EFFICIENCY OF WEIGHT GAIN OF SERIAL SLAUGHTERED BULLS OF A FIVE-BREED DIALLEL

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ABSTRACT

Weight and feed consumption of 197 bulls were recorded monthly in a serial slaughter experiment continuing over a period of 24 mo. The bulls were produced in a modified five-breed diallel of the Angus, Brahman, Hereford, Holstein and Jersey breeds. Our objective was to estimate efficiency of feed conversion for weight gain for each breed and cross. The model included average weight gain per day (ADG) as a dependent variable; independent variables included breed-type, season, month within season, average feed intake per day (ADI), initial weight, weight to the .75 power, breed × ADI and season × ADI effects. The sum of the partial regression coefficients of ADG on ADI and on breed × ADI adjusted for season, month within season, initial weight, weight to the .75 power and season × ADI was interpreted to be an estimate of intrinsic or net efficiency of ADG. There were no significant differences among the various breed-types in intrinsic efficiency of ADG. Average heterosis for intrinsic efficiency of feed conversion was not significant. None of the contrasts among breed-types was significant for intrinsic efficiency of ADG (British vs dairy, 1.1 ± 12.3 g/d; Brahman-dairy crosses vs British-dairy crosses, 32.7 ± 12.9 g/d; British-Brahman crosses vs British-dairy crosses, 13.9 ± 12.4 g/d; British-Brahman crosses vs straightbred British, 3.2 ± 14.8 g/d).

(Key Words: Bulls, Efficiency, Ratios, Regression.)


Introduction

Most studies on efficiency of feed conversion of beef cattle have dealt with British breeds, continental breeds and their crosses (Gregory et al., 1966; Smith et al., 1976; Long, 1980; Cundiff et al., 1981). Efficiency of weight gain of crosses sired by Brahman, British and continental beef breeds was reported by Cundiff et al. (1984). Other studies have dealt with British beef and dairy breeds and their crosses (Davis et al., 1984). Studies in the gulf coastal states of the U.S. have included Brahman and their crosses (Kappel et al., 1970, Babcock and Franke, 1978).

Materials and Methods

Source and Nature of Data. Data were obtained at the Texas A&M University Agricultural Research Center at McGregor from a project designed to evaluate hybrid systems for total efficiency of beef production. Angus, Brahman, Hereford, Holstein and Jersey cows in herds of cooperating breeders were artificially inseminated according to a diallel

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TABLE 1. NUMBER OF ANIMALS CONTRIBUTING WEIGHT GAIN AND FEED INTAKE DATA BY BREED GROUPS FOR VARIOUS SLAUGHTER AGE GROUPS

<table>
<thead>
<tr>
<th>Breed-type</th>
<th>6</th>
<th>9</th>
<th>12</th>
<th>15</th>
<th>18</th>
<th>24</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angus (A)</td>
<td>12</td>
<td>10</td>
<td>8</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Brahman (B)</td>
<td>14</td>
<td>12</td>
<td>10</td>
<td>8</td>
<td>6</td>
<td>4</td>
<td>2</td>
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<tr>
<td>Hereford (He)</td>
<td>14</td>
<td>12</td>
<td>10</td>
<td>8</td>
<td>6</td>
<td>4</td>
<td>2</td>
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<tr>
<td>Holstein (Ho)</td>
<td>13</td>
<td>11</td>
<td>9</td>
<td>7</td>
<td>5</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Jersey (J)</td>
<td>13</td>
<td>11</td>
<td>9</td>
<td>7</td>
<td>5</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Straightbred total</td>
<td>66</td>
<td>56</td>
<td>46</td>
<td>36</td>
<td>27</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>AB</td>
<td>13</td>
<td>11</td>
<td>9</td>
<td>7</td>
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<td>4</td>
<td>2</td>
</tr>
<tr>
<td>AHe</td>
<td>14</td>
<td>12</td>
<td>10</td>
<td>8</td>
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<td>2</td>
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<tr>
<td>AHo</td>
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<td>AJ</td>
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<td>BHe</td>
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<td>11</td>
<td>9</td>
<td>7</td>
<td>5</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>HoJ</td>
<td>12</td>
<td>10</td>
<td>8</td>
<td>6</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Crossbred total</td>
<td>131</td>
<td>111</td>
<td>91</td>
<td>71</td>
<td>51</td>
<td>40</td>
<td>20</td>
</tr>
<tr>
<td>Slaughter age group total</td>
<td>197</td>
<td>167</td>
<td>137</td>
<td>107</td>
<td>78</td>
<td>60</td>
<td>30</td>
</tr>
</tbody>
</table>

