A Computer Model to Predict Composition of Empty Body Weight Changes in Cattle at All Stages of Maturity

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ABSTRACT: We developed methods to integrate two published models that partitioned gains in empty body weight (EBW) to fat and fat-free matter. These models were based on separate mathematical formulations for growing and mature cattle. We assumed that as cattle grow from birth to maturity a transition would occur at some point in the life cycle from the growing to the mature mathematical formulation. This transition point and the rate at which the transition occurs between the two mechanisms were estimated from published data. Evaluation results with data on steers that were full-fed to grow from birth to 815 kg EBW showed that the methods used to integrate the two models provided an accurate prediction of empty body composition at final slaughter. Evaluation results with full-fed growing cattle that were slaughtered at market weights suggest that partitioning of EBW gains can be fully described by the mathematical formulation used for growing cattle. However, for cattle that were restricted in growth, then realimented, the results showed that a model with a transition to the mathematical formulation for mature cattle, during the realimentation phase, accurately predicted the observed final composition. These results suggest that the integrated model would accurately predict the changes in body composition of cattle of all ages, under different systems of nutritional management.

Key Words: Beef Cattle, Growth Models, Body Composition

Introduction

Mathematical models have been developed to predict body composition in growing and mature cattle (Notter, 1977; Sanders and Cartwright, 1979a,b; Loewer et al., 1983; and Oltjen et al., 1986). Evaluations of these models with observed data on growth and body composition from three experiments have demonstrated that the models were more accurate in predicting empty body weight than body composition (Arnold and Bennett, 1991). Keele et al. (1992) developed a computer model to predict composition of empty body gain in growing cattle, and an extensive evaluation with body composition data on 145 treatment means from seven experiments (Williams et al., 1992) showed that the model accurately predicted absolute treatment means for fatness, and some of the nutritional effects on fatness, not associated with changes in empty body weight (EBW). Williams and Jenkins (1997) developed a model that was based on a different mathematical formulation from that used by Keele et al. (1992) to predict composition of EBW changes in mature cattle. It is proposed that as cattle grow from birth to maturity the mathematical formulation to predict composition of gain would change at some point in the life cycle, from that used by Keele et al. (1992) to that used by Williams and Jenkins (1997). Our objective was to develop, parameterize, and evaluate a method that would identify this transition point and use it to integrate the two models into a single model to predict composition of EBW changes as cattle grow form birth to maturity, under varying levels of nutrition.

Materials and Methods

General Considerations

The models are defined by sets of differential equations written in FORTRAN. Solutions are obtained using a fourth-order Runge-Kutta procedure for numerical integration. Descriptions of state variables and other abbreviations are given in Table 1. Time step in the models is 1 d, and changes in state variables are denoted by a lowercase d in front of the state variable.

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Table 1. Description of variables used in body composition model

<table>
<thead>
<tr>
<th>Variable</th>
<th>Units</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBW</td>
<td>kg</td>
<td>Body weight of animal excluding weight of contents of gastrointestinal tract (referred to as empty body weight)</td>
</tr>
<tr>
<td>EBFW</td>
<td>kg</td>
<td>Empty body fat weight</td>
</tr>
<tr>
<td>EBFFW</td>
<td>kg</td>
<td>Empty body fat-free weight</td>
</tr>
<tr>
<td>EBFP</td>
<td>%</td>
<td>Empty body fat percentage</td>
</tr>
<tr>
<td>SREBW</td>
<td>kg</td>
<td>Standard reference EBW; empty body weight of mature cattle that contains 25% fat</td>
</tr>
<tr>
<td>REBFW</td>
<td>kg</td>
<td>Reference empty body fat weight; this is the EBFW calculated with an equation obtained from data on mature nonpregnant, nonlactating cows</td>
</tr>
<tr>
<td>REBFFW</td>
<td>kg</td>
<td>Reference empty body fat-free weight; this is EBW - REBFW</td>
</tr>
<tr>
<td>UEBW</td>
<td>Ratio</td>
<td>Stage of maturity for EBW (EBW/SREBW)</td>
</tr>
<tr>
<td>STUEBW</td>
<td>Ratio</td>
<td>EBW when the transition from $b_1$ to $b_2$ is started</td>
</tr>
</tbody>
</table>

