EFFECTS OF BODY WEIGHT, FRAME SIZE AND RATE OF GAIN ON THE COMPOSITION OF GAIN OF BEEF STEERS

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ABSTRACT

Energy concentration of gain (EG) is an inherent component in beef cattle feeding systems. The National Research Council (NRC) uses equations based on body weight, rate of gain and cattle type to predict EG and, in turn, to calculate dietary energy requirements. From EG, fat and protein deposition can be calculated directly. A dynamic computer growth model also can be used to estimate EG. In both the NRC and the computer model, EG increases from about 3 to 6 Mcal/kg as body weight increases from 200 to 500 kg if daily gain is 1 kg. Both NRC and the model predict EG of calves to be about .3 Mcal/kg greater than a previous NRC system. In contrast to the NRC, model-predicted EG of yearlings is lower at lighter and greater at heavier body weights. Rate of gain affects estimates of EG more for the dynamic model than for the NRC systems. When predicted EG was compared with observed EG for 46 pens of feedlot steers in comparative slaughter trials, NRC estimates exhibited a narrow range compared with observed values with correlation coefficients of r = .38 and r = .71 (previous NRC). Model estimates of EG were closer (r = .85). The NRC predictions of EG systematically erred with initial body composition, diet metabolizable energy and length of feeding period (P < .01) and with initial body weight and rate of gain (P < .05). No systematic errors in model-predicted EG were detected. Enhanced model sensitivity to compensatory growth and rate of gain should reduce both EG and body weight gain prediction errors. Over longer feeding periods, NRC errors may cancel out, but for shorter intervals, the dynamic model estimates are more precise and exhibit less bias.

(Key Words: Body Composition, Growth Models.)

Introduction

Gain of beef cattle can be directly predicted based on energy available for gain and energy content (Mcal/kg) of that gain (EG). Further, composition of gain can be calculated from EG. To estimate nutrient requirements for feeding standards, literature information on EG has been amassed for different animal conditions. Recently, computer models of animal growth have allowed EG to be predicted directly. The objective of this paper is to compare the various predictions of EG of empty body weight gain of beef steers available from the National Research Council (NRC, 1976, 1984) and from the dynamic model of beef cattle growth of Oltjen et al. (1986b) and to discuss the implications of these estimates for use in predicting performance of beef steers.

Experimental Procedure

Equations for determination of the energy content of gain of implanted steers as presented by the NRC (1976, 1984) are shown in Table 1. Also, the dynamic computer model (MODEL) of Oltjen et al. (1986b) was used to estimate EG. In this model, EG is calculated as the sum of energy content of protein and fat gain divided by empty body weight gain (EBWG):

\[ \text{Protein gain, Mcal/d} = 5.539 \times (0.0461 \times \text{NUT2} \times \text{DNA}^{73} - 0.143 \times \text{Protein}^{73}) \]
TABLE 1. ENERGY CONCENTRATION OF EMPTY BODY WEIGHT GAIN (EBWG, KG)
FOR STEERS OF DIFFERENT TYPE AND EMPTY BODY WEIGHT (EBW, KG)

<table>
<thead>
<tr>
<th>Steer type</th>
<th>Energy in gain, Mcal/kg</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>All (.05603 + .01265 EBWG) EBW&lt;sup&gt;-75&lt;/sup&gt;</td>
<td>NRC (1976)</td>
<td></td>
</tr>
<tr>
<td>Medium-frame calves</td>
<td>.0635 EBWG&lt;sup&gt;-85&lt;/sup&gt;EBW&lt;sup&gt;-75&lt;/sup&gt;</td>
<td>NRC (1984)</td>
</tr>
<tr>
<td>Medium-frame yearlings</td>
<td>.0562 EBWG&lt;sup&gt;-85&lt;/sup&gt;EBW&lt;sup&gt;-75&lt;/sup&gt;</td>
<td>NRC (1984)</td>
</tr>
<tr>
<td>Large-frame calves</td>
<td>.0562 EBWG&lt;sup&gt;-85&lt;/sup&gt;EBW&lt;sup&gt;-75&lt;/sup&gt;</td>
<td>NRC (1984)</td>
</tr>
<tr>
<td>Large-frame yearlings</td>
<td>.0498 EBWG&lt;sup&gt;-85&lt;/sup&gt;EBW&lt;sup&gt;-75&lt;/sup&gt;</td>
<td>NRC (1984)</td>
</tr>
</tbody>
</table>