mating plan to produce calves for this project. Each breed was represented by 25 to 30 sires and semen from each sire was assigned randomly to cows in each herd. Details of the source of these cattle and their early management were described by Long et al. (1979). Fourteen bulls of each of 15 breed-types (5 straightbreds and 10 reciprocal F1's pooled) were penned individually and given ad libitum access to feed starting at 6 mo of age. The TDN of the diet was 72%; the diet consisted of 48.5% sorghum grain, 20% cottonseed meal, 25% cottonseed hulls, 4% vegetable fat and 2.5% vitamin and mineral supplement. Feed was weighed periodically into individual storage barrels, from which it was transferred to troughs in individual pens. Feed remaining in the storage barrels was weighed every month to determine monthly feed consumption by each bull. Weight and hip height were recorded every month. Two animals from each breed-type were assigned randomly to one of seven slaughter ages: 6, 9, 12, 15, 18, 24 and 30 mo. Deaths and other removals reduced the total number of bulls to 197 and resulted in unequal numbers in breed-type-age categories (Table 1). By design, numbers from which growth and feed consumption data could be obtained decreased after each slaughter period.

*Data Editing Procedures.* Recording of feed consumption started at approximately 6 mo of age for most animals. Thirty animals did not have feed intake measured for the starting month, although their later records of weight gain and feed intake were used. Inspection of the data indicated that the eating pattern of the cattle, and possibly unidentified sources of weighing errors, could have caused unduly large fluctuations in monthly weights. Therefore, a regression program outlined by SAS (1981) was used for each breed-type to identify influential observations as defined by Belsley et al. (1980) and used by Freund et al. (1986). An influential observation refers to "an observation that, because of its particular values of independent variables, exerts especially heavy influence on the value of parameter estimates or predicted values" (Freund et al., 1986). In addition, average feed intake (as fed) per day (ADI) and average monthly weight were plotted on the same graph against days on feed for each animal. The pattern of growth and feed consumption and their relationships were examined for each animal. Graphical evaluation and statistical significance of data points from the influence analyses were used to determine whether to retain or remove one or more data points for an animal. If the amount of the first ADI was greater than 5% of the corresponding body weight and was statistically influential, then that particular observation of weight and ADI was omitted. Similarly, if an ADI was greater than 10% of the body weight within the interval, and was statistically influential, it was omitted. The assumption made here was that
daily feed consumption could not be more than 5% of body weight in the initial period or 10% of body weight at later periods. Approximately 10 of 760 observations were removed based on these criteria.

Statistical Procedure. These data included repeat measures on the same individuals taken over a period of 24 mo; therefore, the residuals across time may be correlated (first-order autocorrelation), rendering the use of regular least squares procedures inappropriate (Neter and Wasserman, 1974; Maddala, 1977). Also, unequal numbers of observations may complicate the use of generalized least squares procedures (Spector et al., 1982).

Correlation coefficients among monthly weights and among monthly cumulative feed intakes were calculated. Similarly, correlation coefficients among first differences of weight (monthly weight gain) and among monthly feed intake were calculated. First difference is defined as the difference between consecutive weights, which were taken every 29 to 34 d.

Correlation coefficients among cumulative monthly feed intakes and among monthly weights were examined for patterns of change in magnitude as the interval between the observations increased. Similarly, correlation coefficients among first differences of weight (monthly weight gain) and among monthly feed intake were examined for patterns of change in magnitude as the interval between observations increased. These patterns indicate whether the use of first differences reduced the first-order autocorrelation. Statistically, it has been found that using first differences (in this case, monthly weight gain and feed intake) is effective in reducing the first-order autocorrelation of the error terms (Neter and Wasserman, 1974) and consequently enabling the use of regular least squares methods (Neter and Wasserman, 1974; Maddala, 1977). Correlations among residuals of cumulative observations were considerably higher than correlations among residuals of the first differences of observations (Woldehawariat, 1983). Monthly weight gains and feed intakes were divided by the number of days in the interval of measurements to express measures on a daily basis.