Mathematical Formulation

The mathematical formulation in the model of Keele et al. (1992) is summarized in the following equations:

$$\frac{dEBFW}{dt} = b_1 \times \frac{dEBW}{dt} + c_1 \quad [1]$$

where

$$b_1 = k \times \frac{EBFW}{EBW} \quad [2]$$

and

$$c_1 = keq_1 \times (REBFW - EBFFW) \quad [3]$$

We used the acronyms $EBFW$ to represent empty body fat-weight and $REBFW$ to represent the reference empty body fat-weight. These terms are equivalent to $FFM$ (fat-free matter) and $FFMEQ$ (equilibrium fat-free matter at any $EBW$) in the model of Keele et al. (1992). The term $\frac{dEBW}{dt}$ in Eq. [1] is the daily rate of change in $EBW$. The variable $k$ in Eq. [2] at a particular value for $EBFW/EBW$ is the fractional growth rate for $EBFW$ relative to the fractional growth rate for $EBW$. This variable is a function of a breed-specific fattening parameter ($\theta$), a breed-specific empty body fat-free weight at maturity ($EBFFW_{MAT}$), and lagged gain ($LAG$), which allows previous levels of nutrition to affect present composition of gain. The breed value for $SREBW$ is the empty body weight ($EBW$) of cattle older than 6 yr that contains 25% fat. The $EBFFW_{MAT}$ is 75% of $SREBW$. Williams et al. (1995) estimated $\theta$ and $EBFFW_{MAT}$ values for 17 biological types of cattle, and Williams and Jenkins (1997) estimated $SREBW$ values for 18 biological types of cattle from within-breed regressions of empty body fat percentage on $EBW$ in mature cows.

In Eq. [3], $keq_1$ is the rate of equilibration of empty body composition, and $REBFW$ is the amount of $EBFW$ present when an animal achieves an equilibrium at any $EBW$. A $keq_1$ value of .001 was used by Keele et al. (1992) for growing cattle. Assumptions on which Eq. [1], [2], and [3] were formulated, and the derivation of $k$ in Eq. [2], were fully discussed by Keele et al. (1992). For growing cattle, composition of empty body gain is largely determined by Eq. [2]. If $dEBW/dt$ is zero, and $REBFW$ is not the same as $EBFFW$, Eq. [3] forces compositional changes in $EBFW$ toward an equilibrium composition. Thus, the impact of Eq. [3] on empty body composition becomes greater as $dEBW/dt$ decreases to zero. This model was calibrated and evaluated by Williams et al. (1992) with compositional data on growing cattle.

The model of Williams and Jenkins (1997) is summarized in the following equation:

$$\frac{dEBFW}{dt} = \left(\frac{dEBFW}{dEBW}\right) \times \left(\frac{dEBW}{dt}\right) + keq_2 \times (REBFW - EBFW) \quad [4]$$

This model (Eq. [13] in Williams and Jenkins, 1997) predicts the daily change in empty body fat weight ($\frac{dEBFW}{dt}$) as a function of $dEBW/dt$, the reference empty body fat weight ($REBFW$), and the actual empty body fat weight ($EBFW$). To integrate this model with that of Keele et al. (1992), we needed to rewrite Eq. [4] so that it would predict the same quantity as Eq. [1] (i.e., $dEBFW/dt$). This was accomplished with the following equations:

$$\frac{dEBFW}{dt} = (1 - \frac{dEBFW}{dEBW}) \times \frac{dEBW}{dt} - keq_2 \times (REBFW - EBFW) \quad [5]$$

