# USING MATHEMATICAL NUTRITION MODELS TO IMPROVE BEEF CATTLE EFFICIENCY

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## Summary

Mathematical models integrate the scientific knowledge of energy and nutrients supply by the feedstuffs and requirements by the animals that have been accumulated over time and allow us to apply it in different production scenarios. Models have an important role in assisting the improvement of feeding systems and helping to understand the feedback structure that dictates the behavior of production systems. Thus, they can provide essential information to be used in the decision-making process of policy makers, producers, and consultants to maximize production while minimizing the environmental impacts through reduced nutrient excretion in an economically feasible fashion. Several mathematical nutrition models have been developed to account for more of the variation in ruminant production (Tedeschi et al., 2005b). This paper will discuss the usefulness of these models to predict beef production efficiency.

## Introduction

The Cornell Net Carbohydrate and Protein System (**CNCPS**) model has been developed for more than 30 years (Fox et al., 2004) for use in ration balancing and performance prediction programs to account for factors that affect performance, feed efficiency and nutrient excretion in beef and dairy cattle in each unique production situation. Because of the wide variations in breed types and their crosses used for beef production around the world and environments in which they are fed prior to marketing as finished beef, the CNCPS model has focused on accounting for differences in maintenance requirement, mature body size and composition of gain, implant program, feed composition and feeding system. Evaluations of the CNCPS model have demonstrated the impact nutrition models can have on improving performance and reducing feed cost of production and nutrient excretion (Fox et al., 2004; Tedeschi et al., 2005a). The Beef NRC (1996; 2000) model was developed based on the CNCPS framework to specifically predict digestion, metabolism, and performance of beef cattle.

Growth models are being used in individual cattle management systems (**ICMS**) that are being developed for the beef industry to improve profitability, to minimize excess fat produced, to increase consistency of products, and to identify and reward individual owners for superior performance in the feedlot. To accomplish this, cattle are marketed as individuals when at their optimum carcass composition, which typically requires having cattle with different owners in the same pen (co-mingle). 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. A mathematical growth model (Cornell Value Discovery System, **CVDS**) was developed (Guiroy et al., 2001; Perry and Fox, 1997; Tedeschi et al., 2004) to address the following critical control points in launching a successful ICMS:

- 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,
- Predicting carcass composition and backfat deposition rate during growth to avoid discounts for under- or over-weight carcasses and excess backfat, and
- Allocating feed fed to pens to individual animals for the purpose of sorting of individuals into pens by days to reach a target body composition and maximum individual profitability.

## Description of the CVDS Model to Predict Energy and Protein Requirements

*Accounting for body composition at the marketing target end point*. The first step for predicting feed required for the observed growth and incremental cost of gain and body composition as cattle grows is to identify the body composition at the marketing target end point. Carcass value in most markets and cost of gain can be related to proportion of protein and fat in the carcass. The single most recognizable quality grade in the world is USDA choice. Premium brand name products typically utilize the prime and upper 2/3 of the Choice grades and are increasing the value of U.S. beef products. Table 1 shows a summary of several experiments (Guiroy et al., 2001) that support the value of the Choice and prime grades level of fatness to minimize the percent of the beef that is unacceptable to consumers in the U.S.

These data show that EBF was significantly ($P < 0.05$) higher with each incremental increase in grade up to the mid Choice USDA grade. Taste panel scores and percent unacceptable followed the same trend. This data also indicate the correlation between USDA quality grades to changes in EBF as cattle grow. The most critical factor in this table for our model is the EBF at Standard (21.1%), Select (26.2%), and low Choice (28.6%) USDA grades because these are the body composition endpoints for different marketing targets used to identify feed requirements during growth.

The National Beef Quality Audit (Smith et al., 1995) 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 % unacceptable values were lower for the data analyzed by Guiroy et al. (2001) likely because they were uniform calves fed a 90% concentrate diet beginning at approximately 7 mo of age. The National Beef Quality Audit conducted by Smith et al. (1995) also reported that up to 20% of all beef does not meet North America consumer satisfaction in eating quality and recommends that the % of cattle grading low Choice and above be increased.

