp ≤ 5 , then TempFact = 1.05
If 5 ≤ Temp ≤ 15, then TempFact = 1.03
If 15 ≤ Temp ≤ 25, then TempFact = 1.00
If 25 ≤ Temp ≤ 35, then TempFact = 0.9
If Temp > 35 without night cooling, then TempFact = 0.65
If Temp > 35 with night cooling, then TempFact = 0.9

Predicted intake also is adjusted for the effects of age with the SubFact variable:

If Age ≤ 12, Then SubFact = 0.1128
If Age > 12, Then SubFact = 0.0869

The energy concentration of the diet affects intake using the DivFact variable. For lactating and dry cows, net energy diet concentration is calculated as follows:

NEDietConc = NEl__Total / Total DMFed

For replacement heifers, the equation is: NEDietConc = NEm_Total / Total DMFed

If NEDietConc < 1, then DivFact = 0.95
Otherwise DivFact = NEDietConc

Because intake decreases immediately prior to calving, an adjustment to intake is made in this period as well.

If DaysPreg < 210 and if DivFact > 0, then

$$DMI\_RH = ((BW^{0.75}) \times (((0.2435 \times NEDietConc) - (0.0466 \times (NEDietConc^2)) - SubFact) / DivFact)) \times TempFact \times CCFact$$

If DaysPreg > 210 and < 259, then an intake adjustment factor (DMIRH_Factor) is used to adjust the intake of heifers. This DMIRH_Factor is multipled by DMI_RH to obtain the predicted DMI for heifers. The DMIRH-_Factor is calculated as follows:

$DMIRH\_Factor = (1 + ((210 - DaysPreg) \times 0.0025))$ if DaysPreg > 210 and < 259
Otherwise $DMIRH\_Factor = 1$

If DaysPreg > 259, then $DMI\_RH = ((1.71 - (0.69e^{(0.35 \times DaysPreg - 280)}))) / 100 \times BW$

SUPPLY CALCULATIONS

Energy

The percent concentrate in the ration is calculated based on the amounts of feeds designated as "Concentrate" that are fed.

$$PercentConc = (ConcSum / TotalDMFed) \times 100$$

For feeds that are not classified as Vitamin/Mineral supplements, TDN at 1X maintenance (TDN_{1x}) and at the actual increment above maintenance is calculated.

$TDN_X = (Feed_X.TDN / 100) \times (DMFed \times 1000)$
$TDN\_Act_X = (Feed_X.TDN\_Act_X / 100) \times (DMFed \times 1000)$

The following calculations are used to determine the energy value of all feeds that are not classified as Calf Feeds or as Vitamins/Minerals. A different set of calculations is used to calculate the energy value of the milk-based calf feeds, and vitamin and mineral supplements are assumed not to contain energy.

Non-fiber Carbohydrate (NFC) amounts and digestibility

It is assumed that non-fiber carbohydrate digestibility, $NFCDigest = 0.98$
The total digestible NFC $= tdNFC = NFCDigest \times (100 - NDF - CP - Fat - Ash + NDFIP) \times PAF$

Where NFCDigestibility = non-fiber carbohydrate digestibility, NDF = neutral detergent fiber, CP = crude protein, Fat = Fat, NDFIP = neutral detergent insoluble protein, and PAF = processing adjustment factor.

The tdNFC is calculated for each feed and the amounts from the individual ration components are added together.

Crude Protein Contribution to Energy

The contribution of protein to the energy supply is computed in the next set of calculations. Different routines are used to calculate protein digestibility depending on how the feed is classified using the energy equation class (EnergyEqClass) that divides feeds into forages, concentrates, or feeds of animal origin also is used.

Protein digestibility of forages is calculated with the following equation:

$$tdCP = Exp((-1.2 \times (ADFIP / CP))) \times CP$$

Where tdCP = total digestible Crude Protein, ADFIP = Acid detergent insoluble protein, and CP = crude protein.