In Eq. [4] $dEBFW/dEBW$ represents the fraction of $dEBW/dt$ that is fat; hence in Eq. [5] $(1 - dEBFW/dEBW)$ represents the fraction of $dEBW/dt$ that is fat-free matter. If $dEBW/dt$ is zero, then $dEBFW/dt = + keq_2 \times (REBFW - EBFW)$ in Eq. [4]; hence $dEBFW/dt = - keq_2 \times (REBFW - EBFW)$ in Eq. [5], and using the fact that $EBW$ is fat and fat-free matter, this part of Eq. [5] can be written as

$$- keq_2 \times (REBFW - EBFW) = - keq_2 \times [EBW - REBFFW - (EBW - EBFFW)]$$
\[ \text{WILLIAMS AND JENKINS} \]

\[ \begin{align*}
= -\text{keq}_2 \times (\text{EBW} - \text{REBFFW} - \text{EBW} + \text{EBFFW}) \\
= \text{keq}_2 \times (\text{REBFFW} - \text{EBFFW})
\end{align*} \]

The model in Eq. [5] can now be written as

\[ \frac{d\text{EBFFW}}{dt} = b_2 \times \frac{d\text{EBFW}}{dt} + c_2 \]  

where

\[ b_2 = (1 - \frac{d\text{EBFW}}{d\text{EBW}}) \]  

and

\[ c_2 = \text{keq}_2 \times (\text{REBFFW} - \text{EBFFW}) \]

Williams and Jenkins (1997) used a value of .003 for \( \text{keq}_2 \), and this represents a minor difference from the model of Keele et al. (1992). The major difference between the two models is the coefficient \( b_1 \) in Eq. [1] and the coefficient \( b_2 \) in Eq. [6]. The coefficient \( b_2 \) in Eq. [6] is a function of \( \frac{d\text{EBFW}}{d\text{EBW}} \), and Williams and Jenkins (1997) formulated equations specific to the physiological state of the animal to calculate this quantity. For lactating cows that are losing EBW and nonlactating cows that are either losing or gaining EBW, the equation for \( \frac{d\text{EBFW}}{d\text{EBW}} \) is

\[ \frac{d\text{EBFW}}{d\text{EBW}} = \text{BASE} + (1 - \text{BASE}) \times \lambda \times \frac{\text{EBFW}}{\text{REBFW}} \]

where

\[ \text{BASE} = -.157 + .814 \times \frac{\text{EBW}}{\text{SREBW}} \]

The variable \( \lambda \) used in Eq. [9] is a function of days in milk, and this function and its estimation were fully described by Williams and Jenkins (1997). For lactating cows that are gaining EBW, the equation for \( \frac{d\text{EBFW}}{d\text{EBW}} \) is

\[ \frac{d\text{EBFW}}{d\text{EBW}} = \text{BASE} \times \frac{\text{REBFW}}{\text{EBFW}} \]

where \( \text{BASE} \) is the same as in Eq. [9]. We can now represent Eq. [1] and [6] with the following single equation:

\[ \frac{d\text{EBFW}}{dt} = b_1 \times \frac{d\text{EBFW}}{dt} + \text{keq}_1 \times (\text{REBFW} - \text{EBFFW}) \]

where \( b_1 \) is \( b_1 \), and \( \text{keq} \) is \( \text{keq}_1 \) for growing cattle, or \( b \) is \( b_2 \), and \( \text{keq} \) is \( \text{keq}_2 \) for mature cattle.

Assuming that Eq. [1] and [6] are representative of the underlying biological processes that partition \( \frac{d\text{EBFW}}{dt} \) into fat and fat-free matter in growing and mature cattle, respectively, it follows that a life cycle model that predicts composition of gain must be programmed to make a transition from Eq. [1] to Eq. [6], or equivalently put, from \( b_1 \) to \( b_2 \) and from \( \text{keq}_1 \) to \( \text{keq}_2 \). In making this transition, we assume that biological systems respond in a continuous, rather than a discrete manner. Nagorcka (1977) has shown that wool growth in sheep responds to a change in feed intake with a first-order lag constant of 24 d; 63\% of the full response is achieved in 24 d, and this corresponds to 4.2\% of the difference between the full response and the achieved response occurring per day. Keele et al. (1992) used 33 d for 63\% of the full response in LAG to occur, which corresponds to 3\%/d. Using this approach we modeled the transition from \( b_1 \) to \( b_2 \) with a first-order lag function.