The variables ADG and ADI were related by regressing ADG on ADI and other variables. Multiple regression was used to find the combination of independent variables that best described weight gain statistically and also was considered to be logical biologically. The partial regression coefficient of gain on feed intake was interpreted as a measure of intrinsic efficiency of feed conversion. The general equation was:

\[ Y = B_0 + B_1X_1 + e \]  

where \( Y = \text{ADG}, \ X_1 = \text{biologically relevant independent variables}, \) and \( e = \text{residual}. \)

Biologically relevant independent variables (ADI, weight to various powers, initial weight on test, days on feed, initial age on test, arrival weight, arrival age and various interaction and quadratic terms of these), some of which influence weight gain in general and others which may be unique to this experiment, were selected by applying the procedure of maximum coefficient of determination improvement (MAXR) as described by SAS (1979). This was done for each breed-type to find a common within-breed-type model on which to base a general regression model that could be used to characterize all breed-types for efficiency of ADG.

The criteria for selection of independent variables were based on coefficient of determination \((R^2)\), adjusted coefficient of determination \((R^2_{adj})\), which adjusts \(R^2\) for degrees of freedom for each model selected (Judge et al., 1980), and a value, \(Cp\) (described by Neter and Wasserman, 1974), which estimates the sum over all data points of the squared biases plus the squared standard errors in the response variable at all data points. Models with the smallest \(Cp\) value, high \(R^2\) and \(R^2_{adj}\), along with variables considered biologically pertinent, were selected within each breed-type. Weight raised to various powers (.67, .69, .73, .75 and 1) was included in model 1 separately, and the selection procedures were repeated five times to avoid the consequences of near-dependency. The coefficient of determination \((R^2)\) of a model that included weight to the .75 power was slightly higher than the \(R^2\) of models that included weight raised to other powers (Woldehawariat, 1983).

Application of a multicolinearity diagnostic procedure as proposed by Belsley et al. (1980) indicated that days on feed and weight to .75 power were closely related and caused a near-dependency effect. Therefore, days on feed was left out of the model because of the biological relevance of weight to .75 power. Additionally, initial weight had a nonsignificant effect on weight gain within breed-types
and was omitted along with other nonsignificant independent variables. Model 2 was:

\[ Y = B_0 + B_1X_1 + B_2X_2 + e \]  

where \( Y = \text{ADG} \), \( X_1 = \text{ADI} \), \( X_2 = \text{weight to .75 power} \), and \( e = \text{residual} \).

Model 2 is a within-breed-type regression model derived using the procedure of maximum coefficient of determination improvement (MAXR) and various multicolinearity diagnostic methods. To examine the effect of breed-type, the interaction of breed-type with other effects and for comparison and characterization of breed-types for efficiency of ADG, a general model was fitted among breed-types based on the within-breed-type model. This resulted in model 3.

As was the case in model 2, several analyses were performed using appropriate variables as linear, quadratic and interaction terms before arriving at model 3. Similarly, during each statistical analysis, the choice of appropriate independent variables was based on an intuitively chosen magnitude (generally > .28) of the coefficient of determination \( R^2 \), near-dependency effects and significance levels; nonsignificant variables were not included unless they were judged to be of important biological relevance. Additionally, months were classified into four seasons of 3 mo each starting with December and were included along with other variables. Efficiency of weight gain was estimated as the sum of the partial regression coefficients of ADG on ADI and breed \( \times \) ADI from model 3. The partial regression coefficient on ADI estimates the mean efficiency of all breed-types and the partial regression coefficient of the respective interaction term estimates the deviation in efficiency of a breed-type from this mean. All effects in model 3 were assumed to be fixed except the residual term:

\[ Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 + B_5X_5 + B_6X_6 + B_7X_7 + B_8X_8 + e \]  

where \( Y = \text{ADG} \), \( X_1 = \text{breed-type dummy variable} \), \( X_2 = \text{weight to .75 power} \), \( X_3 = \text{assignment weight} \), \( X_4 = \text{season dummy variable} \), \( X_5 = \text{month within season dummy variable} \), \( X_6 = \text{ADI} \), and \( e = \text{residual} \). Linear contrasts (SAS, 1979) of efficiency, determined as the sum of the partial regression of ADG on ADI and on breed \( \times \) ADI, adjusted for the effects included in model 3, of straightbreds vs crosses was used to estimate average heterosis.

A detailed description of fitting regression models for estimation of efficiency of weight gain and comparison of this procedure with that of various versions of the ratio method was presented by Woldehawariat (1983).

