The Cornell Value Discovery System Model

CVDS version 1.0
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Model Documentation

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INTRODUCTION

Individual cattle management systems (ICMS) are being developed in the beef industry to improve profitability, minimize excess fat produced, increase consistency of product, and to identify and reward individual owners for superior performance in the feedlot. In the U.S., Strategic Alliances between cow-calf, feedlot and packer segments of the industry are being established to accomplish this goal. Integrated production and marketing systems are being developed that can make Strategic Alliances work. Their objective is to market animals at their optimum economic endpoint, considering live and carcass incremental cost of gain and carcass prices for various grades, and avoiding discounts.

Cattle are marketed as individuals when at their optimum carcass composition, which typically requires having cattle with different owners in the same pen. This requires allocating and billing feed fed to a pen to the individual animals in the pen. To make individual animal management work, the method used to allocate the feed consumed by animals from different owners that share the same pen must accurately determine cost of gain of each animal in a pen.

There are three critical control points in launching a successful individual cattle management system (ICMS) for growing beef cattle:

1. Predicting optimum finished weight, incremental cost of gain and days to finish to optimize profits and marketing decisions while marketing within the window of acceptable carcass weights and composition

2. Predicting carcass composition and fat thickness (backfat) deposition rate during growth to avoid discounts for under or over weight carcasses and excess backfat

3. Allocating feed fed to pens to individual animals for the purpose of sorting of individuals into pens by days to reach target body composition and maximum individual profitability, requiring mixed ownership of individuals in pens, determination of individual animal cost of gain for the purposes of billing feed and predicting incremental cost of gain, and providing information that can be used to select for feed efficiency and profitability

Additionally, selection procedures for feed efficiency are needed that result in identifying animals with improved efficiency of use of absorbed (metabolizable) energy for maintenance and growth without altering body weight at the target chemical composition. However, it is not practical to determine feed metabolizable and net energy values for maintenance and growth for individual animals on farms. Therefore indirect measures must be used to estimate energetic efficiency.

The CVDS model computes the average expected feed required for the observed daily gain and body weight, using equations developed from experimental data to predict average expected maintenance and growth requirements for the observed body weight and daily gain, and net energy values derived from feeds (Guiroy et al., 2001; Perry and Fox, 1997). Individually fed animals that consume less than the average across a group being evaluated for feed efficiency would have a higher efficiency of use of the feed consumed and/or a lower maintenance requirement; those with a higher intake than expected would likely have a lower efficiency of use of the feed consumed and/or a higher maintenance requirement.

Residual feed intake (RFI) has been proposed as a procedure to estimate this difference by subtracting observed dry matter intake (DMI) of an individual from DMI predicted by an equation developed from the relationship between DMI, ADG and metabolic mean body weight across individually fed contemporaries (Archer et al., 1999; Carstens et al., 2002). In most progeny tests, however feed efficiency for individual animals must be estimated from information available for animals fed in pens under typical feedlot conditions. In this case, a ratio of expected feed required to the observed gain is the only practical measure of feed efficiency.

Because the CVDS model feed required procedure accounts for differences in the effect of body weight and composition of gain on energy requirements, animals with a lower feed to gain ratio may have had a greater intake over maintenance, a greater efficiency of use of the energy consumed, or a combination of both.

Accurate determination of feed required for the observed growth to the target body composition requires accounting for factors affecting animal requirements and feed energy values for maintenance and growth.

MODEL DEVELOPMENT

The growth model predicts growth rate and weight of each individual animal in a pen on a daily basis to predict cost of gain, breakeven sale price, and days to finish each day during growth. In predicting daily gain and accumulated weight each day, this model must account for the following:

1. net energy values for ration ingredients being fed in each unique production situation
2. dry matter intake on a daily basis
3. the effect of environment in each production situation on maintenance requirement and feed available for growth
4. the effect of stage of growth and rate of gain on net energy requirement for growth
5. Live and carcass weights and body composition at various carcass quality and yield grades
6. the effect of implant and feeding program on weight at various carcass quality and yield grades

1. Determining Ration Energy Values

Accurate predictions of DMI and NEg are highly dependent on having feed net energy values that accurately represent the feeds being fed. Further, energy allowable performance must be supported by dietary protein allowable growth.

1.1. Description of the models

The level 1 of the NRC (2000; NRC1) uses a fixed tabular total digestible nutrients (TDN) concentration of feeds to predict DE (Mcal/kg) and ME (Mcal/kg). Metabolizable energy is then used to predict dietary concentrations of NEm and NEg (Mcal/kg) using the equations developed by Garrett (1980). Likewise, fixed tabular ruminally degradable protein (RDP) and RUP values are used to predict degraded protein available to meet ruminal fermentation requirements and undegraded feed protein escaping the rumen.

In contrast, the level 2 of the NRC (2000; NRC2) uses feed carbohydrate and protein fractions and their degradation and passage rates to predict TDN and RUP mechanistically, which are based on the Cornell Net Carbohydrate and Protein System (CNCPS) model (Fox et al., 1992; Russell et al., 1992; Sniffen et al., 1992).

A third option would be the use of a summative equation (SumEq) as described by Weiss et al. (1992) and Weiss (1993, 1999). This model provides a system consistent with the level 2 of the NRC (2000) and it is an approach similar to that used by the NRC (2001); both use similar feed composition values to predict TDN.

1.2. Predictions of total digestible nutrients and digestible energy

The equations to predict TDN and RUP for both NRC1 and NRC2 models were described in the NRC (2000) publication; detailed information of the CNCPS model development are available elsewhere (Fox et al., 1992; O'Connor et al., 1993; Russell et al., 1992; Sniffen et al., 1992; Tedeschi et al., 2000). The CNCPS version 4.0 (Fox et al., 2000) was used for all simulations to perform the NRC2 calculations.

The SumEq described by Weiss et al. (1992; Eq. 1) calculates TDN based on true digestibility coefficients for available soluble carbohydrates, proteins, fatty acids, and NDF, and then adjusts for endogenous fecal energy.

$$\begin{aligned} TDN_{1x} &= 0.98 \times (100 - NDFn - CP - Ash - EE + IADFIP) + DCP \times CP + 2.25 \times (EE - 1) + \\ &\quad 0.75 \times (NDFn - Lignin) \times [1 - (Lignin / NDFn)^{2/3}] - 7 \end{aligned} \quad [1]$$

Where EE is ether extract, ADFIP is ADF insoluble protein, IADFIP (indigestible ADFIP) is 0.7×ADFIP for forages or 0.4×ADFIP for concentrates, DCP (digestibility of CP) is exp(-0.012×ADFIP) for forages or 1 – (0.004×ADFIP) for concentrates; NDFn (NDF adjusted for nitrogen) is NDF – NDIP + IADFIP; and NDFIP is NDF insoluble protein. All values are expressed as percentage of the DM, except ADFIP (% CP).

Digestible energy (Mcal/kg) is computed from TDN as shown in Equation 2 for level 1 of the NRC (2000).

$$DE_{NRC1} = TDN \times 4.409 \quad [2]$$

As shown above, DE_{NRC1} is calculated from TDN, assuming a heat of combustion of 4.409 Mcal/kg of TDN, as established by Swift (1957). Weiss (1999) presented a modification of Equation 1 to predict DE directly from the heat of combustion of the digestible fractions of carbohydrate, protein, and fat, as described by Equations 3 to 6.

$$DNFC = 0.98 \times [100 - (NDF - NDFIP) - CP - Ash - EE] \quad [3]$$

$$\begin{aligned} DCP\ (forages) &= CP \times e^{(-0.012 \times ADFIP)} \\ DCP(concentrates) &= CP \times [1 - (0.004 \times ADFIP)] \end{aligned} \quad [4]$$

$$DFAT = 0.9 \times 3 \times (EE - 1) \quad [5]$$

$$DNDF = 0.75 \times \left[(NDF - NDFIP) - Lignin\right] \times \{1 - \left[Lignin/(NDF - NDFIP)\right]^{2/3}\} \quad [6]$$

$$TDN_{1x} = DNFC + DCP + DFAT + DNDF - 7 \quad [7]$$

Where DNFC is digestible nonfiber carbohydrates (% DM), DCP is digestible CP (% DM), DFAT is digestible fat (% DM), and DNDF is digestible NDF (% DM).

The DE_{SumEq} (Mcal/kg) at a maintenance level of DMI is calculated using Equations 3 to 6 multiplied by their respective coefficients for heat of combustion (Eq. 8) as described by Weiss (1999), in which the metabolic fecal DE is assumed to be 0.3 Mcal/kg. Equation 8 is the one adopted by NRC (2001) for all feeds except animal protein and fat supplements.

$$DE_{SumEq} = 0.0415 \times (DNFC + DNDF) + 0.056 \times DCP + 0.094 \times (DFAT/3) - 0.3 \quad [8]$$

where DE_{SumEq} is digestible energy (Mcal/kg).

This approach was compared with the level 2 of the NRC (2000), which predicts the digestible fractions of carbohydrate, protein, and fat. In order to compare with the DE_{SumEq} values, coefficients of heat of combustion were added to the rumen simulation model (level 2). The coefficients shown in Equation 8 were used to calculate the DE_{NRC2} (Mcal/kg) (Eq. 9); the average gross energy of carbohydrate, protein, and fat used in Equation 8 are very similar to those reported by Baldwin (1995, p. 142) (4.15, 5.65, and 9.39 Mcal/kg, respectively).

$$DE_{NRC2} = \frac{4.15 \times (CHO_j - FECHO_j) + 5.65 \times (Prot_j - FEPROT_j) + 9.39 \times (Fat_j - FEFAT_j)}{DMI_j} \quad [9]$$

where DE_{NRC2} is digestible energy (Mcal/kg) calculated by the level 2 of the NRC (2000) using heat of combustion coefficients, CHO_j is the amount of dietary carbohydrate in the j^{th} feed (kg), $FECHO_j$ is the amount of indigested carbohydrate of the j^{th} feed (kg), $Prot_j$ is the amount of dietary protein in the j^{th} feed (kg), $FEPROT_j$ is the amount of indigested protein in the j^{th} feed (kg), Fat_j is the amount of dietary fat in the j^{th} feed (kg), $FEFAT_j$ is the amount of undigested fat in the j^{th} feed (kg), and DMI_j is the DMI of the j^{th} feed (kg).

1.3. Evaluation of the selected models with animal performance data

Because the objective of these systems is to accurately predict animal performance, 105 treatment groups from seven published studies (Abdalla et al., 1988; Ainslie et al., 1993; Boin and Moura, 1977; Danner et al., 1980; Fox and Cook, 1977; Lomas et al., 1982; Wilkerson et al., 1993) were used to evaluate the accuracy of NRC1, NRC2, and SumEq in predicting the ADG of growing/finishing animals (Table 1). These studies were chosen because they provided adequate characterization of animal, environment, and management information required by NRC1 and NRC2, and feed composition information required by NRC2 and SumEq. The treatment groups were divided into two categories: those in which MP allowable ADG were greater than ME allowable ADG to test the prediction of ME allowable ADG, and those in which MP allowable ADG were less than ME allowable ADG to test the prediction of MP allowable ADG. The comparison of MP allowable ADG for NRC1 and SumEq predictions is important because TDN directly dictates the prediction of microbial growth and supply of protein to the host animal (NRC, 2000); therefore, an under- or over-prediction of TDN will affect prediction of MP available.

Table 1. Summary of the studies used to compare observed and predicted animal performance using tabular TDN and predicted TDN by mechanistic models [a]

References[b]	N[b]	SBW[c], kg	DMI, kg/d	CP, %	ADG, kg/d
1	6	251 ± 5.2	5.4 ± 0.4	12.4 ± 0.4	0.78 ± 0.06
2	4	340 ± 2.6	7.9 ± 0.1	11.5 ± 0.4	1.11 ± 0.02
3	3	235 ± 2.3	6.1 ± 0.2	11.2 ± 0.3	0.91 ± 0.06
4	10	334 ± 9.2	7.3 ± 0.3	10.6 ± 0.6	0.90 ± 0.08
5	12	188 ± 21.2	4.6 ± 0.4	11.9 ± 1.1	0.69 ± 0.14
6	25	162 ± 6.8	4.8 ± 0.2	18.0 ± 1.3	1.08 ± 0.04
7	45	114 ± 1.4	5.5 ± 0.1	11.1 ± 0.1	0.22 ± 0.02

[a] Values are mean ± standard error.
[b] References: (1) Boin and Moura (1977), (2) Fox and Cook (1977), (3) Danner et al. (1980), (4) Lomas et al. (1982), (5) Abdalla et al. (1988), (6) Ainslie et al. (1993), and (7) Wilkerson et al. (1993). The N in the second column indicates the number of treatment groups in each study that were used.
[c] SBW is average shrunk body weight.

The regression analyses of observed and predicted ADG are shown in Table 2. Metabolizable energy was predicted by the NRC2 model to be first limiting in 19 treatment groups. Across these groups, the observed ADG varied from 0.8 to 1.44 kg/d. When ME was first limiting, the ADG predicted by the NRC2 model accounted for more of the variation (80%) than did SumEq or NRC1 models (73 and 61%, respectively). Metabolizable energy allowable ADG predicted with the NRC1 model gave an overprediction bias of 11.4%, but the bias was less than 3% when predicted either with the NRC2 or the SumEq models. The MSE were similar in all predictions, but the NRC2 model had the highest accuracy (lowest RMSPE).

Metabolizable protein was predicted by the NRC2 model to be first limiting in 28 treatment groups. Across these groups, the observed ADG ranged from 0.12 to 1.36 kg/d. The ADG predicted by the NRC2 model accounted for more of the variation (92%) than did SumEq or NRC1 models (79 and 80%, respectively). Metabolizable protein-allowable ADG predicted with the NRC1 model gave an overprediction bias of 4.3%, whereas the bias was less than 2% when predicted either with the NRC2 or SumEq models. Similar to the ME first limiting analysis, the NRC2 model had the highest accuracy (lowest RMSPE).

The evaluation of animal performance fed near a maintenance level of intake is shown in Table 3. The ADG predicted by the NRC1 or SumEq models was different from the observed ADG ($P < 0.05$), but the NRC2 model prediction was not different from the observed values (P > 0.25). The differences in RMSPE were negligible, but the SumEq showed higher accuracy than NRC1 and NRC2.

Table 2. Evaluation of the tabular TDN (NRC1) and predicted TDN by a summative equation (SumEq) and by the NRC (2000) model level 2 (NRC2) to estimate ADG (kg/d) when ME or MP are first limiting [a]

	ADG, kg/d			Regression statistics[b]			RMSPE
	Min.	Mean ± SE	Max.	r^2	MSE	bias,%	
ME first limiting (n = 19)							
Observed	0.80	1.11 ± 0.04	1.44	-	-	-	-
NRC (2000) level 1	0.73	1.25 ± 0.06	1.78	0.61	0.01	-11.4*	0.23
SumEq	0.74	1.13 ± 0.06	1.62	0.73	0.01	-2.2	0.14
NRC (2000) level 2	0.79	1.10 ± 0.05	1.48	0.80	0.01	0.4	0.10
MP first limiting (n = 28)							
Observed	0.12	0.78 ± 0.07	1.36	-	-	-	-
NRC (2000) level 1	0.11	0.81 ± 0.09	1.78	0.80	0.03	-4.3	0.21
SumEq	0.13	0.78 ± 0.09	1.73	0.79	0.03	-0.5	0.22
NRC (2000) level 2	0.12	0.77 ± 0.07	1.45	0.92	0.01	1.9	0.11

[a] Data were obtained from Boin and Moura (1977), Fox and Cook (1977), Danner et al. (1980), Lomas et al. (1982), Abdalla et al. (1988), and Ainslie et al. (1993). Data from Wilkerson et al. (1993) was included in the MP sub-dataset evaluation.

[b] Observed values (Y) were regressed on predicted ADG (X) using tabular TDN of NRC (2000) model level 1 (NRC1) or TDN predicted by a summative equation (Weiss et al., 1992) or by the NRC (2000) model level 2 (NRC2). A positive bias means that Y values (observed) are greater than X values. MSE is the mean square error from the regular regression, SE is the standard error, and RMSPE is the root of the mean square prediction error. Asterisks indicate statistical difference from zero using the *t*-test (unequal variance) at α=0.01 (**), α=0.05 (*), or no difference (no asterisk).

These evaluations suggested that predicting TDN from actual feed analysis with the SumEq or NRC2 models may be more accurate in predicting animal performance than the use of the fixed tabular values (NRC1). The high variation and low accuracy using the NRC1 model is likely to be related to the fixed TDN values that may not reflect differences in energy values of the reported chemical composition of those feeds.

1.4. Evaluation of TDN and RUP values predicted by the selected models

Predicting feed energy. The TDN at the intake to meet the maintenance requirement for NE_m (TDN_{1x}) was computed with the SumEq and the NRC2 models for all feeds in the NRC (2000) feed library (excluding minerals). To compute TDN_{1x} for the NRC2 simulation, a simple balanced diet was formulated with DMI fixed at the maintenance requirement for NE_m. Then, a small amount (100 g) of each feed in the NRC (2000) model feed library was individually added to this diet to obtain a TDN_{1x}. Dry matter intake was then increased as needed to obtain TDN at two levels of intake (2x and 3x) above the maintenance requirement for NE_m. The chemical composition values used for the NRC1, NRC2, and SumEq TDN and RUP values were obtained from the NRC (2000) model feed library.