Based on a survey of retailers, purveyors, and exporters, the ideal mix would be 62% low Choice or better and 38% Select, with no Standard grade beef. This compares to the current 51% low Choice or better, 42% Select and 7% Standard grade and lower (McKenna et al., 2001). The 10% of the United States beef that is exported would have none below low Choice. The strong message from North America consumers is that the external fat must be removed from beef, but intramuscular fat (marbling) is required in the edible portion. This is likely due at least in part to the method of cookery commonly used compared to what is common in most other countries (Dikeman, 1987).

*Accounting for differences in requirements for growth*. It has been determined that cattle of different mature sizes have different fat and protein content of the weight gain at the same weight during growth (Fox and Black, 1984). Therefore, a size scaling procedure to account for differences in energy and protein requirements for growth among cattle of different frame sizes and genders has been developed (Fox and Black, 1984; Fox et al., 1988; Fox et al., 1992; Fox et al., 1999; Tylutki et al., 1994) and was adopted by the NRC Nutrient Requirements of Beef Cattle (NRC, 2000).

In this model, the animal BW at the target empty body fat % (**AFBW**) is divided into the weight of the standard reference weight (**SRW**) of an animal at that composition. This ratio is then multiplied by the animal's actual BW to adjust it to the standard reference animal for use in the energy requirement equation; this value is called the equivalent BW (Eq. [1]).

$$\text{Equivalent SBW} = \text{Current SBW} \times \frac{\text{SRW}}{\text{SBW at Target \%EBF}} \quad [1]$$

The standard reference animal represents the cattle body size used to develop the equations to predict the net energy content of weight gain. Table 2 provides an example of the calculation of net energy required for growth (retained energy) computed with this model for three mature sizes (1102, 1212, and 1322 lb) of cattle. As mature size increases, weight at the same energy content of gain increases, because larger size animals are at an earlier stage of growth at the same weight and therefore have more protein and less fat in the gain. It also shows that energy requirements increase with increasing stage of growth and rate of gain because of more fat in the composition of the gain.

The following equations (Eq. [2] to [7]) from the NRC (2000) were used to compute the retained energy (Mcal/d) values shown in Table 2. Note that equivalent SBW (**EqSBW**) value is the same within the same stage of maturity regardless of the AFBW. This is because the equivalent BW is the degree of maturity (or stage of growth) multiplied by the SRW (1053 lb).

$$RE = 0.0635 \times \left(EqEBW/2.204\right)^{0.75} \times \left(EWG/2.204\right)^{1.097} \quad [2]$$

$$EqEBW = 0.891 \times EqSBW \quad [3]$$

$$EqSBW = SBW \times \frac{1053}{AFSBW} \quad [4]$$

$$SBW = 0.96 \times BW \quad [5]$$

$$AFSBW = 0.96 \times AFBW \quad [6]$$

$$EWG = 0.956 \times ADG \quad [7]$$

*Accounting for differences in requirements for maintenance*. The model used for this purpose is described by Fox and Tylutki (1998). The effects of breed type are accounted for by adjusting the base $NE_m$ requirement of 34.9 kcal/lb (77 kcal/kg) metabolic body weight (**MBW**) for *Bos indicus* and dairy types (-10 and +20% compared to *Bos taurus*). The effects of previous nutrition are accounted for by relating body condition score (**BCS**) to $NE_m$ requirement. On a 1 to 9 scale, maintenance requirement is reduced by 5% for each BCS below 5 and is increased by 5% for each BCS above 5. The effects of acclimatization are accounted for by adjusting for previous month's average temperature (ranges from 31.8 to 47.6 kcal/lb MBW (70 to 105 kcal/kg MBW) at 30 and -20 $^{o}$C, respectively). Environmental adjustments were developed based on the data reported by the NRC (1981).