Below is the equation to calculate protein digestibility of feeds (tdCP) containing proteins from animal sources:

$$tdCP = (CPDigest \times CP)$$

For all other classes of feeds, $tdCP = (1 - (0.4 \times (ADFIP / CP))) \times CP$

Contribution of Fat to the Energy Supply

If Fat < 1, then $tdFat = 0$
Otherwise, $tdFat = (Fat - 1) \times 2.25$
If Category = Fat and EnergyEqClass = Fatty Acid,
$TDN = Fat \times FatDigest \times 2.25$
$DE = 0.094 \times FatDigest \times Fat$
If Category = Fat and EnergyEqClass = Fat,
$TDN = 10 + ((Fat - 10) \times FatDigest \times 2.25)$
$DE = (FatDigest \times (Fat - 10) \times 0.094) + 0.43$

TDN Calculations

Adjustments are made based on feed type in the calculations of TDN. TDN and DE are computed with the following equations if the feed is an Animal Protein:

$$TDN = (CPDigest \times CP) + ((Fat - 1) \times 2.25) + ((NFCDigest \times (100 - CP - Ash - Fat)) - 7)$$
$$DE = (tdNFC \times 0.042) + (tdCP \times 0.056) + (0.094 \times (tdFat / 2.25)) - 0.3$$

For feeds that are not Animal Proteins or Fats and that do contain some NDF (forages, many by-products, concentrates), the following equations are used:

$TDN = tdNFC + tdCP + tdFat + dNDF - 7$
$DE = (tdNFC \times 0.042) + (dNDF \times 0.042) + (tdCP \times 0.056) + (0.094 \times (tdFat /2.25)) - 0.3$

The equation below is used for feeds that do not contain NDF, that are not primarily fat and that are not derived from animals (molasses, for example):

TDN = ((0.98 × PAF) × (100 − CP − Fat − Ash)) + (CP × (1 − (0.4 × (ADFIP / CP)))) + ((2.25 × (Fat − 1) − 7))

DE = (0.98 × PAF) × (0.042 × (100 − CP − Fat − Ash)) + (CP × (0.056 × (1 − (0.4 × (ADFIP / CP))))) + (0.094 × (Fat − 1)) − 0.3

The equations for feeds with fat and ash are:

TDN = ((0.98 × PAF) × (100 − Fat − Ash)) + ((2.25 × (Fat − 1) − 7))

DE = (0.98 × PAF) × (0.042 × (100 − Fat − Ash)) + (0.094 × (Fat − 1)) − 0.3

No energy values are calculated for Vitamins or Minerals.

Energy Calculations and Conversions

For animals other than young calves, the ratio of total dry matter intake to intake used to meet the maintenance requirement (DMI_to_DMIMaint) is calculated with the following equations.

For replacement heifers

DMI_to_DMIMaint = TotalTDN / (0.035 × ($SBW^{0.75}$))
Where DMI to DMIMaint is the amount of intake needed to meet the maintenance requirement, TotalTDN = Total dietary TDN, and SBW = shrunk body weight.

For lactating and mature cows

DMI_to_DMIMaint = TotalTDN / (0.035 × ($BW^{0.75}$))

For young calves

DMI_to_DMIMaint = TotalTDN / (0.035 × ($CalfBW^{0.75}$))

Fat Adjustment

After the total amount of fat in the diet has been determined (code not shown), it is necessary to make an adjustment to the TDN value if the diet contains more than 3 percent fat. Fat digestibility is calculated differently for feeds classified as fatty acids than for other fats. The equations below show how fat digestibility is calculated for 1) fat supplements classified as fats, 2) fat supplements classified as fatty acids, and 3) for other feeds:

1). DigestibleFat = 10 + ((Fat − 10) × FatDigest)
2). DigestibleFat = Fat × FatDigest
3). DigestibleFat = Fat − 1

If (Fat_Total / TotalRegDMFed) > 0.03 Then
Adj_TDN = TDNConc − (((TotalFat) − 3) × (TotalDigestibleFat / TotalFat) × 2.25)
TDNConc = Adj_TDN / ((100 − (TotalFat − 3)) / 100)

Discount Variable

This variable is used to discount TDN to account for depressed digestibility of feeds above maintenance levels. It used to calculate energy availability for all classes of animals except young calves.