Table 3. Evaluation of the tabular TDN (NRC1) and predicted TDN by a summative equation (SumEq) and by the NRC (2000) model level 2 (NRC2) in estimating ADG (kg/d) for steers fed at near maintenance level of intake [a]

	Average Daily Gain, kg/d			
	Observed	NRC1	SumEq	NRC2
Animals	18	18	18	18
Mean	0.30	0.19	0.23	0.25
SE	0.02	0.02	0.02	0.04
Difference[b]	-	0.11**	0.07*	0.05
RMSPE[c]	-	0.15	0.12	0.16

[a] Treatments from the Wilkerson et al. (1993) dataset in which ME was the first limiting nutrient. SE is standard error. Those treatments with no weight gain were excluded. A body condition score 3 was used to account for the effects of a low plane of nutrition, based on NRC (2000).
[b] Difference between observed ADG and either ADG predicted by tabular TDN of NRC (2000) model level 1 (NRC1) or TDN predicted by a summative equation (Weiss et al., 1992) or by the NRC (2000) model level 2 (NRC2). Asterisks indicate statistical difference from zero using the *t*-test (unequal variance) at α=0.01 (**), α=0.05 (*), or no difference (no asterisk).
[c] RMSPE is the root of the mean square prediction error.

Discounting feed energy. The NRC1 TDN values represent a maintenance level of intake (TDN_{1x}) whereas NRC2 calculates a TDN discounted for level of feed intake effects on depression in digestibility as described by Sniffen et al. (1992). Therefore, for cattle consuming feed in amounts exceeding their maintenance requirement, NRC1 should overpredict feed energy values compared to NRC2. Similarly, the SumEq described by Weiss et al. (1992) predicts TDN for animals at maintenance level of intake. Therefore, equations are needed to discount NRC1 and SumEq predictions to compute feed ME, NEm, and NEg concentrations that are used in diet formulation for cattle consuming feed above maintenance. This discount is necessary because the TDN derived from a feed decreases with level of intake (AFRC, 1993; NRC, 2000, 2001; Van Soest, 1994). The TDN predicted by the NRC2 at 1x, 2x, and 3x levels of DMI computed for all feeds in the NRC (2000) feed library were used to develop discount equations for concentrates and forages. This was accomplished by regressing predicted TDN values by NRC2 of 1x on 2x and 3x levels of DMI, for 72 concentrate or 91 forage feeds.

Prediction of RUP. Tabular RUP values given for each feed in the feed library, which are used in the NRC1 model, were evaluated for internal consistency with RUP values predicted from the NRC2 model. Ruminally undegraded protein was computed at different levels of DMI by the NRC2 model for each feed. These values were compared with corresponding tabular RUP, used in the NRC1 model, values for each feed.

Predicting TDN values at maintenance intake. Over all classes of feeds, both NRC2 and SumEq predictions agreed well with NRC1 values, with small biases (Table 4 and Figure 1). However, in individual feed categories, much less of the variation in tabular values was accounted for by either the NRC2 or by the SumEq models, as shown in Table 4 and Figure 2A. The NRC2 model accounted for much more of the variation in SumEq model predictions than it did with the variation in the NRC1 values.

Table 4. Comparison of TDN predicted by a summative equation (SumEq) and the tabular values of the NRC (2000) model level 1 values for maintenance NE_m intake [a]

		NRC1			SumEq			NRC1 vs SumEq		
Feed Classes	N	Min	Mean	Max	Min	Mean	Max	r^2	MSE	bias (%)
All classes	159	40	68.6±1.09	95	30.2	67.5±1.12	105	0.87	25.7	1.7 **
Grass forages	41	47	57.9±1.03	79	38.9	60.7±1.12	72.3	0.51	22.2	0.8
Legume forages	25	45	58.8±1.40	79	36.3	55.5±1.88	73.6	0.76	12.3	4.1 **
Grain-type forages	23	40	62.3±2.37	82	37.0	63.2±2.34	76.1	0.82	24.0	3.6 *
Energy concentrates	35	70	82.8±1.18	95	67.4	81.8±1.08	89.6	0.62	19.1	0.7
Protein concentrates	20	64	81.6±2.20	94	53.0	79.2±2.56	105	0.63	36.4	1.6
Byproducts	15	33	69.8±3.63	89	29.9	70.0±4.42	93.6	0.68	38.4	-0.2

[a] MSE is mean square error from regular regression. Mean values are mean ± standard error. A positive bias means that Y values are greater than X values. Asterisks indicate statistical difference from zero using the *t*-test (unequal variance) at α=0.01 (**), α=0.05 (*), or no difference (no asterisk).

The reasons for the variation in agreement between NRC1 and the NRC2 or SumEq predicted TDN values are (1) the feeds used in the digestion trials represented by the TDN values were different than those represented by the chemical composition values in the NRC (2000) feed library and (2) there are errors in the method used to predict tabular TDN values. The first explanation is based on the observation that most of the experimentally determined TDN values used in the NRC (2000) feed library are from experiments conducted many years ago; however, chemical composition data in that feed library were updated from a survey of recent analyses in feed testing laboratories. Thus, the tabular TDN value in the table may not represent the feedstuff described chemically in that table. This suggests that tabular TDN values are only appropriate when the nutrient composition of the feed of interest is essentially the same as that for the feed used in the digestibility trial used to determine the TDN value. The second explanation is based on the fact that TDN was calculated for many feeds using the difference method, because most feeds were not fed alone to determine TDN directly. Calculating TDN using the difference method can lead to inaccurate and imprecise estimates of TDN (Van Soest, 1994). Similar conclusions about tabular TDN values were reached by the NRC (2001).

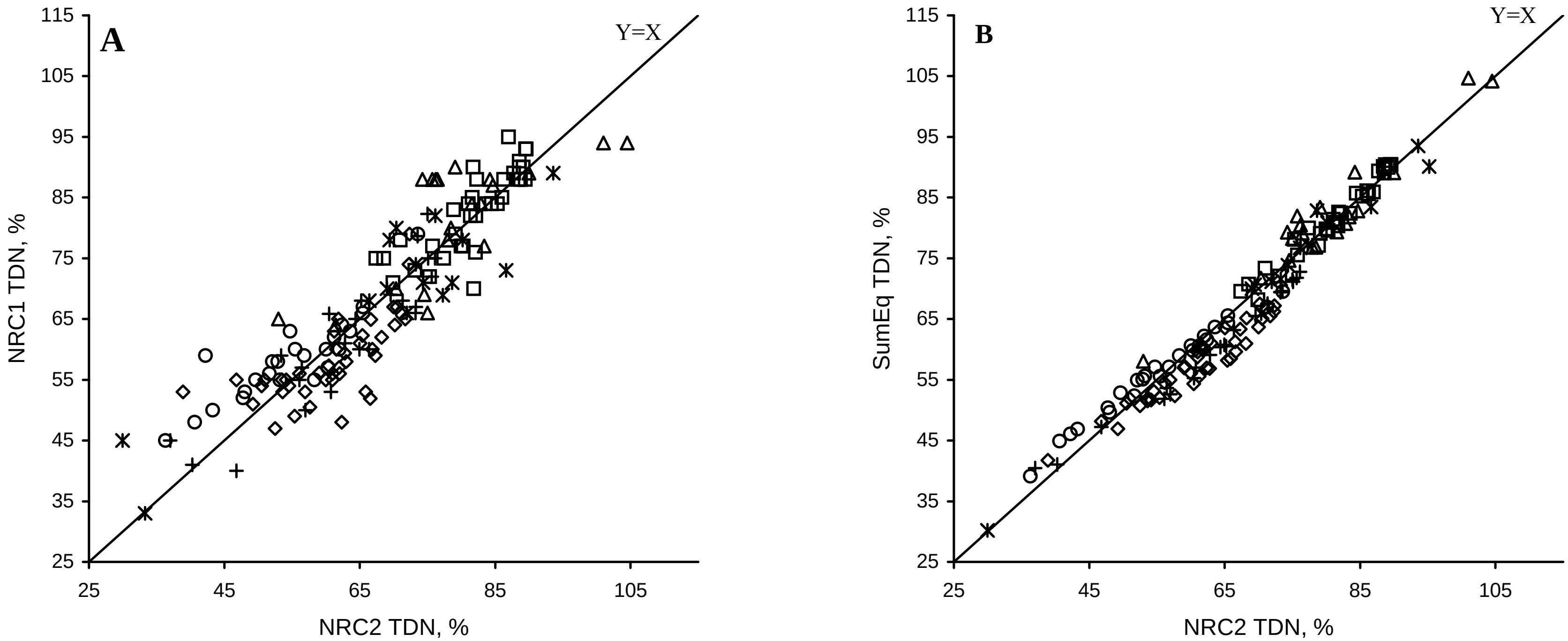


Figure 1. (A) Relationship between tabular TDN (level 1 of NRC, 2000; NRC1) and TDN_{1x} predicted by the level 2 of NRC (2000; NRC2) for all classes of feeds evaluated. The equation is Y = 6.89 + 0.90X with an r^2 of 0.83, mean square error (MSE) of 33.6, and bias of 0.25% ($P > 0.05$). Slope is different from one ($P < 0.05$). (B) Relationship between TDN_{1x} predicted by a summative equation (SumEq; Weiss et al., 1992) and NRC2 for all classes of feeds evaluated. The equation is Y = –0.64 + 1.0X with an r^2 of 0.96, MSE of 8.6, and bias of –1.3% ($P < 0.05$). Slope is not different from one ($P > 0.05$). A positive bias means that Y values are greater than X values. Symbols are grass forages (◊), legume forages (o), grain–type forages (+), energy concentrates (□), protein concentrates (Δ), and by–product feeds (*). A positive bias means that Y values are greater than X values.

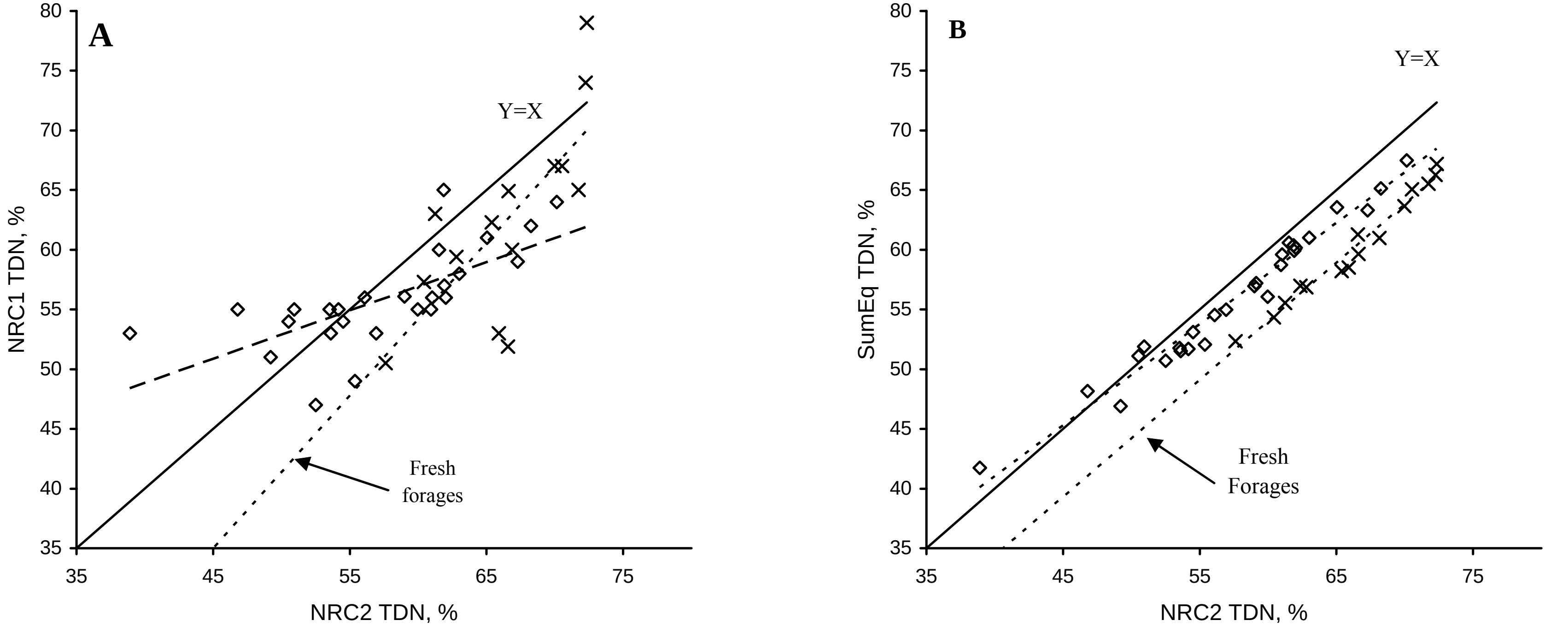


Figure 2. (A) Relationship between tabular TDN (level 1 of NRC, 2000; NRC1) and TDN_{1x} predicted by the level 2 of NRC (2000; NRC2) for grass forages. The equation is Y = 21.1 + 0.61X with an r^2 of 0.48, mean square error (MSE) of 23.7, and bias of –4.5% ($P < 0.05$). Slope is different from one ($P < 0.05$). The symbol "×" and the dotted line represent fresh forages, and the interrupted line is the trend of grass forages without fresh forages. (B) Relationship between TDN_{1x} predicted by a summative equation (SumEq; Weiss et al., 1992) and NRC2 for grass forages. The equation is Y = 11.9 + 0.75X with an r^2 of 0.92, MSE of 3, and bias of –5.3% ($P < 0.05$). Slope is different from one ($P < 0.05$). When fresh forages were excluded, the r^2 was 0.95 with a MSE of 1.9 and bias of –3.6% ($P < 0.05$). The slope for fresh forages was not different from one ($P > 0.05$). The symbol "×" and the dotted line represent fresh forages, and the interrupted line is the trend of grass forages without fresh forages. A positive bias means that Y values are greater than X values.

Figure 2B shows fresh forage feeds having greater values for the NRC2 predictions compared to the SumEq equation. This may be a reflection of the Weiss et al. (1992) equation not being able to account for the high rates of digestion of the available fiber in fresh forages (Doane et al., 1997; Kolver et al., 1998). The lack of fresh forages in the database of Conrad et al. (1984), which was used to develop the Weiss et al. (1992) equation, might also account for the greater TDN values predicted by the NRC2. Another factor could be that using a fixed coefficient of 0.75 for NDF digestibility in the Weiss et al. (1992) equation is inappropriate. Originally, this coefficient was 0.82 in the Conrad et al. (1984) equation, and Gerard and Dupuis (1988) reported a value of 0.96. Ideally, the integration of digestion (kd) and passage rate (kp) as kd/(kd+kp), would provide better digestibility estimates than a fixed coefficient. When fresh forage feeds were excluded from this comparison, the r^2 changed from 0.92 to 0.95, MSE changed from 3 to 1.9, and the bias changed from –5.3 ($P > 0.05$) to -3.6% ($P > 0.05$). A similar systematic bias was observed for grain-type forages (not shown), in which the SumEq model underpredicted TDN_{1x} compared to the NRC2 model predictions.

The results in Figure 1 and Table 4 suggest that the SumEq model predicts TDN values consistent with the NRC2 model, and it can be used with actual feed analysis to determine TDN values to replace the tabular values. This equation can be easily used by feed testing laboratories and in computer programs to predict feed energy values that reflect the actual composition of the feeds being fed. The use of the Weiss et al. (1992) equation has the advantage of simplicity for use in feed laboratories, whereas the NRC2 model is useful for accounting for more of the variation in each unique production situation by adjusting for additional factors influencing feed metabolizable energy and protein values, including particle size and feed processing effects on digestion and passage rates and on microbial protein production in the rumen.

Predicting DE values at maintenance intake. The comparisons made in predicting DE directly from heat of combustion values versus using a fixed value for TDN is shown in Table 5. Either for all feeds or individual feed classes, there were no differences ($P > 0.05$) in DE computed with Equations 2 (DE_{NRC1}), Equation 8 (DE_{SumEq}), and Equation 9 (DE_{NRC2}). The average difference in DE predicted by the SumEq model and from Weiss (1999) predicted directly from feed fractions was small (2.4%). Equation 2 (DE_{NRC1}) uses a fixed coefficient derived by Swift (1957), who found that, on average, 1 kg of TDN was equivalent to 4.409 Mcal/kg of DE from 312 digestion trials with cattle or sheep consuming forage only or mixed feeds. These results suggest that, over all feeds, Equation 2 provides a similar DE value when compared to the use of heat of combustion values for each fraction digested.

The use of heat of combustion would improve the prediction of DE only if accurate values of digestible fractions were available. In order to obtain these values, the depression in digestible fiber due to the competition between passage rate and degradation rate and due to starch interaction should be accounted for. The SumEq used in this evaluation considers only the surface interaction between lignin and NDF on digestibility of NDF, whereas the mechanistic approach of the NRC2 model considers other factors (Fox et al., 2000). It is possible that the errors of the deterministic equations used by Weiss (1999) to estimate digestible fractions will be included in the DE estimate. Based on this discussion, the use of a common 4.409 factor to convert TDN to DE is adequate. However, the prediction of ME and

NE may be more accurate when DE is computed from degraded pools rather than estimated from TDN.