Nonetheless, further examinations have to be conducted for different levels of production, animal type, environment (climate), and modeling approaches. The above adjustment should be used for static models, which are valuable for the mean of a period of growth but cannot be used consecutively in a dynamic model because of double accounting the previous climate effect over and over (Kebreab et al., 2004; Tedeschi et al., 2004). The effects of environment (climate) have an important effect on animal production and have to be accurately accounted for. Berman (2003; 2005) provided some information regarding heat stress for producing animals and such information could be adapted to current models.

*Determining ration energy values*. Predictions of dry matter intake (**DMI**) and net energy for growth (**NEg**) and maintenance (**NEm**) are highly dependent on having feed net energy values that accurately represent the feeds being fed. Tedeschi et al. (2005a) evaluated the accuracy of alternative methods for determining feed energy and protein values: the level 1 of the NRC (2000), which uses tabular values for feed composition and energy; the level 2 of the NRC (2000), which uses the CNCPS (Fox et al., 2004); and a summative equation commonly used by feed analysis laboratories to predict feed energy values from chemical composition (Weiss, 1993; , 1999; Weiss et al., 1992).

Metabolizable energy (**ME**) was predicted by the CNCPS to be first limiting in 19 treatment groups (Tedeschi et al., 2005a). Across these groups, the observed ADG varied from 1.76 to 3.17 lb/d (0.8 to 1.44 kg/d). When ME was first limiting, the ADG predicted by the CNCPS model accounted for more of the variation (80%) than did the summative equation or tabular (73 and 61%, respectively). Metabolizable energy allowable ADG predicted with the tabular system gave an overprediction bias of 11%, but the bias was less than 2% when predicted with the CNCPS or summative equation. The MSE were similar in all predictions, but the CNCPS model had the highest accuracy (lowest RMSPE). Metabolizable protein (**MP**) was predicted by the CNCPS to be first limiting in 28 treatment groups (Tedeschi et al., 2005a). Across these groups, the observed ADG ranged from 0.26 to 3 lb/d (0.12 to 1.36 kg/d). The ADG predicted by the CNCPS model accounted for more of the variation (92%) than did the summative equation or tabular (79 and 80%, respectively). Metabolizable protein-allowable ADG predicted with the tabular gave an overprediction bias of 4%, whereas the bias was less than 2% when predicted with the CNCPS or the summative equation. Similar to the ME first limiting analysis, the CNCPS model had the highest accuracy (lowest RMSPE: 0.11).

*Predicting days to finish, carcass weight, body composition, quality and yield grade*. Fox et al. (2002; 2001a) listed and exemplified the sequence of calculations of the growth model (Guiroy et al., 2001; Perry and Fox, 1997; Tedeschi et al., 2004) developed to account for individual animals when fed in groups. Previous evaluations of this model have indicated the CVDS model predicted DMR with an $r^2$ of 74% and mean bias of 2% (Tedeschi et al., 2004) and feed conversion ration (**FCR**) with and $r^2$ of 84% and a mean bias of 1.94% (Tedeschi et al., 2006) using the data of 362 individually fed steers. Guiroy et al. (2001) reported that the CVDS accurately allocated the feed fed to 12,105 steers and heifers in a commercial feedlot, with a bias of less than 1%. Recent evaluations with pen-fed Santa Gertrudis steers and heifers indicated the model was able to accurately predict the feed that was allocated to the pens with a bias of 2.43% (Bourg et al., 2006a).

Applications of the CVDS Model in Identifying Differences in Feed Efficiency

*Selecting for Efficient Animals*. Fox et al. (2001b) utilized an early version of the CVDS (Cornell Cattle Systems v. 5) to simulate the effect of growth rate and feed efficiency on cost to gain 595 lb (initial BW of 573 lb and final BW of 1168 kg). Based on their simulation (Table 3), an increase of 10% in ADG alone was predicted to increase DMI 7% and improve profits by 18%, probably due to fewer days on feed and thus less non-feed costs. The reduction in feed cost was due to a reduction in feed required for maintenance due to fewer days required to gain 595 lb. On the other hand, when intake was kept the same but efficiency of ME use by the animal was improved by an amount that resulted in a 10% improvement in feed efficiency, profits increased by 43%. The simulations of Fox et al. (2001b) clearly suggested that improving feed efficiency or feed conversion ratio may result in a higher benefit to the producer.