On the day that the transition starts to occur, \( b \) in Eq. [12] is set to the value of \( b_1 \), and from this point on, \( b_2 \) is calculated instead of \( b_1 \). A first-order lag function is then used to make \( b \) approach the value of \( b_2 \) over time, and with this function the daily change in \( b \) is obtained with the following equation:

\[ \frac{db}{dt} = \beta \times (b_2 - b) \]

Thus, if \( b > b_2 \), \( \frac{db}{dt} \) is negative and \( b \) decreases, and the opposite occurs if \( b < b_2 \). The net result over time is a gradual decrease in the difference between \( b \) and \( b_2 \).

In the present formulation, the value of \( b_2 \) as calculated with Eq. [7] could become zero and then negative; hence, a minimum value is needed for \( b_2 \). We assumed that at some stage of maturity beyond SREBW, all gains in EBW would be 100\% adipose tissue. Oser (1965) showed that adipose tissue contained approximately 3\% nitrogenous compounds. Assuming that nitrogenous compounds are mostly protein, and that the fraction of protein in EBFFW is .25, we estimate that a unit increase in adipose tissue would result in an increase of .12 units of EBFFW; hence, a minimum value of .12 was used for \( b_2 \).

We assumed a linear increase from \( \text{keq}_1 \) to \( \text{keq}_2 \) (0.001 to 0.003) and used the following equation to calculate \( \text{keq} \) in Eq. [12] beginning on the day the transition from \( b_1 \) to \( b_2 \) starts to occur:

\[ \text{keq} = .001 + .002 \times \frac{\min(\text{UEBW},1)}{\text{STUEBW}} \times (1 - \text{STUEBW}) \]

where \( \text{UEBW} \) is present stage of maturity (EBW/SREBW), and \( \text{STUEBW} \) is value of \( \text{UEBW} \) on the day the transition from \( b_1 \) to \( b_2 \) starts to occur. The term \( \min(\text{UEBW},1) \) is used to restrict the maximum value of \( \text{keq} \) to .003 when \( \text{UEBW} \) exceeds 1.

This completes the mathematical formulation needed to integrate the separate models described in Eq. [1] and [6], and the flow diagram in Figure 1 illustrates how the integrated model works. In the next section, we discuss the method used to simultaneously estimate the parameter \( \beta \) in Eq. [13] and the point in the life cycle at which the transition from \( b_1 \) to \( b_2 \) starts to occur.
Figure 1. Flow of control in a model that predicts composition of empty body weight changes in cattle from birth to maturity. Numbers in brackets refer to specific equations in the text.

Estimation of $\beta$ and Transition Point

Experimental data reported by Jesse et al. (1976) on 16 Hereford steers fed four different diets in four groups from 227 to 545 kg BW were used to estimate $\beta$ and the transition point. Stage of maturity (EBW/SREBW) in these data ranged from .29 at the start of the experiment to .86 at slaughter. Experimental data were EBW and chemical composition of an initial slaughter group, and group means for EBW and chemical composition of steers at slaughter. Growth and body composition of steers were simulated in separate runs, using EBW and composition of the initial slaughter group as starting values. Estimates of $\theta$ (6.3) and EBFFWMAT (437 kg) for Hereford steers were obtained from Williams et al. (1995). In these simulations the value of $\beta$ was varied from .0 to .03 and for each value of $\beta$ the model was programmed to start the transition from $b_1$ to $b_2$ at input values of $b_1$ ranging from .45 to .55.

In each simulation run, when $b_1$ attained its input value, the value of $b$ in Eq. [12] was initialized to the
value of $b_1$, and STUEBW was initialized to UEBW as in Figure 1. At this point, the model goes into a separate loop in which values for $b_2$, $db/dt$, and $keq$ are calculated with Eq. [7], [13], and [14], respectively, and these variables are used in Eq. [12] to predict composition of $dEBW/dt$. Residual SD was calculated in each run from observed and simulated treatment means for kilograms of fat, and the value of $b_1$ in the run with the minimum residual SD was identified as the parameter value of $b$, and the value of $b_1$ at which the transition should be made.