Table 5. Comparison of DE (Mcal/kg) values predicted at maintenance NE_m intake using the NRC (2000) model and the heat of combustion of digestible nutrients [a]

Feed Classes	Digestible Energy, Mcal/kg				NRC2 x NRC1		SumEq x NRC1	
	NRC1	NRC2	SumEq	SE	r^2	Bias	r^2	Bias
All classes	3.01	2.96	3.01	0.05	0.98	-2.7**	0.89	0.4
Grass forages	2.67	2.58	2.54	0.05	0.98	-3.2**	0.88	-4.9**
Legume forages	2.44	2.44	2.63	0.08	0.99	0	0.96	7.8**
Grain-type forages	2.78	2.64	2.62	0.10	0.99	-4.9**	0.97	-5.5**
Energy concentrates	3.60	3.51	3.59	0.04	0.87	-3.6**	0.67	-0.6
Protein concentrates	3.47	3.56	3.70	0.11	0.99	2.2**	0.94	9.2**
Byproducts	3.27	3.41	3.42	0.17	0.99	4.8**	0.91	1.6

[a] DE_{NRC1} is predicted by the NRC (2000) model level 1 using a common heat of combustion of 4.409 Mcal/kg. DE_{NRC2} is predicted by the NRC (2000) model level 2 and DE_{SumEq} is predicted using the Weiss (1999) equations, using the heat of combustion of 4.15, 5.65, and 9.39 Mcal/kg for digestible fractions of carbohydrate, protein, and fat, respectively. In the DE values, within a row, means did not differ ($P < 0.05$) by Tukey test. Bias are expressed in percentage and they are different from zero at 5% (*) or 1% (**).

Predicting TDN at different levels of intake. In the validation described in Chapter 2 of NRC (2000), the predicted ADG by model level 2 (NRC2) accounted for 92% of the actual ADG with no bias. When the model level 1 (NRC1) system was used, less variation (81%) in ADG was accounted for, with a 12% overprediction bias. These results agree with those in Table 2. This suggests that a discounted TDN should be used for computing net energy values for growing cattle rather than the TDN1x values.

The increase in DMI causes a reduction in digestibility due to losses of potentially digestible NDF and, to a lesser extent, increased starch escaping from the rumen, which may increase fecal starch. These fractions are the slowest to degrade and therefore are the most likely to escape from ruminal degradation (Van Soest, 1994, p. 414). The CNCPS model (Fox et al., 2000) calculates the passage rate based on body weight, dietary concentration of forage and effective NDF, and DMI.

Discount equations for concentrates and forages by regressing TDN_{1x} against TDN_{2x} and TDN_{3x} computed with the CNCPS for two different body sizes, because passage rate is influenced by body weight. Table 6 has the coefficients estimates for growing beef (at two weights) and lactating dairy cattle.

The TDN_{1x} values for concentrates ranged from 30.2 to 104.7% with a mean of 79.8 ± 0.74%, and the NDF varied from 0 to 90% with a mean of 27.1 ± 1.23%. Substituting 79.8% for TDN_{1x} and 27.1% for NDF in the equation for a 550-kg growing animal (Table 6) resulted in a discount of 2.3% and 4.6% at two and three times the maintenance requirement, respectively, or an average discount for concentrates of 2.3% per multiple of maintenance.

For forages, the TDN1x values ranged from 37.3 to 77.4% with a mean of 61.7 ± 0.55%, and the NDF values ranged from 33 to 87% with a mean of 56.9 ± 0.73%. For example, a forage with TDN_{1x} of 61% and NDF of 58% would have a TDN_{3x} of 55.4% (9.2% discount) for a 550-kg growing animal (Table 6).

Table 6. Equations to discount TDN_{1x} (%) for level of intake [a]

	Concentrate			Forage		
	Growing		Cow	Growing		Cow
Variables[b]	250	550	650	250	550	650
Intercept	0.073	0.086	0.100	0.150	0.118*	0.209*
DMI_{Factor}	-4.051**	-4.653**	-4.853**	-17.371**	-15.809**	-20.370**
$TDN_{1x} \times DMI_{Factor}$	0.050**	0.055**	0.060**	0.210**	0.195**	0.249**
$NDF \times DMI_{Factor}$	0.093**	0.101**	0.122**	0.341**	0.298**	0.398**
$TDN_{1x} \times DMI_{Factor} \times NDF$	-0.0002	-0.0001	-0.0005	-0.0031**	-0.0025**	-0.0036**
R^2	0.80	0.81	0.80	0.96	0.98	0.96
MSE	1.16	1.39	1.66	0.82	0.38	0.94

[a] The TDN discount factor (%) was calculated for 250- or 550-kg growing beef cattle or a 650-kg dairy cow using the NRC (2000) model level 2. Symbols indicate whether the coefficient is different from zero at $P < 0.01$ (**) or $P < 0.05$ (*). MSE is the regression mean square error.

[b] The TDN_{1x} (% in DM) is the TDN at DMI to meet NE_m requirements, NDF is neutral detergent fiber (% in DM), and DMI_{Factor} is feed intake in units of maintenance minus 1.

This discount equation for forages applied with a lactating cow (Table 6) was compared with the Mertens (1983; Eq. 10) discount equation which was based on the values presented by Van Soest and Fox (1992), to calculate a TDN_{3x}. The regression between the Mertens (1983) equation (Y-variate) and the equation in Table 6 had an r^2 of 0.99, MSE of 0.6, and bias of -0.6% (P > 0.05), indicating a good agreement between both equations and suggesting that equation of Table 6 can be used to discount TDN_{1x} for forages for NRC1 predictions.

$$TDNDisc_{Mertens} = 0.033 + 0.132 \times NDF - 0.033 \times TDN_{1x} \qquad [10]$$

The mean of the TDN_{1x} for forages in the NRC (2000) feed library calculated by the CNCPS is 57.9% and for NDF is 56.9%. Using these values in the forage equation for a lactating cow gives an average discount of 5% for forages per multiple of maintenance. Using the concentrate (2.3%) and forage (5%) discounts in a diet with 60% forage and 40% concentrate would give an average discount of 3.9%, which is similar to the 4% adopted by NRC (1989), based on Moe (1981).

When we compared our equations (Table 6) with two published equations (Mertens, 1983; NRC, 2001) and reported values from Van Soest and Fox (1992) to predict discounts for typical beef cattle diets, the NRC (2001) predicted considerably lower discounts for all forage diets (pastures, hay, and silages) and higher discounts for high concentrate diets.

The application of the SumEq (Eq. 1) with the discount equations for a 550-kg growing animal (Table 6) in feed testing laboratories to obtain energy values was evaluated in Table 7. The TDN was computed with Equation 1 when used for animals fed at 1x (typically dry cows), at 2x (typically growing cattle and lactating beef cows fed high forage diets), and at 3x (usually feedlot finishing cattle) maintenance requirement. The database used included 28 forages and 47 concentrates analyzed at the Dairy One laboratory (Ithaca, NY) (Paul Sirois, personal communication). The NRC (2000) laboratory survey results are mostly from the Dairy One laboratory (Ithaca, NY).

Table 7. Comparison of energy values predicted for 1x, 2x, and 3x maintenance from chemical analyses of forage and concentrate feeds from Dairy One feed analysis laboratory database

Energy concentration, %DM	Forages[a]			Concentrates[b]		
	Low	Mean	High	Low	Mean	High
TDN_{1x}, % [c]	50	60	74	62	79	96
Average discount, % [d]	6.2	3.8	1.9	2.8	2.7	1.8
Animals fed at maintenance [e]						
NE_m[h], Mcal/kg	0.97	1.31	1.76	1.38	1.91	2.41
Animals fed at 2x maintenance [f]						
NE_m[h], Mcal/kg	0.86	1.23	1.70	1.32	1.85	2.36
NE_g[h], Mcal/kg	0.32	0.66	1.09	0.74	1.21	1.65
Animals fed at 3x maintenance [g]						
NE_m[h], Mcal/kg	0.75	1.15	1.65	1.26	1.78	2.31
NE_g[h], Mcal/kg	0.21	0.59	1.04	0.69	1.16	1.61

[a] Mean value is from 28 forages, low is from straw, and high is from low fiber corn silage.
[b] Mean value is from 47 concentrates, low is from beet pulp, and high is from soybeans.
[c] TDN_{1x} is TDN at maintenance NE_m. Values were predicted by the Weiss et al. (1992) equation and discounted according to each level of DMI above maintenance NE_m.
[d] Discount per multiple of maintenance. Forages and concentrates were calculated with equations listed in Table 6 assuming NDF values for forages of 70.0, 54.5, and 32.9%, and NDF values for concentrates of 41.7, 31.5, and 12.0% for low, mean, and high values, respectively. The equation of 550-kg growing steer was used to calculate the discount.
[e] Typical of dry beef cows.
[f] Typical of backgrounding cattle.
[g] Typical of feedlot finishing cattle.
[h] NE_m and NE_g values are predicted with NRC (2000) equations from TDN_{1x} discounted values.

The results in Table 7 indicate that feeds with the greatest discount are those with a high cell wall concentration, and those with a low cell wall have a low discount, consistent with the CNCPS model predictions. The Dairy One laboratory is using the Weiss et al. (1992)

equation along with discount equations (Van Soest, 1994, p. 415) to provide net energy concentrations appropriate for the level of intake of the cattle being fed with the feed tested (Paul Sirois, personal communication). We believe that in specific production situations, however, the use of the CNCPS model to predict feed energy values in specific production situations is preferred, to account for specific level of intake effects, to adjust for feed particle size and processing effects, and to account for the depression in cell wall digestibility as rumen pH drops below 6.2 (high grain diets).

Predicting RUP at different levels of intake. Table 8 presents the regression statistics of NRC1 (tabular) and predicted RUP values by NRC2 for concentrates and forages compared at three multiples of maintenance (1x, 2x, and 3x). By-product feeds were not included in this analysis because of discontinuing use of animal protein in feeding cattle. For concentrates at maintenance level of intake, the NRC2 model accounted for 91% of the variation in the values listed in the NRC1 model with a 30.1% bias, which means that tabular values averaged 30.1% greater than the NRC2 predicted values. However, the RUP predicted with the NRC2 model with a 3x maintenance level of intake for concentrates accounted for 96% of the variation of the RUP values in the NRC1 model with a bias of only 0.64% ($P > 0.05$), suggesting that NRC1 concentrate values represent a 3x maintenance level of intake. This is an expected result, since the values for concentrates in the NRC1 model feed library were based on the NRC (1989), which was developed using data from animals fed at 3x intake. The mean values for NRC1 RUP (%) and those predicted with the NRC2 model at 1x, 2x, and 3x for concentrates were 41.9 ± 2.43, 29.3 ± 1.90, 36.6 ± 2.09, and 41.7 ± 2.07% of CP, respectively.

Table 8. Relationship of values of ruminally undegradable protein (RUP) between tabular (NRC1) and predicted by the NRC (2000) model level 2 (NRC2) at 1x, 2x, and 3x multiples of maintenance NE_m intake [a]

Regression	n	r^2	MSE	bias (%)
Concentrates[b]				
NRC1 vs. NRC2 RUP at 1x	56	0.91	31.1	30.1 **
NRC1 vs. NRC2 RUP at 2x	56	0.95	37.9	12.8 **
NRC1 vs. NRC2 RUP at 3x	56	0.96	16.8	0.64
Forages				
NRC1 vs. NRC2 RUP at 1x	91	0.39	119.5	-17.5 **
NRC1 vs. NRC2 RUP at 2x	91	0.38	120.9	-25.8 **
NRC1 vs. NRC2 RUP at 3x	91	0.37	122.6	-31.4 **

[a] MSE is mean square error from the linear regression. A positive bias means that Y values (NRC1) are greater than X values (NRC2).
[b] Byproducts were not included.

The result of the analysis of forage RUP values is much less clear (Table 8). At maintenance level of intake, the NRC2 model predictions accounted for only 39% of the variation in the NRC1 model values with a bias of –17.5% ($P < 0.05$) and at 3x it accounted for only 37% of the variation with bias of –31.4% ($P < 0.05$). The bias was inconsistent from class to class of forage. This poor relationship was the result of RUP values in the NRC1 model for forages being assigned by the NRC (2000) to be consistent with type of animal expected to be fed that forage. Feeds expected to be used by gestating beef cows were assigned RUP values appropriate for 1x while those expected to be used by growing and finishing cattle were assigned RUP values appropriate for 2x to 3x maintenance level of intake, respectively. The mean values for RUP (%) in the NRC1 model and RUP predicted by the NRC2 model at 1x, 2x, and 3x for forages were 23.5 ± 1.46, 27.7 ± 1.31, 31.5 ± 1.27, and 34.5 ± 1.25% of CP, respectively.

Equation 11 (R^2 = 0.98 and MSE = 4.6) was developed to estimate RUP in concentrates and forages at any level of DMI given a RUP_{1x} value. It was generated using RUP values predicted for each feed in the NRC (2000) feed library by the NRC2 model at 1x, 2x, and 3x maintenance level of intake. For example, a feed with RUP_{1x} of 50% would have RUP at 3x maintenance of 65.3% or 55.6% if it were a concentrate or a forage, respectively.

$$RUP_{Discounted} = (0.167 + a) + (1 + b) \times RUP_{1x} + (4.3 + c) \times DMI_{Factor} + (-0.032 + d) \times RUP_{1x} \times DMI_{Factor} \quad [11]$$

where RUPDiscounted is the RUP discounted (% CP) to any level of intake between 1x and 3x, RUP_{1x} is RUP at 1x maintenance and DMIFactor is feed intake in units of maintenance minus 1. For concentrate, RUP_{1x} (% CP) ranged from 0 to 60.5% with a mean of 29.3 ± 1.90%; for forages, RUP_{1x} (% CP) ranged from 3.9 to 74.9% with a mean of 27.7 ± 1.31%. The DMIFactor must be greater than zero. Coefficients a, b, c, and d for concentrates are -0.07, 0.01, 0.17, and 0.09, respectively; for forages they are zero.

The accuracy of this equation depends on the amount of soluble protein and the fraction of protein bound in the cell wall (NDFIP) of a feed. Therefore use of a mechanistic model that accounts for different protein fractions and their degradation and passage to predict RUP may be more accurate than the use an empirical relationship (Equation 10).

1.5. Implications of determining ration energy values section

In computing feed energy values (TDN), a summative equation (Weiss, 1993; Weiss et al., 1992) should be used instead of the fixed tabular values in the feed library of the NRC (2000) model for a level 1 solution, because it represents the actual chemical analysis of the feedstuffs being used. Equations were developed to discount this predicted TDN for level of intake for growing and finishing cattle and for lactating beef cows. Tabular RUP values for concentrates were found to be adequate for estimating the undegradability of feed protein at production levels of intake. However, tabular RUP values for forage had no correlation with RUP values predicted by the NRC (2000) model level 2 at any level of intake. An equation is provided to discount (increase) RUP for any level of intake from maintenance RUP either for concentrates or forages.

2. Body Weight and Body Composition at Harvest Time

2.1. *Body composition*

Two marketing endpoints (26.2 and 28.6 % empty body fat; EBF, %) are used in the growth model because of their association with the select and choice grades (Guiroy et al., 2001). The analyses of Guiroy et al. (2001) indicated EBF is significantly ($P < 0.05$) higher with each incremental increase in grade up to the mid Choice grade. Taste panel scores and percent unacceptable followed the same trend. Based on consumer acceptability studies in the U.S., Smith et al. (1987) reported the percent of steaks with low eating quality for the USDA Prime, Choice, Select, and Standard grades were 5.6, 10.8, 26.4, and 59.1%, respectively in data collected from typical feedlot cattle. The percent unacceptable values were lower in the Guiroy et al. (2001) analyses likely because the animals were uniform calves fed a 90% concentrate diet beginning at approximately 7 months of age. Their analyses also indicated a good agreement between grade and changes in body composition as cattle grow. We conclude carcass value in most markets and cost of gain can be related to proportion of protein and fat in the carcass, and the data of Guiroy et al. (2001) can be used to add marketing endpoint options for grades other than select or choice. Body fat in finished cattle when marketed in other regions of the world typically varies from 16 to 21% EBF in the French (INRA, 1989) and Brazilian (Leme et al., 2000) markets to over 30% EBF in segments of the Japanese and Korean markets. Equation 12 shows the relationship found by Guiroy et al. (2001) between EBF and carcass traits and Equation 13 shows the same relationship without REA.

$$EBF = 17.76207 \pm 1.76952 + 4.68142 \pm 0.26578 \times FT + 0.01945 \pm 0.00472 \times HCW + 0.81855 \pm 0.11209 \times Mrb - 0.06754 \pm 0.02095 \times REA \text{ ; } N = 401; R^2 = 0.608; MSE = 12.37 \quad [12]$$

$$EBF_{NoREA} = 14.08796 \pm 1.36961 + 4.71350 \pm 0.26872 \times FT + 0.01316 \pm 0.00435 \times HCW + 0.90855 \pm 0.10983 \times Mrb \text{ ; } N = 401; R^2 = 0.597; MSE = 12.67 \quad [13]$$

Where FT is fat thickness, cm; HCW is hot carcass weight, kg; Mrb is marbling score; REA is rib-eye area, cm^2; N is number of animals; MSE is mean square error of the regression.

2.2. *Body weight*

Cattle of different genotypes are at different weights when they are at the same degree of fatness and energy content of gain (Fox and Black, 1984; Fox et al., 1992; NRC, 2000). Fox et al. (1992) developed a relationship between frame size and weight at 28% body fat (low choice grade), which can be used to predict gain needed and days to finish based on weight desired at low choice grade. These finished weights are based on the used of a non-aggressive implant strategy, and a two phase feeding program (growing program on high quality forage based rations containing approximately 50% grain for approximately 90 to 120 days, then finished on typical high grain feedlot rations). Based on NRC (2000) recommendations, we reduce this weight by 5% for calves fed a high energy ration from weaning to harvest, and increase it by 5% for calves placed in stocker programs at slow rates of gain for extended times prior to finishing on high energy ration.