If a feed is not a milk-based calf feed and contains energy, then
DiscountVariable = ((0.18 × TDNConc) − 10.3) × (DMI_to_DMIMaint − 1)
Where DiscountVariable = Factor used to discount TDN, TDNConc = TDN concentration in the ration, and DMI_to_DMIMaint is the amount of the specified ration needed to meet the maintenance requirement.

The discount variable cannot be < 0 and, if the TDN of a feed is < 60, then the DiscountVariable = 1. Otherwise Discount = (TDNConc − DiscountVariable)/ TDNConc

For feeds other than milk-based calf feeds and if TDNConc > 0, then
TDN_ActX = TDN × Discount

Different discounts are applied depending on the fat content of the ration. These discounts apply to all classes of animals except young calves.

If Fat ≥ 3 and if the animal is a dry cow or a lactating cow, then
MEng = (1.01 × DiscDE) − 0.45 + (0.0046 × (Fat − 3))

If Fat ≥ 3 and the animal is a heifer, then
MEng = 0.82 × DE

Net energy for lactation for feeds having more than 3% fat is computed.
NEl = (0.703 × MEng) − 0.19 + ((((0.097 × MEng) + 0.19) / 97) × (Fat − 3))

If the feeds have < 3% fat, the equation to compute ME for lactating and dry cows is
MEng = (1.01 × DiscDE) − 0.45

The equation for heifers is
MEng = 0.82 × DE

The equation to compute the NEl of low fat feeds is:

NEl = (0.703 × MEng) − 0.19

For feeds that are not classified as fats

MEforNEg = 0.82 × DE
NEg = 1.42 × MEforNEg − 0.174 × $MEforNEg^2$ + 0.0122 × $MEforNEg^3$ − 1.65
NEm = 1.37 × MEforNEg − 0.138 × $MEforNEg^2$ + 0.0105 × $MEforNEg^3$ − 1.12

Otherwise,
MEng = DiscDE
NEl = 0.8 × DiscDE
NEm = 0.8 × MEng
NEg = 0.55 × MEng

Computation of the total energy values for the diet.

MEng_Total = TotalMEConc × TotalRegDMFed
NEl_Total = TotalNElConc × TotalRegDMFed
NEg_Total = TotalNEgConc × TotalRegDMFed
NEm_Total = TotalNEmConc × TotalRegDMFed

If AnimalType is not "Replacement Heifer", then
NEDietConc = NE_Total / TotalRegDMFed
If AnimalType is "Replacement Heifer", then
NEDietConc = NEm_ Total / TotalRegDMFed

Protein Supply and Requirements

Microbial yield (MCP_Total) is calculated as a percentage of discounted TDN (TDN_Act_Total):

MCP_Total = 0.13 × TDN_Act_Total

The following equation is used to calculate the amount of crude protein from each feed.

CP_X = ($Feed_X$CP / 100) × (DMFed × 1000)

To calculate the site of digestion of protein, both passage (kp) and digestion (kd) rates are needed. Separate passage equations are used for concentrates, dry forages, and wet forages.

Concentrate

Kp = 2.904 + (1.375 × BW_DMI) − (0.02 × PercentConc)

Dry Forage

Kp = 3.362 + (0.479 × BW_DMI) − (0.017 × $Feed_X$NDF) − (0.007 × PercentConc)

Wet Forage

Kp = 3.054 + (0.614 × BW_DMI)

The amount of RDP in a specific feed is calculated using the following equation. It is assumed that all of Protein A is ruminally available and that none of Protein C is degraded in the rumen. Thus, only Protein B is affected by digestion and passage rates.

If ($Feed_X$.Kd + Kp) > 0 Then
RDP_X = (($Feed_X$.Kd / ($Feed_X$.Kd + Kp)) × (((($Feed_X$.PrtB / 100) ×($Feed_X$CP /100)) × $Feed_X$DMFed))) + ((($Feed_X$PrtA / 100) × ($Feed_X$CP / 100)) × $Feed_X$DMFed)
Otherwise, RDP_X = 0

The amount of ruminally-undegraded protein is obtained by subtraction:

RUP_X = (CP_X − (RDP_X × 1000)) / 1000

If RUP_Total > 0, then DietRUPDigest = TotalDigestedRUP / RUP_Total
Otherwise, DietRUPDigest = 0.