Okine et al. (2004) compared the profitability of animals with different efficiency traits. Animals started at 551 lb and were slaughtered at 1234 lb. Those with 5% increase in ADG saved US$ 2 per head versus US$ 18 per head for steers with a calculated increase of 5% in feed efficiency (Table 4).

Similar to Fox et al. (2001b), Okine et al (2004) also concluded that an increase in feed efficiency ratio (or a decrease in feed conversion ratio) leads to a higher profit. In part, this is because the same percentage change in DMI is numerically greater than that for ADG, which leads to a greater impact on the outcome; less days on feed. Thus, comparison should be made on a *ceteris paribus* condition in which all variables are kept constant and only one variable is varied at a time. Animals with higher ADG will always be more efficient as long as the maintenance requirement is constant. This happens because of the dilution of the amount of feed required for maintenance compared to the total amount of feed consumed, leading to a more efficient animal per unit of gain. Nonetheless, in practice this may not happen and maintenance requirement increases as ADG increases. Therefore, the most efficient animal will be that one that has a lower increase in maintenance per unit of ADG.

We performed a simulation slightly different than that shown by both Fox et al. (2001b) and Okine et al (2004).

In our simulation, the ADG (4 lb/d) was identical across the first three scenarios; therefore, we assumed that animals would change either DMI or maintenance requirements to obtain the same performance. In a fourth scenario, ADG was increased 10% for the same DMI. A 551-lb steer with AFBW of 1234 kg was fed a diet containing 1.32 Mcal/lb of ME and costing US$ 0.09/lb to set the conditions for the scenarios (Table 5). A purchase cost of US$ 0.88/lb BW and sale price of US$ 0.86/lb of BW were assumed.

When ADG was held constant, 185 days on feed were required to reach the low Choice USDA grade; a 10% increase in ADG reduced days on feed to 168 days. A decrease in efficiency by 10% (increased DMI by 10%) reduced profits by 42% and an increase in efficiency by 10% (decreased DMI by 10%) increased profits by 37%. The increase in efficiency is smaller than that reported by Fox et al. (2001b). Likely, because they changed ADG rather than DMI; increasing ADG by 10% and keeping DMI similar to the standard scenario, would have increased the profit by 44%, identical to the Fox et al. (2001b) finding. Selecting for animals with an increased ADG can improve feed efficiency so long as it does not change the mature size. If mature size is increased, the apparent increase in profit could be offset by the longer days on the feedyard to reach the USDA low Choice grade.

*Performing a Risk Analysis*. We performed risk analysis simulations using the CVDS model to evaluate the impact of initial BW (661 ± 44 lb), diet ME (1.27 ± 0.09 Mcal/lb), and a fixed feed cost of (US$ 0.02/lb) of a finishing steer fed for 120 days. The risk analysis was conducted with @Risk using 5,000 iterations and normal distribution was assumed for initial BW and diet ME (Figure 1). Our simulation indicated an expected ADG skewed to the right and was expected to be between 2.54 and 3.68 lb/d (90% confidence interval, **CI**), the DMR was expected to be between 18.3 and 20.7 lb/d (90% CI), and the FCR was predicted as 5.05 to 7.91 (90% CI).