Results and Discussion

Estimation of $\beta$ and Transition Point

Residual SD for kilograms of fat are plotted in Figure 2 against values of $\beta$ ranging from .0 to .03, at three values of $b_1$ (.49, .495, .50). Residual SD was minimized at a $b_1$ value of .495 and a $\beta$ value of .01. This means that the transition from $b_1$ to $b_2$ should occur when $b_1$ decreases to a value of .495 and that $b_1$ would approach $b_2$ at a daily rate of 1% of the difference between this initial value of $b_1$ and the value of $b_2$ calculated daily with Eq. [7]. For a specific breed, the value of $b_1$ will change dynamically with present and previous rate of growth; hence, the EBW and composition at which $b_1$ attains a value of .495 would vary with breed and past and present levels of nutrition within breed. In these data $b_1$ attained a value of .495 at values of .87 and .67 for EBW/SREBW and EBFFW/EBW, respectively.

Evaluation

The model with a transition from $b_1$ to $b_2$ at a $b_1$ value of .495, and a $\beta$ value of .01 was evaluated with growth data on 11 Group 1 steers from Moulton et al. (1922) that were full-fed from birth to 4 yr of age. In these data, steers were serially slaughtered, and the last three slaughter EBW were 786, 771, and 815 kg at 1,172, 1,345, and 1,431 d of age, respectively. In simulating these data a constant rate of growth was used from birth to weaning, and from weaning to the last slaughter an equation obtained from the regression of EBW on linear and quadratic terms for days on feed in the data was used to calculate $dEBW/dt$. The mean EBW (790 kg) and fat percentage (43.34) of the last three steers slaughtered were used to obtain SREBW for the steers in this experiment, with the following equation from Williams and Jenkins (1997) for mature cattle:

$$FAT\% = -15.7 + 40.7 * \frac{EBW}{SREBW}$$

thus,

$$43.34 = -15.7 + 40.7 * \frac{790}{SREBW}$$

The last piece of information needed is the value for $\theta$, and in this case the Hereford $\times$ Angus value of 6.0 from Williams et al. (1995) was used.

Results of this simulation for the last three steers slaughtered are shown in Table 2. The model predicted a mean empty body fat that was .91% greater than observed. This is compared with a prediction that was 4.74% greater than observed, obtained with a model based on $b_1$ alone, with no transition to $b_2$. In these data, the average value of UEBW for the last three steers slaughtered was 1.45 and the stage of maturity (EBW/SREBW) at which $b_1$ attained a value of .495 in the simulation was .86.

Compensating cattle gain EBW at very high rates at the beginning of the realimentation phase, and these high rates of $dEBW/dt$ would result in a rapid decrease in the value of $b_1$; hence, it is possible that the value of $b_1$ could become smaller than .495 during the realimentation phase. In this case the transition from $b_1$ to $b_2$ in immature compensating cattle would occur at an earlier stage of maturity, compared with cattle that are full-fed throughout life. This was investigated with data from Carstens et al. (1991), in which one group of Hereford $\times$ Angus steers were put on a high-energy finishing diet 56 d after weaning, and at the same time another group of similar steers were restricted in growth for 190 d, then put on the same high-energy finishing diet as the unrestricted steers. At the start of the experiment, stage of maturity for both groups of steers was .28, and both groups of steers were slaughtered at a stage of maturity of approximately .71.
Table 2. Observed and predicted empty body fat percentage (EBFP) and empty body weight (EBW) at slaughter for different experiments