2.3. Computing Adjusted Final Body Weight (AFBW) from Carcass Traits

Guiroy et al. (2001) reported that for each increase in EBF as percent unit, there is a deposition of 14.26±1.52 kg of EBW. Therefore, Equation 14 is used with either Equations 12 or 13 to compute the AFBW from the actual body weight and composition:

$$AFBW = EBW + ((28 - EBF)\times 14.26)/0.891 \qquad [14]$$

Where AFBW is adjusted final shrunk body weight at 28% EBF, kg and EBF is empty body fat, %.

The CVDS model also computes EBF from Yield Grade using the equation developed by Perry and Fox (1997) shown below. Empty body weight is computed from HCW using the equation developed by Garrett et al (1978).

$$EBF = ((0.351\times EBW + 21.6\times YG - 80.8)/EBW)*100 \qquad [15]$$

$$EBW = 1.316\times HCW + 32.29 \qquad [16]$$

Where EBF is empty body fat,%; EBW is empty body weight, kg; YG is yield grade; and HCW is hot carcass weight, kg.

2.4. Computing Adjusted Final Body Weight (AFBW) from Hip Height

Similarly, AFBW can be computed from frame size. Equation 17 and 18 should only be used for bulls and heifers, respectively, between the ages of 5 and 21 months.

$$FS = -11.548 + 0.4878\times HH - 0.0289\times Age + 0.00001947\times Age^2 + 0.0000334\times HH\times Age \qquad [17]$$

$$FS = -11.7086 + 0.4723\times HH - 0.0239\times Age + 0.0000146\times Age^2 + 0.0000759\times HH\times Age \qquad [18]$$

Where FS is frame score, scale 1 to 9; HH is hip height, inches; and Age is age when the hip height was measured, days.

Then, AFBW is computed from FS for bulls and heifers using Equations 19 and 20, respectively.

$$AFBW = 33.35\times FS + 366.52 \qquad [19]$$

$$AFBW = 26.7\times FS + 293.2 \qquad [20]$$

3. Computing Dry Matter Intake and Energy Requirements

3.1. Predicting dry matter intake

Dry matter intake of an animal is determined by demand to meet requirements for maintenance and growth, with physiological limits set by rumen fill, ruminal VFA concentration and pH, and body fat (NRC, 1987). Published information (Hyer et al., 1986; NRC, 1987, 2000; Thornton et al., 1985) indicates there are two types of equations that have been developed to predict DMI as discussed below.

1 *Type I DMI equations*: those developed based on overall average feed intakes of pens of cattle, using average BW and DMI. These equations result in an almost linear relationship between increments in BW and DMI (NRC, 2000).

2 *Type II DMI equations*: those developed from BW and DMI for periods of days on feed (DOF) during feeding trials. These equations result in a curvilinear relationship between increments in BW and days on feed (Hicks et al., 1990a, b; Thornton et al., 1985).

The data developed for DOF during a feeding trial indicate the DMI of feedlot cattle increases rapidly during the first month of a finishing period, plateaus, and later declines when the animal is near its' finished BW (Hicks et al., 1990a, b; Thornton et al., 1985). However, there are major limitations in these equations. The equations developed by Hicks et al. (1990a; 1990b) and Thornton et al. (1985) utilize just three variables to predict DMI: DOF, initial BW, and current BW. As stated by Hicks et al. (1990a; 1990b) "no information on frame size or carcass composition was available to assess carcass fatness in order to adjust for these variables when these equations were developed, and any factor which alters mature weight will alter feed intake".

The NRC (2000) provided equations that can be used to account for the effects of variables that influence individual animal performance in each production situation; diet energy density, degree of maturity, and environment (temperature and mud effects). Therefore, we chose to use the DMI equation adopted by NRC (2000) in our growth model.

In applying the NRC (2000) equation to predict DMI, we converted the adjustments for EBF into an equation (DMI_EBFAdj, Eq. 14) to allow continuous adjustment for this effect if equivalent shrunk BW (EQSBW) is greater than 350 kg.

$$\text{DMI\_EBFAdj} = 0.7714 + 0.00196 \times \text{EQSBW} - 0.00000371 \times \text{EQSBW}^2 \qquad [14]$$

Predicted DMI is adjusted for actual DM fed with feedlot historical data to improve accuracy in the prediction of DTF. Historical average expected DMI is divided by the average individual animal predicted DMI in the pen from initial to finished weight. Then, this relative

DMI is applied to each individual animal in the pen for predictions of DMI over the entire feeding period.

3.2. Predicting requirements for maintenance

In the growth model, maintenance requirements are computed by adjusting the basal metabolism NE_m requirement for breed, physiological state, activity, urea excretion, acclimatization and heat or cold stress as described by Fox and Tylutki (1998). Current temperature, animal insulation, and heat loss vs heat production, which is computed as ME intake minus retained energy (RE), are used to predict the effects of the current environment on NEm requirement. Heat loss is affected by animal insulation factors and environmental conditions.

Dry matter intake is adjusted for the effect of temperature as described by Fox and Tylutki (1998), which reflects the demand to produce more heat and support a higher metabolic rate in cold weather and to reduce heat production in hot weather.

The NE_m requirements for dairy (Holstein only) and beef breeds (all others, including crossbreed of Simmental × Angus) were calculated using thermal neutral maintenance requirements for fasting metabolism (Mcal/d/$SBW^{0.75}$) of 0.078 and 0.070, respectively, based on Fox and Tylutki (1998). In the entire individually fed evaluation data set, 304 animals were fed in individual pens of 4.92 or 5.28 m^2 in a slatted floor confinement barn, and 70 animals were fed individually in outside partially covered, paved group pens of 278 m^2. Thus, animals fed individually in group pens were assumed to be fed in confinement and were assigned a 10% higher NEm requirement than those in individual pens, which were assumed to be stall fed in computing activity requirements based on Fox and Tylutki (1998).

In a recent study, Tedeschi et al. (2002) analyzed the a Nellore cattle database containing 31 bulls and 66 steers to determine NE_m and NE_g when fed high forage diets. The NE_m was similar for bulls and steers; NEm averaged 77.2 kcal/$kg^{0.75}$ EBW, which is nearly identical to those reported by Lofgreen and Garret (1968) of 77 kcal/$kg^{0.75}$ EBW. However, the efficiency of conversion of ME to net energy for maintenance was greater for steers than bulls (68.8 and 65.6%, respectively), indicating that bulls had a greater ME requirement for maintenance than steers (5.4%; $P < 0.05$). Their analyses do not support the NRC (2000) conclusion that Nellore, a *Bos indicus* breed, has a lower net energy requirement for maintenance than *Bos taurus* breeds.

3.3. Predicting requirements for Growth

Accurate prediction of daily gain that can be expected for the ME and protein consumed depends on accurate prediction of energy required for maintenance and composition of gain, which is related to proportion of finished weight at a particular weight (Fox et al., 1992; NRC, 2000; Tylutki et al., 1994). The size scaling system described by the NRC (2000) is used to adjust shrunk body weight (SBW) to a weight equivalent to a standard reference animal at the same stage of growth (SRW). This EQSBW is computed as shown in Equation

15. Then, the shrunk weight gain (SWG) equation is used to predict the energy requirement for growth (Mcal/day).

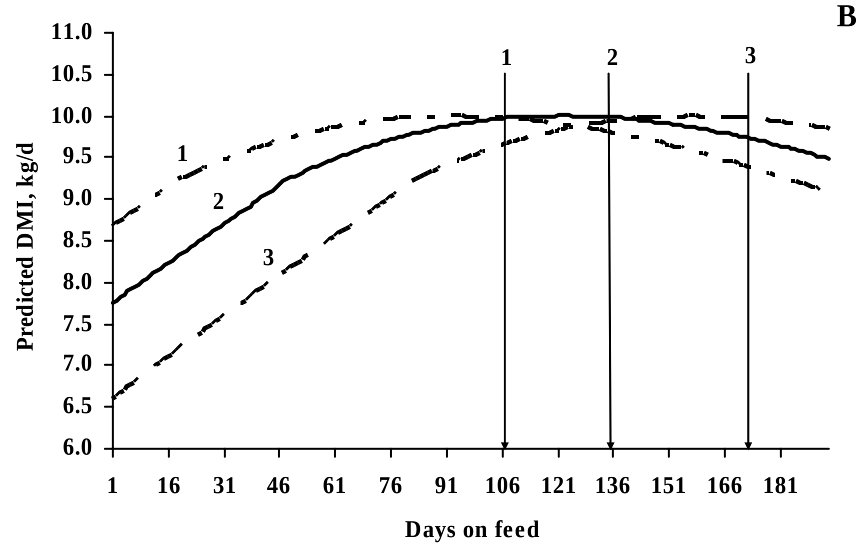
$$EQSBW = SBW \times (SRF/FSBW) \qquad [15]$$

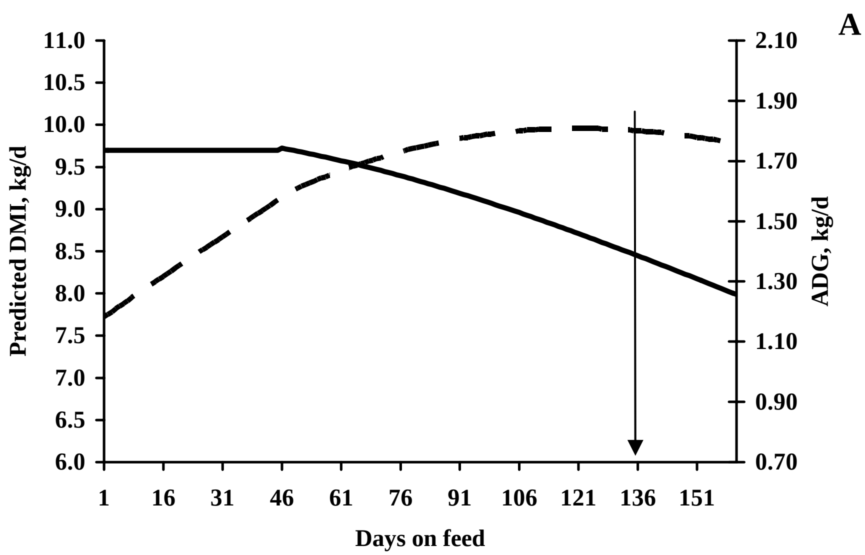
Where SRW is standard reference weight at 28% EBF of the standard reference animal and FSBW is expected finished SBW at 28% EBF.

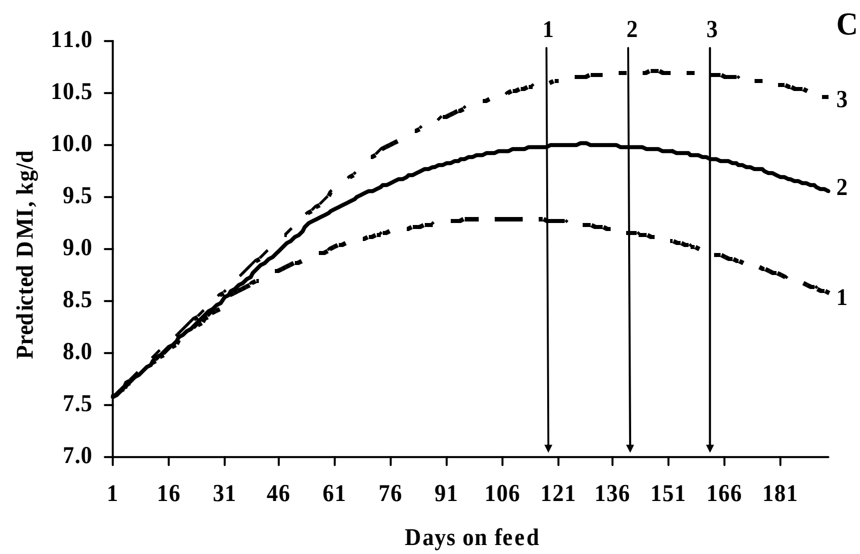
The evaluation of predictions of ADG and weight at the observed days on feed using the growth model was performed with four published studies (Guiroy, 2001; Nour, 1982; Perry and Fox, 1997; Perry et al., 1991).The evaluation dataset included 374 steers that were individually fed. A detailed description of these studies was presented by Guiroy et al. (2001). All animals in these studies were allowed to consume their diets on an ad libitum basis. The dietary NE values (Guiroy et al., 2001; Table 10 in that publication) were computed for each study with the CNCPS 4.0 (Fox et al., 2000), using feed composition information available. A SRW of 478 kg was used for all animals, which is weight for animals finishing at small marbling (USDA low Choice quality grade) or 28% EBF as described in the NRC (2000).

Figure 3A shows the results of applying the growth model equations in the simulation of DMI and SWG of an animal with 310 kg of initial SBW that is expected to finish at 530 kg on a high-energy ration (ME of 2.97 Mcal/kg DM). Figure 3B shows that animals reach finished SBW at 136 days on feed, the same as when using the equation developed by Thornton et al. (1985). The higher DMI predicted early in the feeding period by the Thornton et al. (1985) equation is compensated by a slower decline in DMI by the NRC (2000) equation as used in the growth model. The advantage of using the NRC (2000) equation is that both initial SBW and degree of maturity of the animal are accounted for, with the additional capability of adjusting for the effects of diet energy density and environmental conditions in each production situation. Figures 1B and 1C demonstrate this advantage in using the NRC (2000) equation with the stage of growth adjustment (Eq. 14). Dry matter intake is predicted for three animals with the same finished SBW but different initial SBW (Figure 3B) or with the same initial SBW but different finished SBW (Figure 3C). From Figure 3B, it is clear that animals with greater initial SBW reach finished SBW earlier than animals with lower initial SBW, but that animals at the same SBW and degree of maturity will have similar DMI. Figure 3C depicts how animals with the same initial SBW but different finished SBW will reach different plateaus in DMI at different SBW due to the adjustment for finished SBW as described by Equation 14.

Figure 3. Effects of a continuous adjustment of dry matter intake (DMI, kg/d) on average daily gain (ADG, kg/d). (A) Simulation of DMI (dotted line) and ADG (solid line) of an animal with initial and final BW of 310 and 530 kg, respectively. The vertical line indicates the expected days to finish (136 d). (B) Comparison of predicted DMI for three scenarios (1, 2, and 3) varying initial BW (360, 310, and 250 kg, respectively). The vertical lines indicate the expected days to finish (107, 136, and 171 d, respectively) assuming a final BW of 530 kg. (C) Comparison of predicted DMI for three scenarios (1, 2, and 3) with varying final BW (480, 530, and 560 kg, respectively). The vertical lines indicate the expected days to finish (120, 142, and 161 d, respectively) assuming initial BW of 300 kg.







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4. Predicting Carcass Weight

Carcass weight (CW) as a proportion of empty body weight (EBW) increases as body fat increases (Fox et al., 1976; Garrett and Hinman, 1969; Lofgreen et al., 1962). Thus, live weight and ADG will decline more rapidly than carcass weight and carcass daily gain as animals increase in body fat. We evaluated three published equations (Fox et al., 1972; Garrett and Hinman, 1969; Garrett et al., 1978) to compute CW from EBW. The NRC (2000) factor of 0.891 is used to convert SBW to EBW and vice-versa. Equation 16 is used to size-scale CW to an equivalent CW (EQCW) to allow application to animals varying widely in FSBW, Equation 17 is used to compute the CW proportion (CWp), and finally CW is then computed with CWp and SBW as shown in Equation 18.

$$EQCW = ((EQSBW \times 0.891) - a)/b \quad [16]$$

For initial SBW: $CWp = EQCW / EQSBW$;

$$\text{Otherwise: } CWp = (HCD - CWpAFBW) + EQCW/EQSBW \quad [17]$$

$$CW = CWp \times SBW \quad [18]$$

Where EQCW is equivalent carcass weight, kg; EQSBW is equivalent shrunk body weight, kg; CWp is carcass weight proportion; CWpAFBW is CWp at AFBW; a and b are intercept and slope, respectively, of the regressions of empty body weight on carcass weight; and HCD is historical carcass dressing (kg/kg).

The comparison of three published equations (Fox et al., 1972; Garrett and Hinman, 1969; Garrett et al., 1978) to predict CW from EBW is shown in Table 9. Figure 4A shows the pattern of prediction of these three equations and Figure 4B has the deviation between predicted and observed hot carcass weight. All three equations accounted for 90% of the variation, but the Garrett et al. (1978) equation with size scaling had the best combination of low mean bias, RMSPE and MSE. Therefore, we selected equation of Garrett et al. (1978) to predict CW from EBW.

5. Procedures to Predict Daily Empty Body Fat and Yield Grade

5.1. Predicting daily empty body fat

Empty body fat can be related to carcass marbling score (Guiroy et al., 2001); therefore a sub-model to predict EBF to be used with the growth model for predicting carcass grades during growth was developed. This sub-model was based on published equations as described below. Equation 19 converts SWG to empty weight gain (EWG) using the NRC (2000) relationship and proportion of fat in gain (FIG; Eq. 20) is computed using the equation developed by Garrett (1987), which uses RE.

$$EWG = 0.956 \times SWG \quad [19]$$

$$FIG = 0.122 \times RE/EWG - 0.146 \quad [20]$$

Where EWG is empty weight gain (kg/d), SWG is shrunk weight gain (kg/d), FIG is fat in EWG, and RE is retained energy (Mcal/d).

Fat is accumulated over time (Eq. 21) and EBF is calculated dividing the amount of accumulated fat by EBW as shown in Equation 22.

$$Fat_t = Fat_{t-1} + FIG_t \times EWG_t \quad [21]$$

$$EBF = Fat \times 100/EBW \quad [22]$$

Where Fat is accumulated body fat (kg), EBF is empty body fat (%), EBW is empty body weight (kg), and SBW is shrunk body weight (kg).