The analysis of the FCR indicated a higher correlation between ADG and FCR (-0.971) than DMR and FCR (0.703). Figure 1 also indicated that variation in the standard deviation of mean SBW and initial SBW had the highest impact on the standard variation of the profit (0.524 and -0.512, respectively). Similarly, for each increase in the standard deviation of the mean ADG, profit would increase by 0.233 standard deviation units. A unitary change in the DMR standard deviation would decrease the profit by 0.048 standard deviation units. Therefore, for practical applications, the BW and consequently the cost associated with the purchase of each animal has the highest effect on profitability during the feedlot finishing period. The ADG would have a higher impact on the profit than the DMR, and because these two variables had inverse effects on profit, changing feed efficiency would have a higher impact on profit than a change in ADG or DMR alone. This result is in agreement with that shown in Tables 4, 5, and 6; ADG has a stronger impact on profit than intake, therefore, selecting for higher ADG than lower intake might be more profitable. Tedeschi et al. (2006) reported a phenotypic correlation between DMR and DMI, ADG, and Kleiber ratio of 0.75, 0.65, and 0.55, respectively. The DMR is the expected intake predicted by the model given the information on animal, diet and environment. This is similar to the expected intake predicted by the RFI using mean BW and ADG. Tedeschi et al. (2006) reported the correlation of the residual (observed minus expected intake) between these two approaches was 0.84. Similarly, Bourg et al. (2006b) reported a correlation of 0.80.

*Using Mathematical Models for Genetic Selection*. Additional evaluations of mathematical models have been conducted to assess heritability and genetic correlations. Williams et al. (2005) compared the Decision Evaluator for the Cattle Industry (**DECI**) and the CVDS models to predict DMR, using 504 steers and 52 sires. Heritability for DMR was around 0.33 for both models and genetic correlations between actual DMI and predicted DMR was greater than 0.95. Similarly, Kirschten et al. (2006) evaluated the genetic merits of the CVDS predictions and reported heritability of 0.35 and genetic correlations between DMI and DMR of 0.98, with low re-ranking of sires. These authors suggested that predicted DMR may be used in genetic evaluations with minimal genetic differences between DECI and CVDS models.

## Implications

The CVDS model provides a method for predicting energy requirements, performance and feed required by individual cattle fed in a group with good accuracy by accounting for factors known to affect cattle requirements (e.g. breed type, body size, stage and rate of growth). Feed can be accurately allocated to individual steers, heifers or bulls fed in group pens, based on prediction of final EBF from carcass measures. This allows cattle from different owners to be fed in the same pen, allowing for more efficient marketing of feedlot cattle and collection of data in progeny test programs. Our preliminary analysis suggests this model also has the potential to be used in identifying differences in feed efficiency between individual animals fed in group pens. The predicted feed required for the observed performance appears to be strongly related to actual feed intake, and is moderately heritable. We are hopeful that research underway will provide additional information on the use of the CVDS in selection programs to improve feed efficiency of beef cattle.