The requirement for RDP is calculated in the following equation.

RDPReq = 0.15294 × TDN_Act_Total

RDPSup = TotalDMFed × 1000 × DietCP × CP_RDP

RDPBal = RDPSup − RDPReq

RUPSup = CP_Total − RDPSup

RUPReq = TotalCPReq − (MPBact + MPEndo))/ DietRUPDigest

The efficiency of microbial crude protein synthesis cannot exceed 0.85.

If MCP_Total > (0.85 × (RDP_Total × 1000)), then

MCP_Total = (0.85 × (RDP_Total × 1000))

CP required = RUPreq + RDPReq

MPBalance = (((MPFeed × 1000) + MPBact + MPEndo) − (MPMaint + MPPreg + MPLact + MPGrowth))

Amino Acids

The amino acid supply is calculated using the following equation with arginine (Arg) as an example. The structure of this equation is similar for all of the amino acids that are considered in the model.

TArg = TArg + (((DMFed / TotalDMFed) × (CP / 100) × ((RUP_X × 1000) / CP_X) × (Arg / 100) × TotalDMFed) × 1000)

Where TArg = Total arginine, DMFed = quantity of feed X fed, TotalDMFed = Total dry matter fed, CP = % Crude Protein, RUP_X = RUP in feed X, CP_X = crude protein in feed X.

The next step is to calculate the total digestible supply of each amino acid. Below is the equation for Dig_TArg. The equations for the other amino acids have the same format.

Dig_TArg = Dig_TArg + (((DMFed / TotalDMFed) × (CP / 100) × ((RUP_X × 1000) / CP_X) × ($Feed_X$RUPDigest / 100) × (Arg / 100) × TotalDMFed) × 1000)

Where Dig_TArg = Total digestible arginine,
RUPDigest = RUP digestibility of feed X

The total essential amino acid supply before the contribution of the microbial protein has been added (EAATotalBeforeMP) is calculated.

$$EAATotalBeforeMP = (TArg + THis + TIle + TLeu + TLys + TMet + TPhe + TThr + TTrp + TVal)$$

The variables x1 and x2 are used in the following sets of calculations of the total amount of each amino acid supplied. The equations to calculate the total amounts of each amino acid follow. In all equations, it is assumed that:

If EAATotalBeforeMP > 0 then
x1 = ((TArg (or other amino acid) / EAATotalBeforeMPP × 100)
Otherwise x1 = 0

If ((RUP_Total × 1000) + EndCP + MCP_Total) > 0 then
x2 = ((RUP_Total × 1000) / ((RUP_Total × 1000) + EndCP + MCP_Total)) × 100
Otherwise, x2 = 0

TotalArg = 7.31 + (0.251 × x1)
TotalHis = 2.07 + (0.393 × x1) + (0.0122 × x2)
TotalIle = 7.59 + (0.391 × x1) − (0.0123 × x2)
TotalLeu = 8.53 + (0.41 × x1) + (0.0746 × x2)
TotalLys = 13.66 + (0.3276 × x1) − (0.07497 × x2)
TotalMet = 2.9 + (0.391 × x1) − (0.00742 × x2)
TotalPhe = 7.32 + (0.244 × x1) + (0.029 × x2)
TotalThr = 7.55 + (0.45 × x1) − (0.0212 × x2)
TotalVal = 8.68 + (0.314 × x1)

The total essential amino acid supply is calculated below:

TotalEAA = 30.9 + (0.863 × EAATotalBeforeMP) + (0.433 × MCP_Total)

Total flows of RUP of specific amino acids are calculated below:

TotalRUPArgFlow = 0.863 × TArg
TotalRUPHisFlow = 0.863 × THis
TotalRUPIleFlow = 0.863 × TIle
TotalRUPLeuFlow = 0.863 × TLeu
TotalRUPLysFlow = 0.863 × TLys
TotalRUPMetFlow = 0.863 × TMet
TotalRUPPheFlow = 0.863 × TPhe
TotalRUPThrFlow = 0.863 × TThr
TotalRUPTrpFlow = 0.863 × TTrp
TotalRUPValFlow = 0.863 × TVal

Duodenal flow (g/day) is calculated using an equation of the form below for each amino acid. Arginine is given as an example.