Table 9. Comparison of equations to predict carcass weight (CW) from empty body weight with and without equivalent CW adjustment [a]

Equations	Mean Bias, kg	RMSPE, kg	Regression	
			MSE	r^2
Without equivalent carcass weight adjustment				
Fox et al. (1972)	-18.7	22.9	174.5	0.89
Garrett and Hinman (1969)	-2.50	13.5	174.5	0.89
Garrett et al. (1978)	6.67	15.0	174.5	0.89
With equivalent carcass weight adjustment				
Fox et al. (1972)	-30.0	32.7	155.9	0.90
Garrett and Hinman (1969)	-11.3	16.8	153.6	0.90
Garrett et al. (1978)	-2.98	12.7	153.6	0.90

[a] RMSPE = root mean square prediction error and MSE = mean square error.

Because this model requires an estimate of initial body fat, a database was developed to predict that parameter. The initial slaughter data from five studies (Crickenberger, 1977; Danner, 1978; Harpster, 1978; Lomas, 1979; Woody, 1978) containing 143 animals was used to develop this equation. These studies used Hankins and Howe (1946) to estimate body composition. An equation to predict EBF from EBW was developed using this database. Additionally, the equations devised by Simpfendorfer (1974; Eq. 23) and by Owens et al. (1995; Eq. 24) were evaluated.

$$iEBF = 0.00054 \times iEBW2 + 0.037 \times iEBW - 0.61 \quad [23]$$

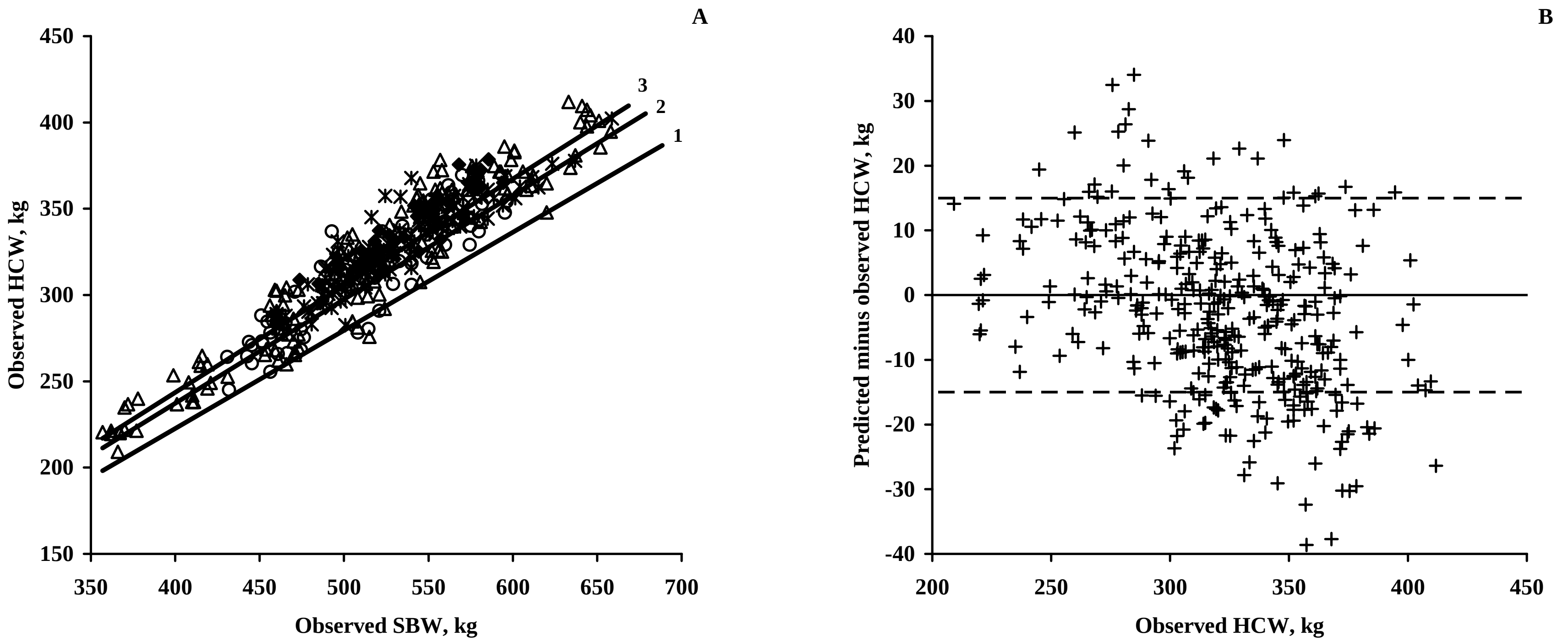

Figure 4. Relationship between hot carcass weight (HCW, kg) and shrunk body weight (SBW, kg). (A) Comparison of three published equations (1 – Fox et al., 1972, 2 – Garrett and Hinman, 1969, and 3 – Garrett et al., 1978). The data points are from Nour and Thonney (1987), Δ; Perry and Fox (1997), o; Perry et al. (1991), *; and Guiroy (2001), ♦. (B) Deviation (predicted using Garrett et al. (1978) equation minus observed) vs observed HCW indicated that 76% of the points lie within ± 15 kg (dotted lines).

$$iEBF = 0.000494 \times iEBW2 + 0.0991 \times iEBW - 11.34;\ R^2 = 0.89 \quad [24]$$

Where iEBF is initial empty body fat (kg) and iEBW is initial empty body weight (kg).

Table 10 has the comparison of our new equation (Eq. 25) to predict initial EBF from EBW with those published by Simpfendorfer (1974) and Owens et al. (1995). The Owens et al. (1995) equation predicts lower values for EBF when EBW was below 200 kg when compared to Simpfendorfer (1974). All three equations accounted for a similar proportion of the variation, but the new equation had a lower mean bias and RMSPE. Therefore we used Equation 25 to predict initial EBF.

$$iEBF = 0.244 \times iEBW - 15.4135 \quad [25]$$

Where iEBF is initial empty body fat (kg) and iEBW is initial empty body weight (kg).

Table 10. Comparison of equations to predict initial empty body fat (iEBF, kg) from initial empty body weight (iEBW, kg)

	Equations		
	Simpfendorfer (1974)	Owens et al. (1995)	New Equation[a]
Mean bias	-2.46	-2.13	-0.16
RMSPE[b], kg	9.43	12.51	8.70
Regression[b]			
MSE, kg^2	67.2	76.1	77.8
r^2	0.86	0.84	0.84

[a] Equation is iEBF = -15.4135 +0.244×iEBW.
[b] RMSPE = root mean square prediction error and MSE = mean square error. Regression parameters of observed on predict EBF using 70 data points, which contain 143 animals.

Figure 5 shows the prediction of EBF (Equations 19 to 22 and 25) in the growth model. The sub-model explained 81% of the variation but had an overprediciton bias of 14.4% (Figure 5A), which is explained by the intercept being different from zero ($P < 0.05$). This low accuracy, but high precision, in predicting EBF might be due to the errors integrated in the equations used to predict EBF (Equations 6 to 9). Figure 5B indicates that within the range 26 – 32% of EBF, which corresponds to the body composition of most feedlot animals commercially harvested, the sub-model overpredicted 77% of the EBF points by less then 6 units (%) on average. This systematic bias was eliminated ($P > 0.05$) when EBF calculated in Equation 9 was multiplied by an adjustment factor of 0.85. In a second evaluation with pen average data (n = 63 pens containing 590 animals), these equations accounted for 70% of the variation with an overprediction bias of 10%. These results suggest a bias of 10 to 14% needs to be subtracted from the predicted body fat until more data are developed to improve this prediction.

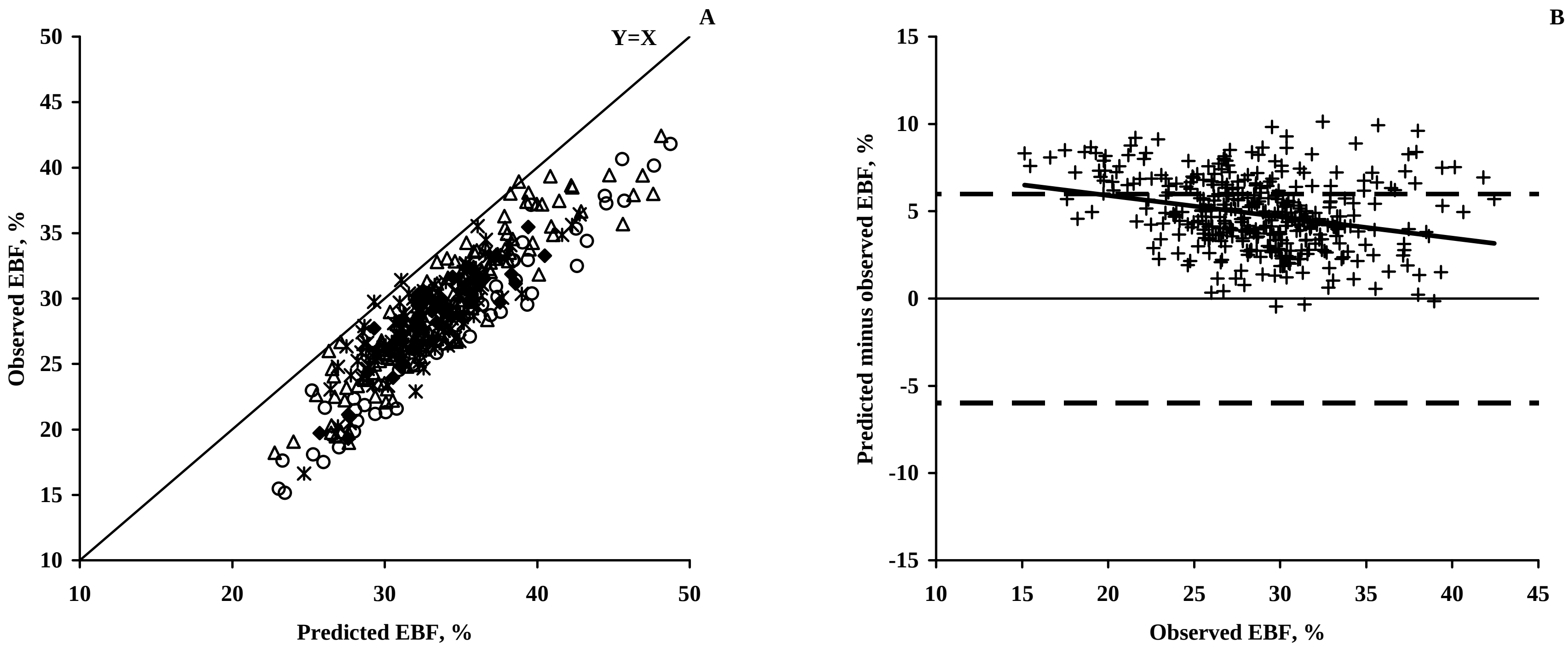

Figure 5. Prediction of empty body fat (EBF, % of empty body weight) at the end of the feeding period using the day-step model simulation. (A) Relationship between observed and predicted EBF. The data points are from Nour and Thonney (1987), Δ; Perry and Fox (1997), o; Perry et al. (1991), *; and Guiroy (2001), ♦. The regression is Y = -2.38 + 0.93×X with N = 358 animals, $r^2 = 0.81$, and bias = -14.4% ($P < 0.05$). Intercept and slope are different from zero and unity, respectively ($P < 0.05$). (B) Deviation (predicted minus observed) vs observed FSBW indicated that 71% of the points lie within ± 6 % (dotted lines). The solid line shows a systematic bias.

Table 11 summarizes the sequence of calculations in the growth model used to predict days required to reach a target composition. Figure 8A shows that the model accounted for 90% of the variation in individual animal ADG with no bias and Figure 8B indicates no deviation tendency. As a result, Figure 6A shows the observed weight at the actual total days on feed was accurately predicted (r^2 =0.86) and no bias with no deviation tendency (Figure 6B). When ADG was predicted using mean body weight and actual DMI, the variation accounted for was reduced to 81% (Figure 8A), compared to the model daily DMI adjusted for the ratio of actual/predicted DMI. In the above data, weight at 28% EBF could be accurately determined because final body fat of each individual animal was known. A small data set was available to evaluate the ability of model equations that use hip height and age to predict AFBW. The data set consisted of 29 bulls of five different breeds fed to finished weights. When only hip height and age were available to predict AFBW, the regression accounted for 58% of actual AFBW variation. However, when carcass measurements from ultrasound were used to generate inputs for the equation of Guiroy et al. (2001), the regression between observed and predicted AFBW had an r^2 of 0.75. Feed required for the observed ADG with AFBW computed with hip height and age or ultrasound to predict carcass fat depth, rib eye area and grade accounted for 93 and 96%, respectively, of the variation in feed required with AFBW computed from actual carcass measures. These results indicated ultrasound can be used to improve the prediction of AFBW.

Table 11. Sequence of calculations in the growth model

Step	Description
1	Determine NE_m and NE_g concentration of the diet
2	Determine the expected SBW at 28% body fat (Choice AFBW)
3	Determine the expected SBW at USDA Select grade using the following relationship: Select AFSBW = Choice AFSBW – (14.26 × (28.6 - 26.15)/0.891)
4	Determine the expected SBW at YG = 4
5	Predict daily DMI based on current SBW, diet energy, environmental conditions, and Choice AFSBW
6	Predict feed required for maintenance (FFM, kg) based on current SBW and environmental conditions as follows: FFM = NE_m required / diet NE_m
7	Predict NE available for gain (EFG, Mcal) from DMI and diet NE_g as follows: EFG = (DMI – FFM) × diet NE_g
8	Predict daily SWG from EFG and the current EQSBW of the animal to account for composition of gain
9	Compute the new SBW of the animal by adding SWG in step 6 to the initial SBW
10	Repeat steps 5 to 9 for each additional day until animal reaches expected finished SBW
11	Compute daily CW from EQCW
12	Compute carcass daily gain
13	Adjust predicted DMI of individuals with ratio of pen actual/predicted as appropriate
14	Allocate feed to individual animals in pens when sorted by days to finish at re-implant time with the feed allocation model (Guiroy et al., 2001)

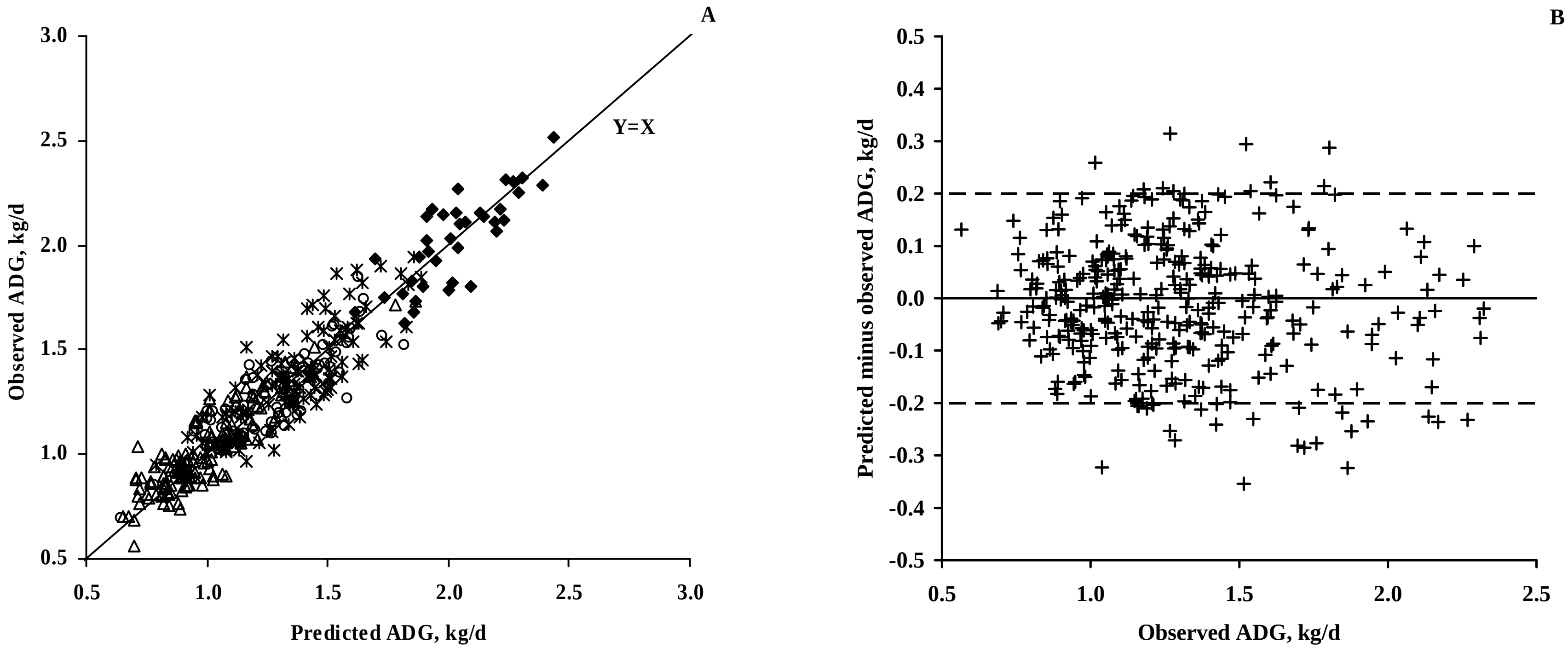

Figure 6. Prediction of ADG (kg/d) using the day-step model simulation. (A) Relationship between observed and predicted ADG. The data points are from Nour and Thonney (1987), Δ; Perry and Fox (1997), o; Perry et al. (1991), *; and Guiroy (2001), ♦. The regression is Y = 0.1 + 0.93×X with N = 362 animals, $r^2 = 0.90$, and bias = 0.9% ($P > 0.05$). Intercept and slope are different from zero and unity, respectively ($P < 0.05$). (B) Deviation (predicted minus observed) vs observed ADG indicated that 87% of the points lie within ± 0.2 kg/d (dotted lines).