Fat gain, Mcal/d =
NE<sub>g</sub> (Feed intake - MAINT/NE<sub>m</sub>)
   - Protein gain
EBWG, kg/d =
Protein gain/1.219 + Fat gain/9.385

where NUT2 is an empirical Michaelis-Menten function:
NUT2 = .83 + .20P/.(15 + P)

and P is the proportion of normal metabolizable energy intake, DNA is empty body DNA (g), protein is empty body protein (kg), feed intake is daily dry matter intake (kg), MAINT is net energy for daily maintenance requirement (Mcal) and NE<sub>g</sub> and NE<sub>m</sub> are feed contents of net energy for gain and maintenance (Mcal/kg dry matter), respectively. The constants 5.539 and 9.385 are energy contents (Mcal/kg) of dry protein and fat, respectively, and if the fat-free body is 22.01% protein, the energy content of fat-free gain is 1.219 Mcal/kg. To estimate EG for the MODEL, NRC (1984) feed net energy values for desired rates of gain were used, and feed intake was adjusted daily to maintain that rate of gain. Medium-frame implanted calves and compensating yearlings were started at 200 and 300 kg live weight with empty body fat contents of 11 and 13%, respectively; large-frame cattle were 20% heavier but had similar fat content.

Based on the assumption that energy content of dry protein and fat is 5.539 and 9.385 Mcal/kg, respectively, and that fat-free EBWG is 22.01% protein (Garrett and Hinman, 1969), then fat and protein composition of EBWG may be calculated directly from EG:

FAT, % + PROTEIN, %/.2201 = 100%
9.385 FAT, % + 5.539 PROTEIN, % = EG•100%

Thus
FAT, % = -14.93 + 12.25 EG
PROTEIN, % = 25.30 - 2.70 EG

This is slightly lower than the equation based on a literature survey proposed by NRC (1984), converted to an empty body weight gain basis assuming that EBWG is 95.6% of shrunk weight gain (NRC, 1984):
PROTEIN, % = 28.03 - 2.94 EG

Each system was used to predict EG for 46 pens (Table 2) of medium-frame steers used in comparative slaughter trials at the University of California. Because the data set was for steers similar to those used to calibrate the MODEL, actual (not NRC-predicted) empty body weight gains and average empty body weights were used in the NRC (1976, 1984) equations to estimate EG (Table 1). For the NRC (1984) estimate, steers over 250 kg initial empty body weight with less than 18% initial empty body fat were classified as yearlings. Sixteen pens of cattle received no hormonal adjuvants. Both NRC systems assume that EG is increased by 5% by hormonal adjuvants. Protein synthesis in MODEL was increased by 4.2% for implanted steers. The relationship between predicted and observed EG within each system was evaluated by linear regression. Systematic errors for prediction of EG were investigated using simple correlation coefficients for residual (predicted - observed) EG with other variables.
TABLE 2. DESCRIPTION OF THE STEER DATA USED FOR COMPARISON

<table>
<thead>
<tr>
<th>Item</th>
<th>Mean</th>
<th>SD(^1)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initial empty body</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight, kg</td>
<td>249</td>
<td>22</td>
<td>216-294</td>
</tr>
<tr>
<td>Fat, %</td>
<td>16.2</td>
<td>2.6</td>
<td>11.9-21.2</td>
</tr>
<tr>
<td><strong>Final empty body</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight, kg</td>
<td>395</td>
<td>47.9</td>
<td>266-470</td>
</tr>
<tr>
<td>Fat, %</td>
<td>26.1</td>
<td>4.6</td>
<td>14.5-33.9</td>
</tr>
<tr>
<td><strong>Gain, empty body</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daily, kg</td>
<td>.98</td>
<td>.29</td>
<td>33-1.55</td>
</tr>
<tr>
<td>Energy concentration, Mcal/kg</td>
<td>4.74</td>
<td>.84</td>
<td>3.14-6.49</td>
</tr>
<tr>
<td>Diet, metabolizable energy, Mcal/kg</td>
<td>2.57</td>
<td>.29</td>
<td>2.01-3.06</td>
</tr>
<tr>
<td>Intake, kg/d</td>
<td>8.54</td>
<td>1.45</td>
<td>4.91-11.29</td>
</tr>
<tr>
<td>Days on feed</td>
<td>152</td>
<td>35</td>
<td>112-252</td>
</tr>
</tbody>
</table>

\(^1\) Standard deviation.