Arg_Flow = (TotalArg / 100) × TotalEAA

The contribution of microbial crude protein and endogenous protein to the amino acid supply is calculated as follows. The form of this equation is similar for all amino acids.

TotalMCPEndArgFlow = Arg_Flow − TotalRUPArgFlow

The next step is to calculate the supply of each amino acid in RUP that is digestible. The form of the equation for each amino acid is similar to that given for arginine below:

If TArg > 0, then dTotalRUPArg = TotalRUPArgFlow × (Dig_TArg / TArg)
Otherwise, dTotalRUPArg = 0

The amount of a specific amino acid that is digestible and is of microbial or endogenous origin then is calculated. Arginine is used as the example but similar calculations are made for all amino acids.

dTotalMCPEndArg = 0.8 × TotalMCPEndArgFlow

The flow of digestible arginine, or other amino acids) then is calculated.

Dig_Arg_Flow = dTotalRUPArg + dTotalMCPEndArg

The protein in the duodenum must be converted from crude protein to a metabolizable protein basis. Microbial crude protein is converted to metabolizable protein with an efficiency of 0.64:

MPBact = 0.64 × MCP_Total
MPFeed = TotalDigestedRUP
MPEndo = 0.4 × EndCP

The next computation is to determine the percent of a specific amino acid of metabolizable protein. The arginine equation is similar to those of the other amino acids.

If (MPBact + (MPFeed × 1000) + MPEndo) > 0, then
ArgPctMP = 100 × (Dig_Arg_Flow / (MPBact + (MPFeed × 1000) + MPEndo))
Otherwise, ArgPctMP = 0

Minerals

Two sets of equations for the calculation of the supply of minerals are presented here for all classes of animals except for young calves. Both the amount of mineral supplied and the amount of the mineral that is absorbable are calculated. The first equations are for the macrominerals using calcium as an example. In the mineral equations, d is used for mineral supplements instead of x to denote the feed.

Supplied = Supplied + ((Feed$_d$Ca / 100) × Feed$_d$DMFed)
Absorbable = Absorbable + (((Feed$_d$Ca / 100) × Feed$_d$DMFed) × (Feed$_d$CaBio))

The second set of equations represents those used for trace minerals using zinc as an example.

Supplied = Supplied + (Feed$_d$Zn × Feed$_d$DMFed)
Absorbable = Absorbable + ((Feed$_d$Zn × Feed$_d$DMFed) × (Feed$_d$ZnBio))

Ration density (RD) = Supplied / TotalDMFed

YOUNG CALF SUB-MODEL

Both the requirements and supply portions of the young calf sub-model are in this section.

Requirements

ENERGY REQUIREMENTS

For young calves, the efficiencies with which feeds are used for maintenance and gain, Km and Kg, for milk-based and other feeds are fixed.

Milk-fed
CalfKm = 0.8 for milk-based feeds
CalfKg = 0.69 for milk-based feeds

Fed Milk and Starter
CalfKm = 0.75 if the feed is not milk-based
CalfKg = 0.57 if the feed is not milk-based

The equation to calculate the basal maintenance requirement of a calf without stress is:

NEmCalf = 0.086 × (CalfBW$^{0.75}$)

The next step is to calculate the CalfKm and CalfKg for the proposed ration using the fixed efficiencies of conversion of ME to NEm and NEg.