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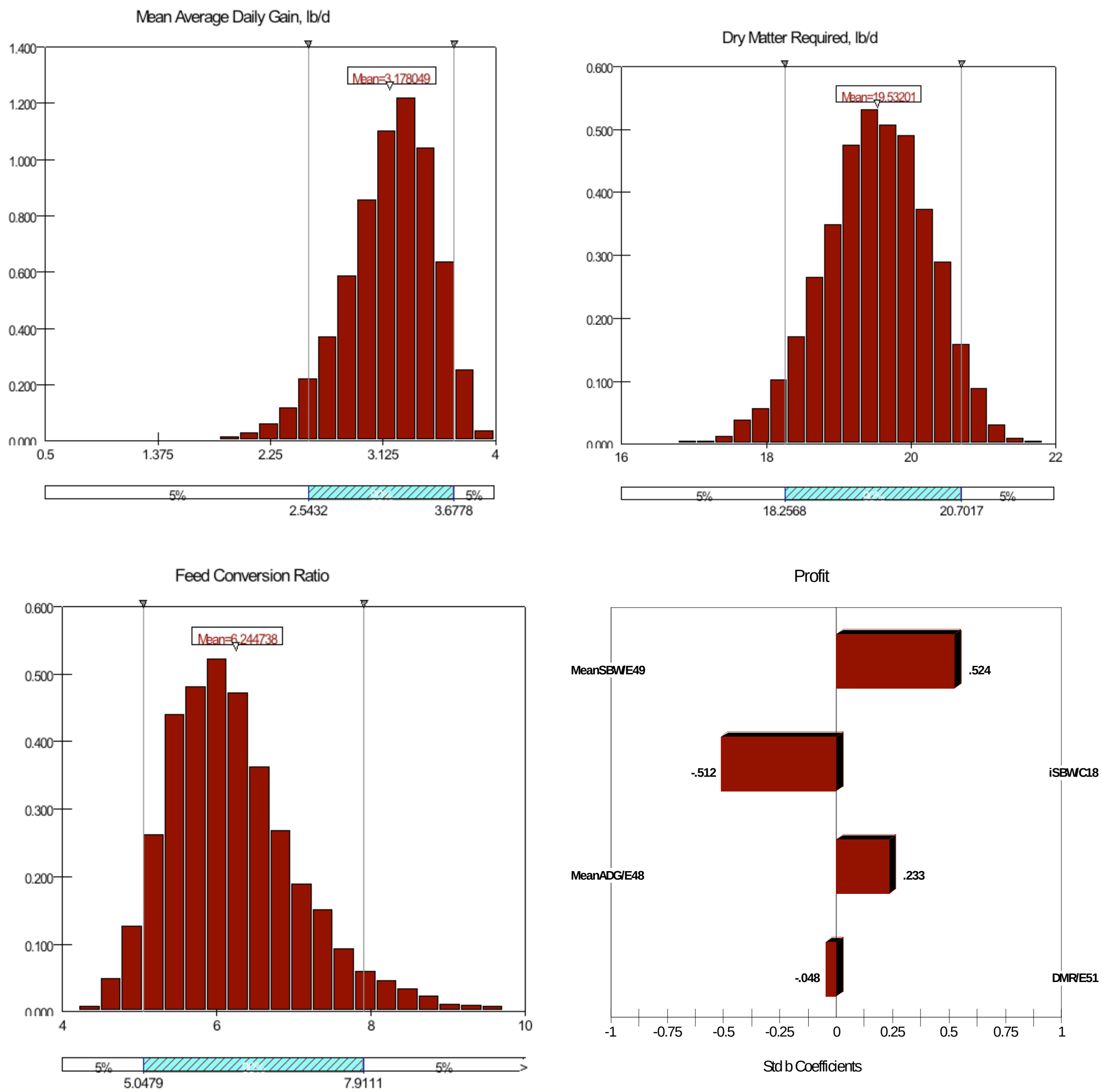


Figure 1. Simulation results of average daily gain, dry matter required, feed conversion ratio, and profit predicted by the CVDS model varying initial body weight and dietary metabolizable energy for a steer fed for 120 days.

Table 1. Relationship of carcass and empty body fat (EBF) to quality grade

| N | USDA Quality Grade [a] | Carcass fat % | Mean EBF [b] % | EBF Std Error | Taste panel score [c] | Not acceptable [c] % |
|---|---|---|---|---|---|---|
| 45 | 3.5 | 23.6 | 21.1 $^{u}$ | 0.63 | 5.3 | 40 |
| 470 | 4.5 | 29.0 | 26.2 $^{v}$ | 0.19 | 5.6 | 13 |
| 461 | 5.5 | 31.6 | 28.6 $^{w}$ | 0.20 | 5.8 | 8 |
| 206 | 6.5 | 33.0 | 29.9 $^{x}$ | 0.29 | 6.2 | 0 |
| 90 | 7.5 | 34.2 | 31.0 $^{xy}$ | 0.44 | - | - |
| 51 | 8.5 | 35.2 | 31.9 $^{y}$ | 0.59 | - | - |
| 32 | 9.5 | 35.8 | 32.5 $^{z}$ | 0.74 | - | - |

[a] Standard = 3 to 4; Select = 4 to 5; low Choice = 5 to 6; mid Choice = 6 to 7; high Choice = 7 to 8; low Prime = 8 to 9; mid Prime = 9 to 10.
[b] Column means with different superscripts are significantly different at $P < 0.05$.
[c] Taste panel scores (1 to 8) and percent unacceptable values are from a subset of this data base.
Adapted from Guiroy et al. (2001).