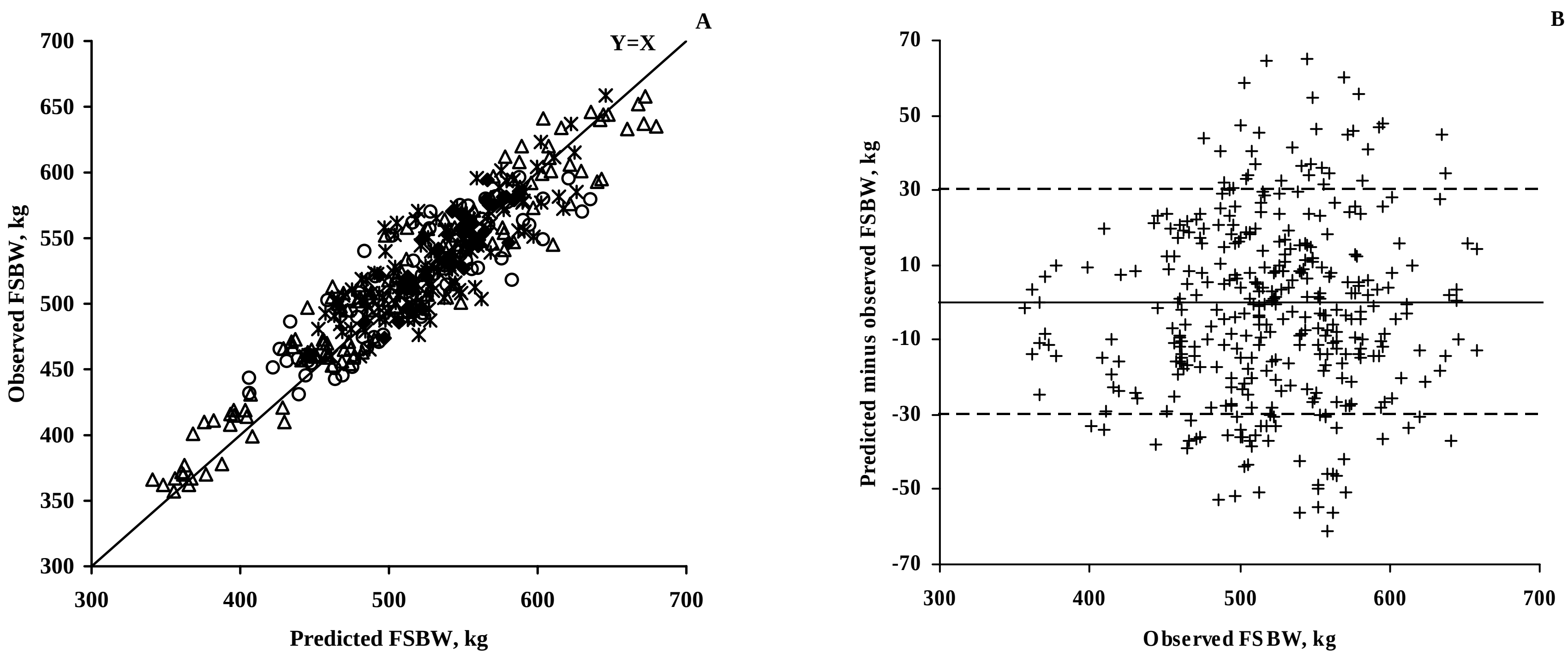

Figure 7. Prediction of final shrunk body weight (FSBW, kg) at the end of the feeding period using the day-step model simulation. (A) Relationship between observed and predicted FSBW. The data points are from Nour and Thonney (1987), Δ; Perry and Fox (1997), o; Perry et al. (1991), *; and Guiroy (2001), ♦. The regression is $Y = 85.8 + 0.84 \times X$ with N = 362 animals, $r^2 = 0.86$, and bias = 0.4% ($P > 0.05$). Intercept and slope are different from zero and unity, respectively ($P < 0.05$). (B) Deviation (predicted minus observed) vs observed FSBW indicated that 79% of the points lie within ± 30 kg (dotted lines).

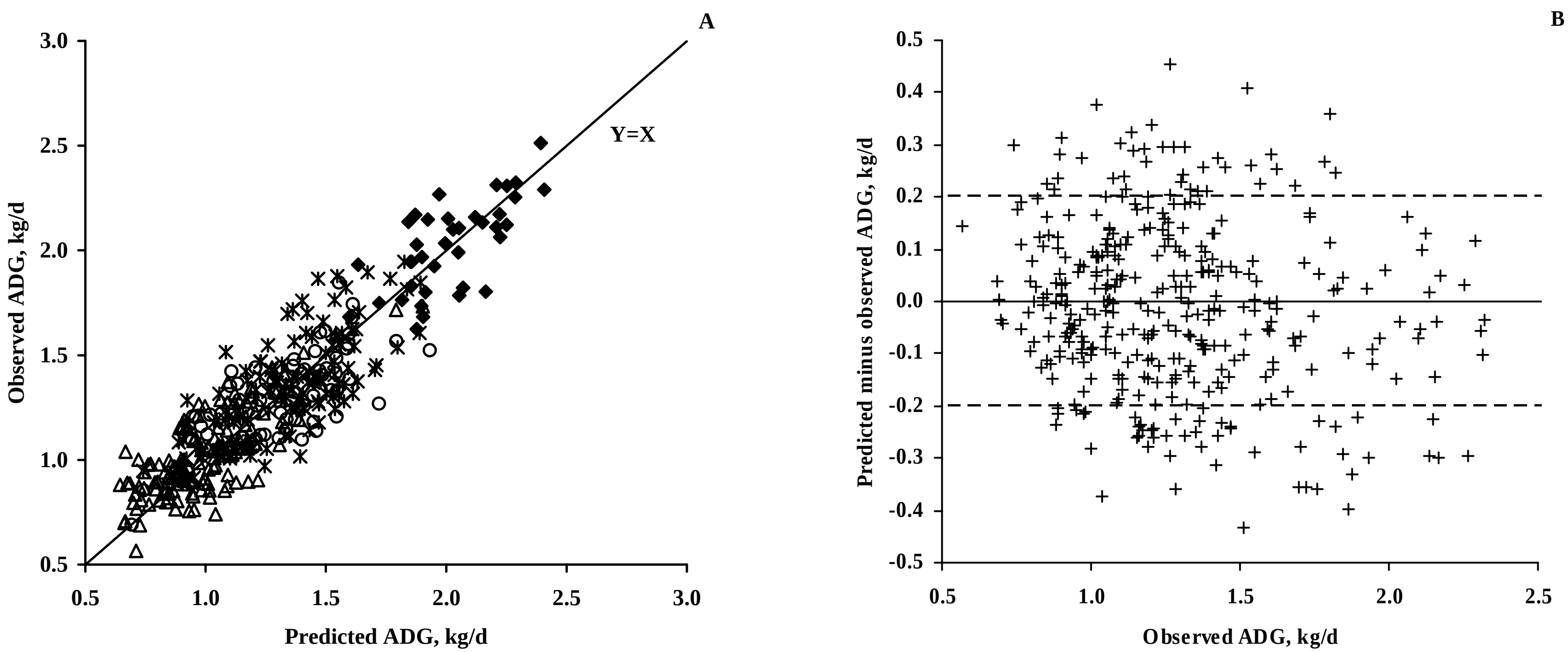

Figure 8. Prediction of ADG (kg/d) using mean shrunk body weight (kg). (A) Relationship between observed and predicted ADG. The data points are from Nour and Thonney (1987), Δ; Perry and Fox (1997), o; Perry et al. (1991), *; and Guiroy (2001), ♦. The regression is Y = 0.17 + 0.88×X with N = 362 animals, $r^2 = 0.81$, and bias = 0.8% ($P > 0.05$). Intercept and slope are different from zero and unity, respectively ($P < 0.05$). (B) Deviation (predicted minus observed) vs observed ADG indicated that 75% of the points lie within ± 0.2 kg/d (dotted lines).

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5.2. Predicting Yield Grade

An equation to predict yield grade (YG) from empty body fat (EBF, %) was developed using 407 steers from three datasets (Guiroy, 2001; Nour, 1982; Perry and Fox, 1997). These datasets were comprised of purebreds (390) and crossbreds (17) of Angus (204), Simmental (44), Holstein (113), and Hereford (29). The validation was performed with independent data from six studies (Crickenberger, 1977; Danner, 1978; Harpster, 1978; Lomas, 1979; Perry et al., 1991; Woody, 1978). These datasets had a mix of pen- and individual fed steers (820) and heifers (146) of purebreds (789) and crossbreds (177) of Holstein (88), Angus (83), Charolais (144), Brangus (103), Chianina (31), and Hereford (340).

Equation 26, which was developed to predict YG from EBF (n = 389), accounted for 57% of the variation in YG (MSE = 0.38). This equation is very similar to that developed by Fox and Black (1984; Equation 27), which uses carcass fat.

$$YG = -0.604 + 0.127 \times EBF \qquad [26]$$

$$YG = -1.7 + 0.15 \times CF \qquad [27]$$

Where YG is yield grade, EBF is empty body fat (% of empty body weight), and CF is carcass fat (% of empty body weight).

Figure 9 shows the evaluation of Equation 26 in predicting YG. Equation 26 explained 49% of the variation in YG, using EBF as the only predictor (Figure 9A), with a significant bias ($P < 0.01$) of -3.2%. Figure 9A also compares Equation 26 with Equation 27 (Fox and Black, 1984). Both equations had similar and satisfactory predictions of YG in the range of 2.5 and 3.5; however, below 2.5 and above 3.5, Equation 27 tended to over- and underpredict YG. Figure 9B shows a large deviation between predicted and observed YG, which is likely due to the intrinsic variation of the observed values. However, within the range 2.5 to 3.5, 77% of the predicted YG values were ± 0.5 units.

Table 12 shows the risk associated with predicting YG at three YG thresholds using Equation 26. As the YG threshold increases, the ratio of error 1 (observed YG is greater than threshold and predicted YG is lower than threshold) to error 2 (observed YG is lower than threshold and predicted YG is greater than threshold) increases more then 8 times, indicating the risk of an overprediction is greater than an underprediction of fat content of the carcass at higher YG values.

Therefore, we developed an equation (Eq. 28) to compute the minimum value of EBF that would yield a desired yield grade. Equation 28 is based on inverse prediction statistics (Neter et al., 1996) for 80% confidence limits.

$$MinEBF = 4.749 + 7.861 \times YG - 8.006 \times \sqrt{1.052 - 0.0317 \times YG + 0.0051 \times YG^2} \qquad [28]$$

Where YG is desired yield grade and MinEBF is the minimum EBF (%).

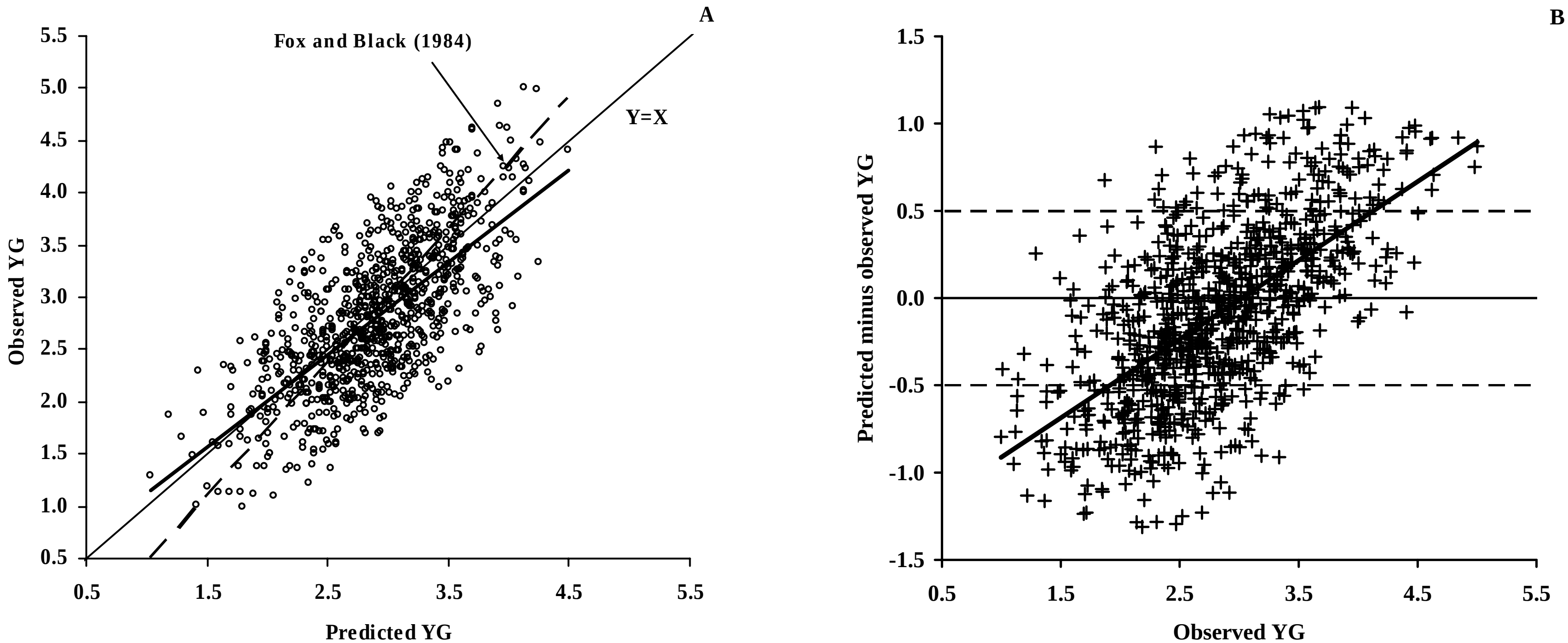

Figure 9. Evaluation of the equation to predict YG from empty body fat (EBF, %). (A) Relationship between observed and predicted yield grade (YG). The data are from six studies (Crickenberger, 1977; Danner, 1978; Harpster, 1978; Lomas, 1979; Perry et al., 1991; Woody, 1978). The regression (solid line) is $Y = 0.23 + 0.89 \times X$ with N = 915 animals, $r^2 = 0.49$, and bias = -3.2% ($P < 0.01$). Intercept and slope are different from zero and unity, respectively ($P < 0.05$). The dotted line shows the YG predicted using the equation developed by Fox and Black (1984). (B) Deviation (predicted minus observed) vs observed YG indicated that 65% of the points lie within ± 0.5 (dotted lines). The solid line shows a systematic bias.

Table 12. Comparative risk of prediction of yield grade (YG) given the observed YG for three thresholds [a]

Error	Yield Grade		YG Threshold		
	Observed (YGo)	Predicted (YGp)	3.0	3.5	4.0
--	≤ Threshold	≤ Threshold	46.4	77.3	94.4
--	≥ Threshold	≥ Threshold	29.1	7.8	1.3
1	≥ Threshold	≤ Threshold	9.6	9.2	3.6
2	≤ Threshold	≥ Threshold	14.9	5.7	0.7

[a] Values are percentage of 915 animals.

6. Accounting for Implant Strategies on AFBW

There are two possible options for modifying the inherited mature size of cattle (NRC, 2000): (1) placing animals on different planes of nutrition or (2) using a particular anabolic implant strategy.

Anabolic implants are known to shift the composition of gain in cattle by increasing protein deposition and decreasing fat at a particular weight (NRC, 1984, 2000). Implanted animals reach the same body composition at a heavier weight when compared to non-implanted animals (Hutcheson et al., 1997; Perry et al., 1991).

Guiroy et al. (2002) quantified the change in final BW due to a particular implant strategy when animals are adjusted to the same final body composition. The database used in their study had 13 implant trials involving a total of 13,640 animals (9,052 steers and 4,588 heifers). Fifteen different implant strategies were used among these trials, including no implant (control), single implants, and combinations of implants. The following discussion was extracted from Guiroy et al. (2002).

Table 13 presents the AFBW computed for each implant strategy with the 9,052 steers. Shrunk BW adjusted to 28% EBF ranged from 520 kg in non-implanted steers to 564 kg in steers implanted and re-implanted with Revalor-S. Table 13 also shows implant strategies with similar AFBW (not different within a category at $P > 0.10$) grouped in five categories, including the mean AFBW for each category and the change increment from the no implant treatment. All differences in AFBW between categories were significant ($P < 0.01$).

The increment was the lowest (13.7 ± 4.6 kg) in category 2 that included animals receiving either an estrogenic implant (Comp-ES) or an intermediate dose of Estradiol-17β plus trenbolone acetate (TBA) (Rev-IS). This increment was the highest (41.8 ± 2.6 kg) in category 5 that included animals receiving Revalor-S, Revalor-IS or Rev-3 as the first implant and Revalor-S as the second implant. The other categories (3 and 4) fell in between 2 and 5, reflecting the dose response previously mentioned. The SE for the prediction of the increase in AFBW was low, especially for categories 3, 4, and 5 in Table 13.