If the feed is classified as a calf feed (milk-based) and if cMEng ≠ 0, Then
CalfKm = CalfKm + (0.86 × (Feed$_X$DMFed × Feed$_X$cMEng))
CalfKg = CalfKg + (0.69 × (Feed$_X$DMFed × Feed$_X$cMEng))

An adjustment is made to ensure that no energy values are computed from mineral supplements:

NonMineralFeeds = NonMineralFeeds + (Feed$_X$DMFed × Feed$_X$cMEng)

For all other classes of feeds if MEng ≠ 0
CalfKm = CalfKm + (0.75 × (Feed$_X$DMFed × Feed$_X$MEng))
CalfKg = CalfKg + (0.57 × (Feed$_X$DMFed × Feed$_X$MEng))
NonMineralFeeds = NonMineralFeeds + (Feed$_X$DMFed × Feed$_X$MEng)

If NonMineralFeeds > 0 Then
CalfKm = CalfKm / NonMineralFeeds
CalfKg = CalfKg / NonMineralFeeds

LOWER TEMPERATURE ADJUSTMENTS TO CALF MAINTENANCE REQUIREMENT

The maintenance requirement for young calves is adjusted to account for cold stress as follows:

Temperature (°C)	*Calves > 2 months*	*Temperature (°C)*	*Calves < 2 months*
> 5	0	> 15	0
0 to 5	0.13	10 to 15	0.13
−5 to 0	0.27	5 to 10	0.27
−10 to −5	0.40	0 to 5	0.40
−15 to −10	0.54	−5 to 0	0.54
−20 to −15	0.68	−10 to −5	0.68
−25 to −20	0.81	−15 to −10	0.86
−30 to −25	0.94	−20 to −15	0.94
<−30	1.07	−25 to −20	1.08
		−25 to −30	1.21
		<−30	1.34

The resulting equation for the maintenance requirement of young calves with the temperature adjustment is:

NEmCalf = (NEmCalf × (1+TempFactor))

The next step is to recalculate ME required for maintenance with the NEm that has been adjusted for temperature effects.

If CalfKm ≠ 0 Then
MEMaint = NEmCalf / CalfKm
Otherwise MEMaint = 0

The following equation is used to calculate the amount of intake devoted to meeting the maintenance requirement:

If DietNEmCalf ≠ 0 Then
DMIForNEmCalf = NEmCalf / DietNEmCalf
Else DMIForNEmCalf = 0

A similar calculation is used to calculate the dry matter intake available for growth and the net energy available for growth:

DMIForGrowth = (TotalDMFed − DMIForNEmCalf)

NEFGCalf = DMIForGrowth × DietNEmCalf

If CalfKg ≠ 0 Then MEFGCalf = NEFGCalf / CalfKg
Else MEFGCalf = 0

If NEFGCalf > 0 Then
EnergyADGCalf = Exp((0.8333 × (Log((1.19 × NEFGCalf) / (0.69 × (CalfBW$^{0.355}$))))))

CALF PROTEIN REQUIREMENTS

Calf protein requirements are computed with the following equation:

ProteinReqCalf = CalfADG × 0.188 (30 g N/kg gain = 187.5 g Net Protein / kg gain)

Total apparently digested protein (TotalADP) is calculated as follows where 0.93 and 0.75 are the assumed digestibilities of milk-based feeds and starter feeds respectively:

TotalADP + ((TotalMilkCP × 0.93) + (TotalStarterCP× 0.75)) × 1000

The ratio of ADP to CP is calculated as follows:

ADP_to_CP = TotalADP / ((TotalMilkCP + TotalStarterCP) × 1000)

Calf Protein Maintenance Requirements

EUN = Endogenous urinary N losses = 0.2 × (CalfBW$^{0.75}$)
MFN = Metabolic fecal N = (MilkDMI × 1.9) + (StarterDMI × 3.3))
BV = Biological value = (0.8 × (TotalMilkCP / TotalCP)) + (0.7 × (TotalStarterCP / TotalCP))

ADPmaint = 6.25 × (((1 / BV) × (EUN + MFN)) − MFN)

CPmCalf = ADPMaint / ADP_to_CP if ADP_to_CP>0

ADPgrowth = (ProteinReqCalf × 1000) / BV

ADPAllowGain = ((TotalADP − ADPmaint) × BV) / 0.188

CALF MINERAL REQUIREMENTS

A factorial approach is not used to estimate mineral requirements for young calves. The requirements for calves are based on the amounts of milk-based feed, starter, and grower that are offered. It is assumed that the values presented in Table 10 = 6 for milk replacers, calf starter, and grower meet the mineral requirements of the young calf. Table 16-2 indicates the desired ration densities for each of the three categories of feeds (milk-based calf feeds, calf starter, and calf grower). The densities for calf grower are used as the standard for all feeds in the Feed Library except milk-based feeds and calf starter.