**Results and Discussion**

The energy concentrations of empty body weight gain for steers as predicted by the two NRC publications are shown in Figures 1a and 2. Fat and protein composition of gain, as calculated from EG, also are presented in these figures. Figure 1a illustrates that energy value of gain increases from about 3 to 6 Mcal/kg as body weight increases from 200 to about 500 kg if rate of gain is held constant at 1 kg/d. Body weight, as used here and throughout this paper, is shrunk body weight, which is equivalent to live weight used by NRC (1984). The NRC (1976) equations did not specify frame size and age (calf or compensating yearling). Its estimates fell between the recent NRC (1984) values for medium-frame calves and compensating yearlings. Medium-frame compensating yearlings and large-frame calves have less energy in gain than medium-frame calves, but they have more than large-frame compensating yearlings. Reid et al. (1968) suggested that body composition is a function of body weight within cattle of the same breed and sex. Others (Geay and Robelin, 1979; Byers, 1980) found that energy content of gain increases with rate of gain.

In Figure 2, the impact of rate of empty body weight gain on EG at a constant weight of 350 kg is shown. According to the NRC (1984) equations, EG gradually increases from about 4 to 5 Mcal/kg as gain increases from 0 to 1.5 kg/d for medium-frame steer calves. The NRC (1976) estimate is slightly less, although EG for...
COMPOSITION OF BODY WEIGHT GAIN

Figure 2. Energy concentration and composition of different empty body weight gain for steers of 350 kg body weight (BW): 76 = NRC (1976); MC = medium-frame calves, MY = medium-frame compensating yearlings, LC = large-frame calves and LY = large-frame compensating yearlings from NRC (1984); MODEL MY = medium-frame compensating yearlings from Oltjen et al. (1986b).

both slow and fast gains are similar. Medium-frame compensating yearlings and large-frame calves have EG values about .5 Mcal/kg less at equal gains, and large-frame compensating yearlings have EG values about .5 Mcal/kg below the large-frame calves. Energy, protein and fat content of gain varies less with rate of gain (Figure 2) than with body weight and body type (Figure 1a). For example, at empty body weight gains of 1 kg/d, fat content of gain is 42, 43, 36 and 30% for NRC (1976) steers, medium-frame calves, medium-frame compensating yearlings or large calves and large-frame compensating yearlings (NRC, 1984), respectively. These values change by 7, 6, 5 and 4 percentage units for each kilogram change in rate of empty body weight gain. Byers and Rompala (1979) found slopes of 36 and 48 percentage units/kg for 350-kg small and large-frame steer calves, respectively, with mean fat contents of gain of 46 and 34%. Rompala et al. (1985) observed a slope of 8 percentage units/kg for mean gain of 15% fat in normally growing, late-maturing (Charolais and Simmental) 350-kg steers.

Figure 1b is similar to Figure 1a except that MODEL (Oltjen et al., 1986b) was used to calculate the effect of body weight on the energy content of gain. Again, EG increased from about 3 to 6 Mcal/kg as body weight increased from 200 to about 500 kg. Frame size effects on EG were similar to those observed for the NRC (1984) in Figure 1a, with large-frame cattle about 1 Mcal/kg lower at similar body weights. The lines for compensating yearlings, in contrast with those of the NRC, do not remain below the calf lines as body weight increases. Instead, EG of yearlings increased to values higher than for calves as the animals became larger, suggesting that final body composition of yearling cattle should become similar to those put on feed as calves. Fox et al. (1972), using small-frame steers and Rompala et al. (1985), using large-frame steers, found that gain contained less fat during early compensation but more during later stages of compensation than gains of cattle not subjected to a feed restriction period. Whether yearling cattle achieve the same final body compositions as calves will depend on the length of the feeding period.