Table 13. Shrunk body weight adjusted to 28% empty body fat (AFBW) for fourteen different implant strategies on steers

Implants[a]	N[b]	AFBW[c], kg	Category	Common AFBW, kg	Change in AFBW, kg
Control	730	519.5	1	519.5[d]	-
Comp-ES	267	529.9	2	533.1[e]	13.7 ± 4.6
Rev-IS	266	536.5			
No/Rev-S	732	549.4	3	549.8[f]	30.4 ± 2.3
Rev-S	1567	549.8			
Rev-G/Rev-S 35d	78	544.5			
No/Rev-S 35d	80	548.4			
Ral/Rev-S	493	551.5			
Syn-S/Rev-S	1414	554.3	4	554.7[g]	35.3 ± 2.3
Rev-IS/Rev-IS	794	555.2			
Rev-G/Rev-S	730	555.2			
Rev-3/Rev-S	154	562.6	5	561.1[h]	41.8 ± 2.6
Rev-IS/Rev-S	915	558.7			
Rev-S/Rev-S	832	563.7			

[a] Initial implant/Second implant.
[b] Number of pooled animals per treatment.
[c] The AFBW values within a category are not statistically different ($P > 0.10$). Average SE of the least square mean pairwise comparison was 4.88 kg.
[d,e,f,g,h] Within a column, means without a common superscript letter differ ($P < 0.01$). Average SE of the least square mean pairwise comparison was 2.99 kg.

Table 14 presents the results for heifers using the same analysis described above for steers. The AFBW values ranged from 493 kg in non-implanted heifers to 532 kg in heifers implanted and re-implanted with Revalor-H. The analysis of the heifer trials resulted in three different categories of implant strategies. Results from Table 14 indicate similar increments in AFBW over no implant to those shown for steers in Table 13.

Table 15 shows the number of steers or heifers in each of the USDA quality grades, and the percentage grading USDA choice – or higher for each of the 5 implant categories for steers and the three implant categories for heifers. Nonimplanted steers averaged 62.5% low Choice or greater; values for implanted steers were lower. Nonimplanted heifers averaged 52.5% low Choice or greater; the value for those in implant category 2 were higher while that of implant category 3 was lower. The categorical data analysis indicated an association between implant categories and USDA grades ($P < 0.01$) for steers and heifers. However, since these were all time constant trials and Table 14 shows implanted cattle should reach the same EBF (as % of empty BW) at a heavier weight, these data have limited value in determining the effect of implants on carcass grade.

Table 14. Shrunk body weight adjusted to 28% empty body fat (AFBW) for seven different implant strategies on heifers

Implants[a]	N[b]	AFBW[c], kg	Category	Common AFBW, kg	Change in AFBW, kg
Control	52	493.5	1	493.5[d]	-
Rev-H	809	521.8			
Rev-IH/Rev-IH	805	525.1	2	523.6[e]	30.2 ± 5.8
No/Rev-H	99	525.5			
Rev-IH/Rev-H	888	531.6			
Syn-H/Rev-H	896	531.6	3	532.2[f]	38.8 ± 5.7
Rev-H/Rev-H	894	534.5			

[a] Initial implant/Second implant.
[b] Number of pooled animals per treatment.
[c] The AFBW values within a category are not statistically different ($P > 0.10$). Average SE of the least square mean pairwise comparison was 4.97 kg
[d,e,f] Within a column, means without a common superscript letter differ ($P < 0.01$). Average SE of the least square mean pairwise comparison was 3.83 kg.

Perry et al. (1991) studied the growth performance and composition of gain responses to an implant containing both TBA and estradiol in three breed types of steers when harvested at the same degree of marbling as determined by ultrasound. Within each of the breed categories (Holsteins, Angus, and Angus × Simmental), final marbling scores and carcass fat percentages were not different between implanted and nonimplanted steers.

Table 15 also shows the average predicted EBF for the cattle in each USDA quality grade within each of the implant categories, demonstrating the variability in EBF at a particular grade. In some comparisons, implanted cattle had significantly more EBF than controls at the same grade. In other cases, the EBF was similar in adjacent quality grades; this reflects differences in marbling in cattle at the same EBF. The EBF at a particular quality grade were similar to those reported by Guiroy et al. (2001) for controls, but were typically higher for implanted cattle. This is likely due to differences in breed types in this data base (no Holsteins and some Brahman breeding).

Table 15. Average USDA quality grade and predicted empty body fat within a USDA quality grade for each implant category

Sex	Category	Ch- [a]	Variables[b]	USDA Grade[c]						
		%		Std	Se	Ch-	Ch	Ch+	Pr-	Pr
S	1	62.5	N EBF	11 26.0	261 27.7	297 29.3^{y}	93 30.5^{y}	35 31.3^{y}	18 31.5^{y}	11 33.0
S	2	56.8	N EBF	4 26.0	226 28.1	153 30.2^{x}	130 31.5^{xy}	17 33.7^{x}	3 39.0^{x}	-- --
S	3	55.3	N EBF	74 25.1	1242 28.0	1139 29.7^{x}	339 31.0^{y}	95 32.3^{xy}	35 32.4^{y}	20 33.2
S	4	54.2	N EBF	83 25.4	1261 28.1	1152 29.9^{x}	298 31.1^{y}	114 32.3^{x}	16 32.8^{y}	9 32.9
S	5	46.3	N EBF	99 24.8	921 27.9	657 29.7^{xy}	163 31.6^{x}	58 31.5^{y}	3 32.0^{y}	-- --
S			SE	0.94	0.20	0.23	0.35	0.68	1.09	0.91
H	1	52.5	N EBF	-- --	47 25.6	35 27.6^{xy}	12 27.9^{y}	4 30.9	1 30.3	-- --
H	2	56.0	N EBF	49 23.3	746 25.9	746 28.0^{x}	182 29.5^{x}	57 31.1	22 32.0	6 32.8
H	3	49.8	N EBF	77 23.2	1266 27.7	1005 27.6^{y}	239 29.5^{x}	62 30.8	21 32.3	6 30.7
H			SE	0.41	0.28	0.34	0.55	0.97	1.50	2.12

[a] Percentage of animals that graded USDA low Choice (Ch-) or greater. There is an association between implant strategies and USDA grades ($P < 0.01$).
[b] N is number of animals, EBF is empty body fat, % of empty BW, and SE is the average SE of the least square means pairwise comparison.
[c] USDA Grades are Std = Standard, Se = Select, Ch- = low Choice, Ch = Choice, Ch+ = high Choice, Pr- = low Prime, and Pr = Prime.
[xy] Within a column and same sex, means without a common superscript letter differ ($P < 0.01$).

7. CVDS Model Application

The primary goal of ICMS is to harvest each individual animal at its' most profitable point in growth. The growth model provides predicted performance data for individual animals that are needed to make economic predictions. Daily feed intake and ADG are used to predict accumulated weight and feed required, which can be used with feed costs to compute incremental cost of gain. Accumulated weight and feed required can be used with animal, feed and non feed costs to compute break even sale price for each animal on any day. Accumulated weight and composition can be used with market prices, grade and weight discounts, and break even sale price to compute profitability each day. Predicted days to reach the target market weight can be used for risk management, and harvest and purchase scheduling.

The CVDS model through the growth model can be used to predict growth rate, accumulated weight, days required to reach a target body composition, and carcass weight of individual growing beef cattle with an acceptable degree of accuracy. The information provided can be used with economic information (animal, feed, interest, death loss, and yardage costs and expected live or carcass prices and discounts) to compute incremental cost of gain, accumulated total costs, and break even sale prices during growth to determine optimum time to harvest each individual animal.

8. Equations Summary

This section describes the equations and relationships used in developing the CVDS model. More information on the scientific background and development of the growth model can be found in Tedeschi et al. (2003) and Fox et al. (2003)

8.1. Energy Requirement and Growth Simulation

Similar to NRC (2000), we adjust NEm requirement (Mcal/d) depending on cattle type as follows:

If Beef: a1 = 0.07

If Dairy: a1 = 0.078

Equivalent weight ($EqSBW_t$, kg) is computed using information of a medium-frame size steer slaughtered at USDA low choice grade (28.61% of empty body fat, Guiroy et al., 2001). The final shrunk body weight (FSBW, kg) is used for growing/finishing animals and the mature weight (MW, kg) is used for the replacement heifers as shown below:

If Growing: $EqSBW_t = (478 \times SBW_t) / FSBW$

If Replacement Heifers: $EqSBW_t = (478 \times SBW_t) / MW$

Equivalent carcass is computed using the equation developed by Garret and Hinman (1969).

$$EqCW_t = (0.891 \times EqSBW_t - 30.26) / 1.36$$

A quadratic equation was developed to continuously accommodate the influence of body fat on intake ($BFAF_t$) based on NRC (2000) adjustment factors. This adjustment is used if $EqSBW_t$ is greater then 350 kg.

$$BFAF_t = 0.7714 + 0.00196 \times EqSBW_t - 0.00000371 \times EqSBW_t^2$$

The environmental influence on dry matter intake and energy for maintenance (insulation) were used as described in NRC (2000).

$WS_t = 0.27778 \times Wind_t$

$CETI_t = 27.88 - 0.456 \times Tc_t + 0.010754 \times Tc_t^2 - 0.4905 \times RHC_t + 0.00088 \times RHC_t^2 + 1.1507 \times WS_t - 0.126447 \times WS_t^2 + 0.019876 \times Tc_t \times RHC_t - 0.046313 \times Tc_t \times WS_t + 0.4167 \times HRS_t$

$DMIAFN_t = 119.62 \times (-0.9708 \times CETI_t) / 100$

There are some adjustments if current temperature (Tc) is below 20 ^oC and/or -20 ^oC.

If $Tc_t \leq -20$: $DMIAF_t = 1.16$

If $-20 \leq Tc_t \leq 20$: $DMIAF_t = 1.0433 - 0.0044 \times Tc_t + 0.0001 \times Tc_t^2$

Similarly, if current temperature is greater than 28 ^oC

If $20 \leq Tc_t \leq 28$: $DMIAF_t = ((1 – DMIAFN_t) \times 0.75 + DMIAFN_t)/100 + 1.05$

If $Tc_t \geq 28$: $DMIAF_t = ((1 – DMIAFN_t) * 0.75 + DMIAFN_t)/100 + 1$

Adjustment of intake for mud depth is as follows:

$Mud1Adj_t = 1 - 0.01 \times Mud_t$

In the NRC (2000), the body condition score is used to account for compensatory growth in the following manner:

$Comp_t = 0.8 + (BCS_t - 1) \times 0.05$

However, we developed a dynamic adjustment based on data summarized by Tedeschi et al. (2003) in order to change the energy requirement for maintenance during the first 45 days after the commence of re-feeding.

The predicted dry matter intake is based on NRC (2000) with the adjustments discussed above.

For calves (Age ≤ 12 months):

$PredDMI_t = ((SBW_t^{0.75} \times (0.2435 \times NEm_t - 0.0466 \times NEm_t^2 - 0.1128)) / NEm_t) \times BFAF_t \times DMIAF_t \times Mud1Adj_t \times ImplantsFactor \times HolsteinFactor \times (RDMI_t/100)$

For yearlings (Age > 12 months)

$PredDMI_t = ((SBW_t^{0.75} \times (0.2435 \times NEm_t - 0.0466 \times NEm_t^2 - 0.0869)) / NEm_t) \times BFAF_t \times DMIAF_t \times Mud1Adj_t \times ImplantsFactor \times HolsteinFactor \times (RDMI_t/100)$

Where:

ImplantsFactor is 0.94 if not using Implants, otherwise it is 1,
HolsteinFactor is 1.08 if Holstein breeding, otherwise it is 1, and
$RDMI_t$ is relative dry matter intake.

We account for the effect of mud on the insulation of the animal based on degrees of HairCoatt. If HairCoatt is 1 (dry and clean condition) or 2 (some mud on lower body) the adjustment is:

$$Mud2Adj_t = 1 - (HairCoat_t - 1) \times 0.2$$

Otherwise, if If $HairCoat_t$ is 3 (wet and matted condition) or 4 (covered with wet snow or mud) the adjustment is:

$$Mud2Adj_t = 0.8 - (HairCoat_t - 2) \times 0.3$$

Hide adjustment ($HideAdj_t$) is calculated based on hide thickness as follows: (1) thin = 0.8; (2) average = 1; and (3) thick = 1.2.

External insulation is computed based on Wind (kph) and Hair length (cm), and it is adjusted for Mud and Hide.

$$EI_t = (7.36 - 0.296 \times Wind_t + 2.55 \times Hair_t) \times Mud2Adj_t \times HideAdj_t$$

Tissue insulation depends on body condition score of the animal and is computed as:

$$TI_t = 5.25 + 0.75 \times BCS_t$$

Retained energy is used heat production, which is used to compute lower critical temperature (LCT, ^oC). Therefore, we calculate retained energy (RE) and heat production (HP) as follows:

$$RE_t = (PredDMI_t - (SBW_t^{0.75} \times (a1 * Comp_t \times Activity_t))/NEm_t) \times NEg_t$$

$$HE_t = (ME_t \times PredDMI_t - RE_t) / (0.09 * SBW_t^{0.67})$$

Therefore, total insulation (IN) and LCT are computed as:

$IN_t = TI_t + EI_t$

$LCT_t = 39 - (IN_t \times HE_t \times 0.85)$

If LCT_t is greater then the current temperature (Tc_t), which means the animal is under cold stress, requirement for metabolizable energy under cold stress ($MEcs_t$) is calculated as follows. Otherwise, $MEcs_t$ is zero.

$MEcs_t = 0.09 \times SBW_t^{0.67} \times (LCT_t – Tc_t) / IN_t$

$NEmcs_t = (NEm_t / MetEn_t) \times MEcs_t$

$NEmAdj_t = a1 \times (Activity_t + NEmcs_t)$

Feed for maintenance is computed as:

$FFM_t = (SBW_t^{0.75} \times NEmAdj_t / NEm_t$

For replacement heifers, we estimate the energy requirement for pregnancy as follows. If not pregnant we the days pregnant is calculated based on target calving age (TCA,d), target pregnant age (TPA, d), and age.

TPA = TCA * 30.5 - 280

BPADG = (TPW - iSBW) / (TPA - Age * 30.5)

If t > (TPA - Age * 30.5): DaysPregt = Int_t - (TPA - Age * 30.5))

Otherwise:

DaysPredt = 0

Average daily gain (ADG, kg/d) and conceptus weight (kg/d) are estimated based on Bell et al. (1995) and NRC (2000).

For Dairy cattle:
If $DaysPreg_t < 190$: $ADGpreg_t = 100$ and $PregCW_t = 0$

Otherwise:

$ADGpreg_t = 665 * CBW / 45$

$PregCW_t = (18 + ((DaysPreg_t - 190) \times 0.665)) \times CBW / 45$

For Beef cattle:

$ADGpreg_t = (CBW \times (18.28 \times (0.02 - 0.0000286 \times DaysPreg_t) \times Exp(0.02 \times DaysPreg_t - 0.0000143 \times DaysPreg_t^2))) / 1000$

$PregCW_t = (CBW \times 0.01828) \times (Exp(0.02 \times DaysPreg_t - 0.0000143 \times DaysPreg_t^2)) / 1000$

Metabolizable energy for pregnancy is computed as follows:

If DaysPregt > 190:

$MEpreg_t = (2 \times 0.00159 \times DaysPreg_t - 0.0352) \times (CBW / 45) / 0.14$

Otherwise:

$MEpreg_t = (CBW \times (0.05855 - 0.0000996 \times DaysPreg_t) \times Exp(0.03233 \times DaysPreg_t - 0.0000275 \times DaysPreg_t^2) / 1000) / 0.13$

Feed for pregnancy is then computed as:

$FFP_t = MEpreg_t / ME_t$

Energy for gain (EFGt, Mcal/d) and shrunk weight gain (SWG, kg/d) are computed based on NRC (2000) equations.

$EFG_t = (PredDMI_t - FFM_t - FFP_t) \times NEg_t$

$SWG_t = 13.91 \times EqSBW_t - 0.6837 \times EFG_t^{0.9116}$

The dressing percentage (CWPt, %), carcass weight (CWt, kg), and new SBW are computed as:

$CWP_t = EqCW_t \times 100 / EqSBW_t$

$CW_t = CWP_t \times SBW_t / 100$

$SBW_{t+1} = SBW_t + SWG_t$

8.2. Economical Calculations

Table 16 has the economical calculations and Table 17 has some economical indexes that are used for growing animal in the CVDS model.

Table 16. Economical calculations used in the Cornell Value Discovery System model[1]

Variable	Description	Equation
PuC	Purchase	iSBW(kg) × (Purchase($×100/kg) / 100)
FC	Feed cost	Total DMI(kg) × Feed Cost($/kg)
TC	In trucking	InTruck($)
PrC	In Processing	InProc($)
YC	Yardage	Yardage($/d) × DOF(d)
AInt	Int. on animal	PurCost($) × (AnInt(%/yr)/100) × DOF(d) / 365
FInt	Interest on feed	FeedCost($) × (FeedInt(%/yr)/100) × DOF(d) / 365
Death losses:		
FCD	Feed cost	FeedCost($) × DeathDays(d)/DOF(d)
YCD	Yardage	Yardage($/d) × DeathDays(d)
FIntD	Interest on feed	FInt($) × DeathDays(d) /DOF(d)
ASold	Animals sold	(1 – Death(%)/100) × Animals
DC	Death cost	(PuC+TC+PrC+AInt+FCD+YCD+FIntD) × (An – ASold)/ASold
TotalC	Total costs	(PuC + FC + TC + PrC + YC + AInt + FInt + DC)
Carcass discounts:		
lCWC	CW < min CW	SBW(kg) × (UnderCW($×100/kg)/100) × (CD(%)/100)
uCWC	CW > max CW	SBW(kg) × (OverCW($×100/kg)/100) × (CD(%)/100)
YG discounts:		
lYGC	YG < min YG	SBW(kg) × (UnderYG($×100/kg)/100) × (CD(%)/100)
uYGc	YG > max YG	SBW(kg) × (OverYG($×100/kg)/100) × (CD(%)/100)
GrossS	Gross sales	SBW(kg) × (Sale($×100/kg)/100) – (lCWC + uCWC + lYGC + uYGC)
NetR	Net return	GrossS – TotalC

[1] DOF – days on feed, iSBW – initial shrunk body weight (kg), CD – carcass dressing (%), An – Animals, DeathDays is the average growth days that animals die in the beginning of the feedlot (default = 18 d).