<table>
<thead>
<tr>
<th>Treatment or steer #</th>
<th>Age, d</th>
<th>EBW, kg</th>
<th>Observed EBFP</th>
<th>Predicted EBFP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A1</td>
</tr>
<tr>
<td>Moulton et al. (1922)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>527</td>
<td>1172</td>
<td>786</td>
<td>44.56</td>
<td>43.02</td>
</tr>
<tr>
<td>513</td>
<td>1345</td>
<td>771</td>
<td>41.79</td>
<td>43.94</td>
</tr>
<tr>
<td>501</td>
<td>1431</td>
<td>815</td>
<td>43.56</td>
<td>45.67</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
<td>43.30</td>
<td>44.21</td>
</tr>
<tr>
<td>Carstens et al. (1991)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hereford × Angus steers</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unrestricted</td>
<td>508</td>
<td>464</td>
<td>30.98</td>
<td>33.17</td>
</tr>
<tr>
<td>Restricted</td>
<td>598</td>
<td>456</td>
<td>24.61</td>
<td>26.87</td>
</tr>
<tr>
<td>Short et al. (1994)</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Hereford-sired steers</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Unrestricted</td>
<td>456</td>
<td>421</td>
<td>29.00</td>
<td>27.25</td>
</tr>
<tr>
<td>Restricted</td>
<td>686</td>
<td>563</td>
<td>29.00</td>
<td>29.97</td>
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<tr>
<td>Charolais-sired steers</td>
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<tr>
<td>Unrestricted</td>
<td>456</td>
<td>512</td>
<td>26.00</td>
<td>27.58</td>
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<tr>
<td>Restricted</td>
<td>686</td>
<td>608</td>
<td>27.00</td>
<td>27.72</td>
</tr>
</tbody>
</table>

1Predicted with a model based on a transition from b1 to b2 at a b1 value of .495.
2Predicted with a model based on b1 alone, with no transition to b2.

Simulated results using a model based on b1 alone with no transition to b2 showed that for unrestricted steers the value of b1 ranged from .90 at the start of the experiment to .68 at slaughter. For restricted steers, b1 decreased from a value of .85 at the start of the realimentation phase to .43 at slaughter, and during realimentation b1 attained a value of .495 at a stage of maturity of .56. These simulated results indicate that the model based on b1 with a transition to b2 at a b1 value of .495 would have no impact on the composition of gain in unrestricted steers, and that the opposite would be true for compensating steers. Therefore, the experiment was simulated again with a model based on a transition from b1 to b2.

Observed and simulated results for the experiment of Carstens et al. (1991) are shown in Table 2. At final slaughter the observed difference in empty body fatness between unrestricted and restricted steers was 6.37%. This difference was predicted at 6.30% when the experiment was simulated with a model based on a transition from b1 to b2 and 3.36% when the experiment was simulated with a model based on b1 alone with no transition to b2. These results also show that the predicted fatness in unrestricted steers was the same for both models. The simulated results obtained with a model based on a transition from b1 to b2 matched the observed results for these data and suggest that this model has the potential of accurately predicting composition of gain in compensating cattle. In Figure 3, predicted kilograms and percentage of empty body fat are plotted against EBW during the realimentation phase for the restricted steers. At an EBW value of 358 kg, b1 attained a value of .495, and at this time the transition to a model based on b2 was started. The graph shows a continuous change in empty body fatness over an EBW range of 280 to 455 kg. These results indicate that the transition from b1 to b2 modeled by the distributed lag function in Eq. [13] forces a continuous response in composition.

Williams et al. (1995) estimated \( \theta \) values for 17 biological types of steers, using growth and composition data on these steers from the first three cycles of the Germ Plasm Evaluation (GPE) program (a comprehensive investigation conducted to characterize...
production performance for diverse breeds of cattle). These estimates were obtained with a model based on \( b_1 \) alone with no transition to \( b_2 \). The appropriateness of this model was investigated by checking the simulated results for values of \( b_1 \) that were smaller than .495. In all 17 simulations the value of \( b_1 \) was found to be greater than .6 at the end of each simulation. This suggests that the model based on a transition from \( b_1 \) to \( b_2 \) at a \( b_1 \) value of .495 would have no impact on \( \theta \) values obtained by Williams et al. (1995). Steers in the GPE program had ad libitum access at weaning to a diet similar to that given to the unrestricted steers in the experiment of Carstens et al. (1991), and in both cases the value of \( b_1 \) remained above .495 until slaughter.