Direct comparisons between NRC equations and the MODEL are made in Figures 1c and 2 for medium-frame steers. Both NRC (1984) and MODEL calves have similar EG over all body weights (Figure 1c). The compensating yearlings (NRC, 1984) have EG below all others with values about .5 Mcal/kg less than those for calves. However, the MODEL compensating yearling line crosses and remains .3 Mcal/kg more than the calf lines between about 400 and 500 kg body weight. Whether calf gain consists of more fat and less protein at all weights, as the NRC (1984) suggests, than genetically similar cattle that have experienced a period of restricted growth is doubtful. Compensatory growth experiments cited above and the dynamic model used here both contradict this hypothesis. The somewhat higher line for MODEL compensating yearlings at greater body weight will cause composition differences to narrow as the animals finish.

In Figure 2 the effect of rate of gain on EG for medium-frame compensating yearlings weighing 350 kg from the various sources is compared. As shown previously, the former NRC (1976) equation estimates higher values than the later NRC (1984) equation. The lines for the more recent NRC and the MODEL intersect at about .7 kg/d gain, with MODEL EG being more sensitive to rate of weight gain. Expressed as fat composition of gain (%), the NRC (1976), NRC (1984) and the MODEL predict 36, 33 and 30 for .5 kg/d; 39, 36 and 39 for 1.0 kg/d; and 42, 38 and 45 for 1.5 kg/d empty body gain, respectively. Corresponding protein compositions (%), as calculated from EG, are 14, 15 and 15 for .5 kg/d; 13, 14 and 13 for 1.0 kg/d; and 13, 14 and 12 for 1.5 kg/d empty body gain for the NRC (1976), NRC (1984) and the MODEL, respectively. The pro-
tein values estimated using EG in the equation based on the NRC (1984) literature survey are about 10% higher than those solved directly from EG.

Mean values of EG for 46 pens of steers can be used to evaluate EG predicted by the three systems (Figure 3). Both NRC systems predicted rather constant EG values. The ranges of EG were only 35% (NRC, 1976) and 16% (NRC, 1984) of the observed range; corresponding correlations (r) between predicted and observed EG values were .71 and .38, respectively. The MODEL, which was developed explicitly to predict body composition, had a slope of .60 and a greater correlation coefficient (.85), although this was still lower than desired. Systematic errors (Table 3) for prediction of EG were detected with several variables for both NRC systems. For steers put on feed with fatter body compositions, both NRC systems overpredicted EG (P < .01). The insensitivity of EG to rate of gain (Figure 2), which usually is depressed with such cattle, may have caused this systematic error. Conversely, EG of thin animals with the potential for compensatory gain would be underpredicted. This explanation is confirmed (P < .05) by the negative correlation coefficients of residual error (predicted EG minus observed EG) with rate of gain (−.29 and −.33). At high dietary energy concentrations, EG was underpredicted (P < .01). Because cattle fed such diets gain faster, the relative insensitivity of the NRC systems to rate of gain probably explains this observation. Also, as days on feed increased, EG became overpredicted. Perhaps this was because the EG of calves, which are on feed longer, is predicted to be greater than for yearlings throughout the feeding period. This contrasts with the change of EG (Figure 1c) predicted by the MODEL. Regarding the effect of hormonal adjuvants, NRC (1976) overpredicted mean EG of implanted steers (P < .05) by .26 Mcal/kg, whereas NRC (1984) underpredicted mean EG of nonimplanted steers (P < .05) by .38 Mcal/kg. There was no systematic error with implant for MODEL (P > .5).