Table 17. Economical indexes used in the Cornell Value Discovery System model[1]

Description	Equation
Feed cost per gain, $/kg	FC/(SBW - iSBW)
Total cost per gain, $/kg	TotalC/(SBW-iSBW)
Sale break even, $ × 100/kg	TotalC × 100/SBW
Purchase break even, $ × 100/kg	(GrossS – TotalC – PuC) × 100/iSBW
Annual margin for all costs, %	(GrossS – TotalC) × 36500 / (TotalC × DOF)
Annual turnover	365/DOF

[1] Check Table 1 for acronyms.

TUTORIALS

1. Allocating feed to individuals in group pens

Grid pricing structures have increased. Producers who have the genetics to meet premium grids are taking advantage of them through retained ownership. In addition, as feed costs represent 50% of the cost of feeding cattle, producers are interested in selecting for feed efficiency. However, the average herd size in the U.S. is under 25 beef cows, while most commercial feedlots have pen sizes that have capacities of 50 head or greater. Therefore pens of cattle must contain cattle from different owners. This tutorial describes how to use the Cornell Value Discovery model (CVDS) to allocate feed to individual animals fed in the same pen.

This sample data set consists of twenty cattle, 10 steers and 10 heifers, having varied initial weight and mature size and owned by three different farms. They all arrived at the same time and are fed till they reach USDA low Choice; therefore they are marketed at two different times.

Step 1- Create a new simulation

1. Open the CVDS software.
2. Click on **File, New.**
3. In this simulation we will only be using the "**Individual Management**" and "**Environment**" tab. The other two tabs "**Group Management**" and "**Economics**", will be used when evaluating animals as a group, not as individuals.
4. Click on **Individual Management** tab.
5. At the end of the Database box, click on left button "**Create a new database**".
6. Give the file a name (e.g. "**Tutorial**") and click open. You will receive message that database was created successfully.

Step 2- Create a template for data entry

1. In bottom right corner click "**Imp/Exp**".
2. Select the "**Excel via ActiveX**" and click on "**Template**" button. You will be asked for a file name (e.g. "**Tutorial**").
3. A message will tell you that the data has been successfully exported and will tell you the location. Note the location, click **OK**, and then **Return**. You now have an Excel spreadsheet with 7 sheets. Filling in the sheets with the data requested will build your data base.

Step 3 – Data entry

1. Locate and open file "**Tutorial.XLS**". Note that the most likely location is in C:\My Documents\CVDS\CVDS Files for PC with MS Windows 95, 98, or ME and

C:\Documents and Settings\<LoginName>\My Documents\CVDS\ CVDS Files for PC with MS Windows NT, 2000, or XP.

2. Complete all sheets (Animal, Pen, Owner, Diet, Feeds, and Period) with the animal data Available.
   a. The first column in each sheet will be labeled "***sheet name* Record**", e.g. "**Pen Record**". This column is to be filled in with sequential numbering.
   b. Hover over top cell in each column. A comment box will give instructions specific to that column.
   c. "**Pen ID**" must be numeric only, no alpha characters.
   d. In "**Diet**" sheet enter either **ME** <u>or</u> **NEg** and **NEm**.
   e. In "**Feed**" enter either **AsFedIntake** and **DM** <u>or</u> **DMIntake**, *not both*
   f. The **"FeedCost**" should reflect the cost of the feed ($/lb) on the same basis you entered, either "**AsFedIntake**" or "**DMIntake**".
   g. In "**Feed**" each ration will have its own **Diet Record**. For example in "**Tutorial**" example there are two diets fed to two pens, giving four diets total.
   h. Generally, if column heading is shaded gray, no data input is needed. The model will compute the needed data.
   i. In "**Period**", user may enter the final weight, or interim weights if available.
   j. In "**Period**" and "**Animal**" user must indicate if weights are shrunk. If cattle have been weighed after being off feed and water for 8 hours, or hauled for more than 4 hours, then the weight will be considered shrunk. Otherwise enter "False" in these columns.
   k. In "**Period**" RDMI is relative dry matter intake. Generally user will enter 100, unless they have reason to believe cattle will eat more or less than expected.
   l. In "**Animal**":
      - Marbling can be entered as "**Mrb Class**" and "**Mrb Pctl**", or user can enter numerical representation in the "**Mrb**" column.
      - **AFBW** is the weight at which you believe the animal will grade low Choice. It can be entered by user or left empty and it will be automatically calculated using hip height or carcass measurements. If user allows CVDS to compute **AFBW**, then after running the model the column "**cAFBW**" will be filled in.
      - "**Exclude**" is entered as "**True**" if data on this animal is not to be used, e.g. simulations of interest.
   m. Print "**Animal**" sheet which will provide user with a "key" which gives Animal Record and corresponding animal information (e.g. Animal ID, Pen ID, Owner Record, Sex, etc.)
   n. When finished entering data in all of the required sheets, **Save the** spreadsheet.

Step 4. Importing data from the spreadsheet into the database

1. Return to CVDS software and under "**Individual Management**" tab click "**Imp/Exp**" button.
2. If importing from a spreadsheet, select the "**Excel via ActiveX**".
3. Click "**<u>I</u>mport**" button.
4. User will be requested to enter name of file. Select "**Tutorial.XLS**", then "**<u>O</u>pen**".

5. A box will pop up with the question: "**Do you want to import all tables**", check "**Yes**".
6. Data import will take some time depending on your computer characteristics, be patient.
7. If successful, a box will appear telling user that data have been imported successfully. Click "**OK**", then "**Return**".
8. Now under each of the buttons, user should find data entered from spreadsheet.

Step 5. Entering environmental data

1. Before computations can be completed, environmental data must be entered.
2. Go to "**Environmental**" tab.
3. Select "**Open monthly environmental file**".
4. Select and "**Open**" "**T&R Environment Data.Dat**" file under …\CVDS\CVDS Files folder.
5. Check boxes: "**Adjust NEm to heat/cold stress?**" and "**Adjust DMI due to environment affect?**"; in this example, we want to adjust these computations with the environment information.

Step 6. Using data to calculate and provide results

1. Under "**Individual Management**" click "**Calculate**".
2. Again depending on your computer characteristics, this procedure will take time; get some coffee and be patient.
3. Upon completion, user will see the calculation results under the "**Simulation Results**" tab.

Step 7. Interpretation of results

1. Results can be exported to an Excel spreadsheet or viewed and/or printed directly from the software.
    a. To **export results** to a spreadsheet, click on "**Imp/Exp**", check "**Export results only?**" box, and then "**Export**".
    b. User will be asked to name the file, e.g. "**Tutorial Results**". After naming file, click "**Open**".
    c. Note location of results file. Once exported, it can now be used to manipulate data in any form required.
2. Under the "**Simulation Settings**" tab, the user can define how the results are to be reported. The results can be sorted by Animal, Pen, Owner or Sex, or combinations. Once the user chooses how the data are to be sorted, clicking the "**Results**" tab will cause the data to appear on the screen in the manner described.
3. We will use **Animal Record** 1 for an example interpretation. Recall that **Animal Record** 1 is **AnimalID** 70, a steer owned by **Owner Record** 1, Wooded Acre.
4. From the results user can see the last **Weight Date**, **Starting body weight (BW)**, and **Ending BW**.

5. **DMI** is the amount of DM per day the animal needed to consume to meet requirements for maintenance and growth. **Total DM Required** is the amount consumed for the entire feeding period.
6. **Allocated Total DM Required** is that share of the total feed delivered tha was charged to this individual. To arrive at this figure, **Total DM Required** for each animal is summed to compute Total DM Required by all the animals in that pen. Then each individual's Total DM Required is divided by the Pen Total DM Required to determine the percent of the pen total the individual consumed. This percentage is then multiplied by the total DM delivered to arrive at the individual's share of the feed. For instance, Animal record 1 had a Total DM Required of 3,149.9 lb. The sum of Total DM Required for Pen 1 was 32867.9 lb. Therefore #1 consumed 9.58 percent of the total. The amount of feed delivered to the pen (Entered in column labeled "**Feed Fed**" in the "**Pen**" sheet of the spreadsheet that was imported) was 33,009 lb. Therefore the share of actual feed fed that was allocated to animal #1 was 3163 lbs. (0.0958 * 33,009 lb). The table below summarizes the information that is computed for three animals.

Animal Record	Start BW	Ending BW	ADG	Allocated DM Req.	Feed Efficiency
1	863	1348	3.73	3163	6.5
2	706	1114	3.14	2488	6.08
3	870	1325	3.50	3011	6.59

In this example, Animal Record #1 had the highest ADG, but was in the middle relative to feed efficiency. For the purpose of selection it is a lower risk procedure to select on the basis of sire groups compared to selection on individual animals. Therefore, using the owners as sire groups, we will examine how to use CVDS to make selection decisions.

Data	Sire Groups			Average
	1	**2**	**3**	
Starting BW	813	684	678	721
Ending BW	1262	1273	1242	1260
Predicted ADG	3.5	3.9	3.1	3.5
Empty body fat, %	31.6	29.6	29.3	30.1
Predicted Feed Efficiency	6.4	5.9	6.2	6.1

To keep the importance of selecting for feedlot performance in perspective, one must remember that the feedlot sector is only one part of the entire beef production system. The three sectors are 1) cow/calf, 2) feedlot and 3) carcass. Assigning profit potential along the same lines, several studies have shown that the cow/calf segment contributes 50%, the feedlot contributes 30% and the carcass segment contributes the remaining 20% to total profitability. For the purposes of this demonstration, we will assume that the cows that produced these steers had equal reproductive performance, and the carcasses from these steers all met the minimum criteria for weight, quality grade and yield grade. It is never advisable to select for single traits, therefore, selecting on feed efficiency alone will not lead to long term sustainability.

Sire number 2 produced steers that gained faster than calves out of the other two sires. Though the steers from Sire 2 were 31 lbs. heavier at finish, and we know that larger cattle gain faster, the difference in ending BW is not large enough to explain a 26% increase in ADG. Nutrient requirements are determined from the needs of maintenance and growth. As the steers from Sires 2 & 3 were of similar ending weight, and body weight is a major determinant in maintenance requirements, their feed required for maintenance was similar. Requirements for growth are determined by rate of gain and vary as the cattle mature due to changes in the composition of gain. Cattle with the same percent empty body fat (EBF) are defined as being at the same stage of growth, and therefore have similar requirements for growth. One might view the maintenance requirement as an overhead cost. More profitable businesses produce more for the same amount of overhead. In the same way, cattle that have the same maintenance requirement, but grow faster are more efficient, because they dilute the cost of maintenance with their increased rate of gain. Therefore steers out of Sire 2 were the most efficient, and selection of replacement heifers out of this sire, should result in cattle that are more efficient.

7. **Allocated Feed Cost**, is the feed cost of the **Allocated Total DM Required.** Animal record #1 will be charged $124.23 for his share of the feed bill. Again the table below summarizes the information generated on three animals.

Owner	Feed	Yardage
1	124.23	51.60
2	97.7	51.60
3	118.22	51.60

8. **Sort by Owner.** This command will sort cattle by owner and either sum the variables or take an average. Cattle can also be sorted by pen and by sex.
   a. Select “**Simulation Settings**”, then “**Output**”. Now check the **Owner** box and finally the **Results** button.
   b. The Table below summarizes the data for the three owners.

Feedlot Performance of Steers from Three Owners

Owner	Start BW	End BW	ADG	Feed Efficiency
Wooded Acre	813	1262	3.5	6.4
Wannabe Acre	684	1273	3.9	5.9
Peaceful Acre	678	1242	3.1	6.2

Total expenses owed for Feed and Yardage
by steers of three owners

Owner	Feed	Yardage
Wooded Acre	340.15	154.8
Wannabe Acre	552.88	245.6
Peaceful Acre	431.12	213.6

From these tables, feedlot performance can be evaluated, as well as providing a reconciliation of the receipts and expenses for each owner.

INPUTS REQUIRED TO ALLOCATE FEED BASED ON ANIMAL PERFORMANCE

1. Feed Efficiency for Individual Steers/Heifers Fed in Groups

Feed costs represent 60% of the total cost incurred in the feeding cattle (Baker and Ketchen, 2000). Computer simulations with Cornell Cattle Systems 5, which is based on the growth model of Fox et al. (1992), Tylutki et al. (1994) and Fox et al. (1999) as applied in the NRC (2000; 2001) show that a 10% improvement in feed efficiency can result in a 43% improvement in feedlot profit (Fox et al., 2001b). Simulation models developed with published research data on cattle requirements that account for biological differences (mature size, growth rate, milk production, pregnancy requirements, environmental effects) can be used to identify differences among cattle in feed efficiency (Fox et al., 2001b). If differences in individual feed efficiency can be detected economically, this information has the potential to be used in the development of selection indexes. These selection indexes can then be used to increase the competitiveness and profitability of the beef herd.

Until recently it has been cost prohibitive to evaluate feed consumption on an individual basis in progeny fed in a commercial feedlot. Recent improvements in predicting the impact of environmental conditions on maintenance requirements and in determining the composition of gain has led to the development of a model that can accurately allocate feed to individuals in group pens (Guiroy et al., 2001). This model uses the animals' own growth rate and average body weight during test to compute feed required for the observed body weight and growth rate. This paper describes the procedures to allocate feed as described by Guiroy et al. (2001). The procedure described can be used for either steers or heifers fed to harvest with carcass data collected as described.

2. Feed Required by Individual Steers/Heifers Fed in Groups

2.1. Steps for computing feed required

1. Feed analysis of the ration ingredients and the ration dry matter formula are used to predict the net energy value of the ration dry matter for maintenance and growth with the Cornell Net Carbohydrate and Protein System (CNCPS; Fox et al., 2000), as described by Fox et al. (2001a).
2. Beginning and ending weight and days on test are used to compute average weight and average daily gain during the test.
3. The animals' average body weight during test is used to predict their average daily maintenance requirement.
4. The average daily maintenance requirement is adjusted for the effect of environment on the energy required for maintenance.

5. This average daily maintenance requirement is divided by the net energy value of the ration for maintenance to compute the feed required for maintenance/day.
6. The animals' expected weight at 28% body fat (average fatness of low choice grade) is predicted from carcass measures (carcass weight, backfat, rib eye area, and marbling score).
7. This 28% fat weight is divided into the weight of the animal used to develop the net energy requirement equations (standard reference weight) to get the ratio of the animal to this standard reference weight (standard reference weight ratio).
8. The standard reference weight ratio is multiplied by the average weight during the test to get the weight equivalent to the standard reference animal (Equivalent weight).
9. The average daily gain during the test and the equivalent weight are used to compute the daily net energy required for gain.
10. The net energy required for gain is divided by the ration net energy value for growth to obtain feed dry matter required for growth.
11. The feed required for maintenance and gain are added together to determine dry matter required/day.
12. Feed efficiency is then the dry matter required/day divided by the average daily gain.

The actual feed fed to the pen is allocated to the individual animals to determine the cost for each individual animal as follows:

1. The dry matter required/day required for each animal in a pen are summed to get the total required/day for the pen.
2. Each animals' dry matter required/day is divided by the total for the pen to compute the proportional share of the actual feed fed to the pen.
3. The proportional share for each animal is multiplied times the total feed fed to the pen to obtain the amount and cost of the feed for each individual animal.

2.2. Collecting inputs required

1. Body weights
   - Initial weight when placed on feed in the feedlot
2. Carcass measurements
   - Weight
   - Fat depth
   - Rib eye area
   - Marbling
3. Ration
   - Dry matter formula (keep as constant as possible during the entire test)
   - Ration ingredient analysis (take as many samples as needed to represent each ration ingredient during the entire test)
     a. Dry matter, NDF, Lignin, CP, protein solubility, NDIP, ADIP.
     b. Total feed fed to each pen during the test.
4. Environment description (average for each month during the test)
   - For the entire test
     a. Lot type (choose from the list)

   b. Square feet/head
- Average for each month during the test
   a. Wind speed and temperature the cattle are exposed to, lot conditions (choose from the list)

3. Input Forms

FORM 1 - PEN IDENTIFICATION

Pen Space: Square feet per head:_________

Animal Data-IN:		Pen No:_______		
Date	ID	Breed	Weight	BCS
Animal Data-OUT:		Pen No:_______		
Date	ID	Breed	Weight	

FORM 2 – ANIMAL IDENTIFICATION

Date: ___________		
Animal ID	Hip Height	Birthdate

FORM 3 – RATION IDENTIFICATION

Ration		
Date	Ingredient	Lbs/batch
Date	Pen No.	Amount fed

FORM 4 – ULTRASOUND INFORMATION

Ultrasound Data					
Date					
	An ID	BF	Rump Fat	IMF	REA

FORM 5 – ENVIRONMENT INFORMATION

Environmental data							
	Temp. (^{o}F)	RH (%)	Mud (in.)	Wind (MPH)	Hair Coat[1]	Hair Depth (in.)	Min. Temp. (^{o}F)
Month							

[1] 1=No mud; 2=mud on lower body; 3=mud on lower body and sides; 4=heavily covered with mud.

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