Further evaluation was done by simulating experimental data published by Short et al. (1994). In this experiment, crossbred cows (various crosses of Red Angus, Angus, Tarentaise, Charolais, and Hereford) were mated to either high yearling weight index Charolais bulls or to average index Hereford bulls. After weaning, half of the steers from each of these matings were put directly on a finishing diet (unrestricted) and slaughtered after 0, 90, 180, and 270 d on this diet. Remaining steers were fed to restrict growth for 365 d (restricted) then put on the same finishing diet as the unrestricted steers and slaughtered after 0, 45, 90, and 135 d on this diet. We did not have \( \theta \) and EBWFFMAT values for the steer genotypes in this experiment. These values were approximated with average values for crossbred steers that were produced in the first three cycles of the GPE project at MARC, from matings of Hereford, Angus, and Charolais bulls to Hereford and Angus dams (Williams et al., 1995).

Results of these simulations for final slaughter groups, using a model based on a transition from \( b_1 \) to \( b_2 \) and a model based on \( b_1 \) alone, are shown in Table 2. For unrestricted steers of both sire breeds, both models predicted the same fatness for the final slaughter groups, and this result is similar to that obtained with unrestricted steers in the data of Carstens et al. (1991). However, for the restricted steers, the model based on \( b_1 \) alone predicted a much greater fatness in the final slaughter groups compared with a model based on a transition from \( b_1 \) to \( b_2 \).

Performance of the model for growing cattle with and without a transition from \( b_1 \) to \( b_2 \) is compared in Figure 4 with observed data on 11 Group 1 steers from Moulton et al. (1922). The solid squares represent observed individual fat percentages of the 11 steers, and the solid lines are the predicted fat percentages. Using a model with no transition from \( b_1 \) to \( b_2 \), the predicted fatness was greater than observed values. The model with a transition from \( b_1 \) to \( b_2 \) predicted the observed fatness of the five heaviest steers very closely, and the transition in this case started to occur at about 470 kg EBW.

The dashed lines in Figure 4 represent simulated fat percentages with a management system in which steers were restricted at 172 kg EBW to grow at a rate of .5 kg/d for 400 d. At the end of the restriction period these steers were simulated to grow on the same diet as the unrestricted steers. Simulated results showed that these steers became leaner than the unrestricted steers during the growth restriction phase. On realimentation, simulated results with a model based on no transition from \( b_1 \) to \( b_2 \) showed that steers approached and eventually slightly exceeded the fatness of the unrestricted steers predicted with the same model. The model with a transition from \( b_1 \) to \( b_2 \) predicted that these steers approached and eventually achieved a level of fatness similar to that observed in the data.

In summary, two published models that were based on separate mathematical formulations to predict composition of EBW changes in growing and mature cattle were integrated with a distributed lag function. These mathematical formulations are representative of the net effects of the biological processes that are responsible for the retention of consumed food nutrients in fat and protein at the whole-animal level. This integrated model greatly improved the accuracy of predicting observed composition in compensatory growth experiments compared with the model for growing cattle. The model is driven by rate of EBW gain and predicts composition of this gain. Using the energy values of fat and protein, retained energy can be obtained, and this would establish a relationship between rate of gain and retained energy. This relationship was demonstrated by Williams and
Jenkins (1997). This work concludes the first phase of developing a nutrition model. The next phase is the development of the relationship between retained energy and rate of gain, followed by the development of methods to predict the efficiency of ME utilization for gain using separate efficiencies for retaining ME in fat and protein. The final phase will be the development of a model to predict ME requirements for maintenance.

Implications

Previously published models used different mathematical formulations to predict composition of gain in growing and mature cattle. A method that integrates these models was presented. Evaluation results of the integrated model showed that it increased the accuracy of predicting composition of gain in compensatory growth experiments. These efforts have resulted in a model that uses rate of gain as its input to predict composition of gain in cattle that have been grown under different systems of nutritional management from birth to mature weights. Composition of gain is related to retained energy; hence, retained energy can be used to drive the model, and this provides a new basis for building a nutrition model.

Literature Cited