To calculate the desired concentrations of each mineral, the following equation is used:

TABLE 16-2 Ration Densities of Required Minerals for Three Categories of Feeds for Calves

Mineral	Milk-Replacer	Starter	Grower
Calcium	1.0	0.7	0.6
Phosphorus	0.7	0.45	0.4
Magnesium	0.07	0.1	0.1
Sodium	0.4	0.15	0.14
Potassium	0.65	0.65	0.65
Chlorine	0.25	0.2	0.2
Sulfur	0.29	0.2	0.2
Iron	100	50	50
Manganese	40	40	40
Zinc	40	40	40
Copper	10	10	10
Iodine	0.5	0.25	0.25
Cobalt	0.11	0.1	0.1
Selenium	0.3	0.3	0.3
Vitamin A	9	4	4
Vitamin D	0.6	0.6	0.6
Vitamin E	50	25	25

If TotalDMFed>0 Then
RDReq = ((MilkFeeds × m) + (CalfStarter × n) + (RegFeeds × o)) / TotalDMFed
Where m = concentration of mineral X in MilkFeeds, n = concentration of mineral X in calf starter, and o = concentration of mineral X in regular feeds.

Calf Supply and Diet Evaluation

In the calf submodel, milk-based feeds are in a separate category in the feed library because the energy values for these feeds are calculated differently from feeds that may be used as starter feeds. Any feed in the library except for the milk-based calf feeds may be used as a starter feed. The information for the starter feeds is taken from the appropriate category of the main feed library.

Calf Energy and Protein

The energy calculations to obtain TDN, DE, and ME are included in the main energy computation section. To get the appropriate energy and protein values, the totals from the calf feeds are calculated and then the totals from the other feeds are obtained. Finally, the contributions from the two groups of feeds are added together.

In the following sets of calculations, it is assumed that the initial value of the variable is 0.

TotalNEm = TotalNEm + (DMFed × cNEm)
TotalNEg = TotalNEg + (DMFed × cNEg)
TotalME = TotalME + (DMFed × cMEng)
TotalCP = TotalCP + (DMFed × (cCP / 100))
TotalDCP = TotalDCP + (DMFed × (cDCP / 100))

If Category = "Calf Feed − Milk" Then
MilkDMI = MilkDMI + DMFed
MilkME = MilkME + (DMFed × cMEng)

TotalMilkADP = TotalMilkADP + (DMFed × (cDCP / 100))
TotalMilkCP = TotalMilkCP + (DMFed × (cCP / 100))

Otherwise

StarterDMI = StarterDMI + DMFed
StarterME = StarterME + (DMFed × cMEng)
TotalStarterADP = TotalStarterADP + (DMFed × (cDCP / 100))
TotalStarterCP = TotalStarterCP + (DMFed × (cCP / 100))

To convert starter/regular feeds from CP to cDCP:

$$cDCP = 0.75 \times CP$$

Here are the equations to obtain the total values:

TotalNEm = TotalNEm + NEm_Total
TotalNEg = TotalNEg + NEg_Total
TotalME = TotalME + MEng_Total

DietNEmCalf = TotalNEm / TotalDMFed
DietNEgCalf = TotalNEg / TotalDMFed
DietMECalf = TotalME / TotalDMFed

Mature Weights

Mature weight is used both to estimate the target growth rates of replacement heifers and to predict calf birth weights. The user has the option of entering the mature weight based on herd observations or of using default values.

The default weights for various breeds are:

Aryshire	545 kg
Brown Swiss	682 kg
Guernsey	500 kg
Holstein	682 kg
Jersey	454 kg
Milking Shorthorn	568 kg

Calf birth weight is calculated from mature weight using the following equation:

$$CBW\_From\_MW = 0.06275 \times MW$$

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