Table 2. Relationship of stage of growth or maturity (u), body weight at 28% EBF (AFBW), and rate of gain (ADG) in computing retained energy

| | AFBW, lb | | Stage of maturity (u), % | | |
|---|---|---|---|---|---|
| | 50 | 60 | 70 | 80 | 90 |
| 1102 | 551 | 661 | 771 | 882 | 992 |
| 1212 | 606 | 727 | 849 | 970 | 1091 |
| 1322 | 661 | 793 | 926 | 1058 | 1190 |
| Equivalent SBW, lb | 527 | 632 | 737 | 843 | 948 |
| | ADG, lb/d | | | Retained energy, Mcal/d | |
| 2.20 | 3.37 | 3.86 | 4.34 | 4.79 | 5.24 |
| 2.64 | 4.12 | 4.72 | 5.30 | 5.85 | 6.40 |
| 3.31 | 5.26 | 6.03 | 6.77 | 7.48 | 8.17 |

Table 3. The effect of improvement in rate of gain and feed efficiency on profits [a]

| Variables | Average steer | Effect of 10% higher ADG | Effect of 10% higher feed efficiency |
|---|---|---|---|
| DMI, lb/d | 18.69 | 19.86 | 18.69 |
| ADG, lb/d | 3.22 | 3.53 | 3.61 |
| Feed:gain ratio | 5.82 | 5.67 | 5.18 |
| Feed cost, $ | 176 | 172 | 157 |
| Non feed cost, $ | 98 | 91 | 89 |
| Total cost of gain, $ | 274 | 263 | 246 |
| Profit, $ | 65 | 77 | 93 |

[a] Adapted from Fox et al. (2001b). Values were computed using Cornell Cattle System v. 5.0.

Table 4. Simulated cost and saving of steers with calculated 5% increase in feed efficiency or average daily gain compared to actual performance [a]

| Variables | Actual data (200 d) | Calculated 5% increase in FER (200 d) | Calculated 5% increase in ADG (200 d) |
|---|---|---|---|
| DMI, lb/d | 20.83 | 19.79 | 21.84 |
| ADG, lb/d | 3.42 | 3.42 | 3.59 |
| Feed:gain ratio | 6.08 | 5.78 | 6.08 |
| Total cost of gain, $ | 424 | 406 | 422 |
| Savings for 200 d, $/hd | --- | 18 | 2 |

[a] Adapted from Okine et al. (2004).

Table 5. The impact of changing feed efficiency, DMI, or ADG by 10% on profits [a]

| Variables | Standard | Increased DMI 10% | Decreased DMI 10% | Increased ADG 10% |
|---|---|---|---|---|
| DMI, lb/day | 20.61 | 22.68 | 18.51 | 20.61 |
| ADG, lb/d | 3.57 | 3.55 | 3.55 | 3.90 |
| Feed:gain ratio | 5.78 | 6.40 | 5.22 | 5.27 |
| Feed cost, US$ | 326.98 | 361.86 | 295.43 | 298.37 |
| Total cost, US$ | 935.71 | 971.92 | 903.96 | 898.10 |
| Profit, US$ | 86.27 | 49.91 | 117.85 | 124.39 |
| Total cost/gain, US$/lb/d | 0.71 | 0.77 | 0.66 | 0.65 |
| Purchase breakeven, $/lb BW | 1.04 | 0.98 | 1.11 | 1.12 |
| Annual margin for all costs, % | 18.29 | 10.13 | 25.72 | 30.09 |

[a] Values were computed using the CVDS model version 1.0.18.