Extensive field testing and years of experience have shown that the NRC equations quite accurately predict gains of growing and finishing cattle. How can the predictions be accurate if they systematically overpredict EG at low rates of gain? Changes in maintenance may be responsible. Webster (1978) and others (Koong et al., 1982; Ferrell et al., 1986) showed with several species that the maintenance require-

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**Figure 3.** Relationship between predicted and observed energy concentration of empty body weight gain for medium-frame steers: 1976 = NRC (1976), 1984 = NRC (1984) and MODEL = Oltjen et al. (1986b).
TABLE 3. SIMPLE CORRELATION COEFFICIENTS FOR VARIABLES WITH POSSIBLE SYSTEMATIC ERROR WITH RESIDUAL (PREDICTED-OBSERVED) ENERGY CONCENTRATION OF GAIN WITHIN SEVERAL PREDICTION SYSTEMS

<table>
<thead>
<tr>
<th>Variable</th>
<th>NRC (1976)</th>
<th>NRC (1984)</th>
<th>Oltjen et al. (1986b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial empty body weight</td>
<td>-.14</td>
<td>-.37*</td>
<td>-.20</td>
</tr>
<tr>
<td>Proportion fat</td>
<td>.43**</td>
<td>.43**</td>
<td>.18</td>
</tr>
<tr>
<td>Diet ME</td>
<td>-.48**</td>
<td>-.39**</td>
<td>-.18</td>
</tr>
<tr>
<td>Feed intake</td>
<td>.06</td>
<td>-.14</td>
<td>-.03</td>
</tr>
<tr>
<td>Days on feed</td>
<td>.46**</td>
<td>.53**</td>
<td>.13</td>
</tr>
<tr>
<td>Daily empty body gain</td>
<td>-.29*</td>
<td>-.33*</td>
<td>-.19</td>
</tr>
</tbody>
</table>

*P < .05.
**P < .01.

ment (fasting heat production) is related to rate of gain at a given body weight. Over a range of body weights, maintenance requirements have been scaled to body weight\(^4\) for growing steers (Thonney et al., 1976) versus body weight\(^1\) for cattle held at constant weight (Taylor and Young, 1967). At low rates of gain, maintenance scaled to body weight\(^7\) may be over-predicting the maintenance requirement, particularly at light body weights. Thus, the amount of net energy for gain is reduced. Coupled with a systematic overprediction of EG, this causes underprediction of gain of these cattle, as was observed in the test data set. The opposite would be true with faster rates of gain, wherein maintenance and EG would be underpredicted, so that gain is overpredicted. This effect should be less pronounced due to smaller errors in underprediction of EG (Figure 2) and of maintenance (Armstrong and Blaxter, 1984). These limitations also affect MODEL predictions because maintenance is scaled to empty body weight\(^7\), which causes a slight systematic error of prediction for EG with rate of gain (r = -.19).

The ability of the NRC to predict growth of compensating cattle accurately remains unclear. If the observations of EG for compensating cattle made by Fox et al. (1972) and Rompala et al. (1985) are interpreted correctly, then a low EG early followed by a later increase is justified as predicted by the MODEL (Figure 1c). Predicted EG for NRC (1984) does not exhibit this behavior. How can the NRC system compensate? Again, an underestimated maintenance requirement early in compensation would compound the error in gain prediction, especially if NRC EG is too high. Scaling maintenance to body weight\(^7\) also affects MODEL predictions, but its lower EG partially compensates for this error. If one compares medium-frame compensating yearling EG (Figure 1c), it is apparent that initial EG is much less (and thus gain for a given retained energy is greater) for MODEL than the NRC. This relationship is reversed at greater body weights. Averaged over a feeding period, the NRC prediction errors will cancel each other.

The system chosen to predict performance of growing cattle, therefore, must depend on the precision needed at specific time intervals. Because the NRC was developed for prediction over a feeding period, small errors or errors that eventually cancel each other have little consequence, particularly in traditional production systems. However, prediction errors by the NRC equations may be large in the short term. The NRC equations were not developed for, and should not be expected to predict, short-term effects. The MODEL, on the other hand, is dynamic and was developed in order to account for the day-to-day fluctuations in performance (Oltjen et al., 1986a). Hence, in a production environment where tactical feeding and marketing decisions are made weekly or daily using current information, the added precision and lack of bias presented by this dynamic computer model should be useful.
Unfortunately, the accuracy of prediction by all current models is limited. Reasons for marked variation among pens of cattle (Figure 3) remain to be defined and controlled.

**Literature Cited**