### Results and Discussion

Efficiency of feed conversion for weight gain estimated by the proposed regression method was determined for each breed-type. Mean squares and significance levels of variables using model 3 are presented in Table 2. Estimated efficiencies of ADG determined using equation 3 are presented in Table 3 for the various breed-types.

Efficiency of ADG was not significantly different (Table 2) among the various breed-types evaluated using the regression method. Ranking of breed-types for efficiency of weight gain in this investigation using the regression procedure differed from some previous investigations that used the ratio method. For example, efficiency of Angus was reported by Gregory et al. (1966) to be low compared to other breed-types, but Angus ranked intermediate in the present study (Table 3). Similarly, the Hereford has been reported to be one of the most efficient breeds (Gregory et al., 1966; Preston and Willis, 1975), but in the present investigation it was below average (Table 3).

However, the relatively high efficiency of Brahman-dairy crosses using the regression method (Table 3) is similar to results of some

### Table 2. Mean Squares from Analysis of Covariance of ADG as the Dependent Variable

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>Mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breed-type</td>
<td>14</td>
<td>.113 NS</td>
</tr>
<tr>
<td>Weight (75)</td>
<td>1</td>
<td>38.013**</td>
</tr>
<tr>
<td>Initial weight</td>
<td>1</td>
<td>5.060**</td>
</tr>
<tr>
<td>Season</td>
<td>3</td>
<td>2.990**</td>
</tr>
<tr>
<td>Month (season)</td>
<td>8</td>
<td>1.490**</td>
</tr>
<tr>
<td>ADI</td>
<td>1</td>
<td>19.167**</td>
</tr>
<tr>
<td>Breed ( \times ) ADI</td>
<td>14</td>
<td>.125 NS</td>
</tr>
<tr>
<td>Season ( \times ) ADI</td>
<td>3</td>
<td>2.127**</td>
</tr>
<tr>
<td>Residual</td>
<td>1,747</td>
<td>.135</td>
</tr>
</tbody>
</table>

\( \ast R^2 = .31 \)

\( ** p \leq .01 \)

\( NSP > .05 \)
previous investigations using the ratio method (Kappel et al., 1970; Babcock and Franke, 1978). The Hereford-Holstein cross tended to rank much lower using the regression method (Table 3). However, these rankings are not based on significant differences, as indicated by the nonsignificant interaction between breed and ADI (Table 2).

The lack of correspondence between the present results using the regression method and previous investigations using the ratio method could be due to differences in the statistical method (regression vs ratio) and/or differences in statistical adjustments employed. In the present study weight to .75 power, assignment weight, season, month within season and breed × season interaction were included in statistical models.

Differences in efficiency among individuals or breeds have been ascribed to differences in appetite, weight, age and various extraneous factors (Blaxter, 1964). If these biological and environmental factors are kept constant, then it would be possible to measure differences in intrinsic efficiency that arise from individual or breed differences due to digestive, metabolic or conversion processes. In ad libitum feeding systems, appetite controls intake. However, Taylor and Young (1966) found a high correlation between voluntary feed intake and weight of animals at the same age. These investigators stated that this correlation implied that individual variation in appetite either is small or, if not, it is highly correlated with weight. Therefore, adjusting for differences in size at least partially adjusts for differences in appetite.

In the present investigation, efficiency of weight gain was estimated directly from the regression relationship of weight gain and feed intake as the summation of the partial regression coefficient of ADI and the interaction of breed by ADI after adjusting or accounting for differences due to the effects of weight to .75 power, initial weight, season, month within season and season × ADI. This measure of efficiency may be interpreted as corresponding to intrinsic efficiency of weight gain.

In addition to adjustment for relevant biological and environmental factors that influence efficiency of weight gain, the type of statistical procedure (ratio vs regression) used to determine efficiency also could contribute to differences in efficiency of weight gain between the present and some previous investigations. Crampton and Hopkins (1934a,b) recommended the use of weight gain or final weight as a measure of efficiency of feed conversion after correcting for initial weight and feed consumption by multiple regression methods. They stated that the use of a ratio assumes that gain is independent of initial weight and that gain is proportional to feed intake, which might subsequently introduce systemic errors. Similarly, Koch et al. (1963) calculated efficiency as a deviation from a regression that used weight gain as a dependent variable and feed consumption and average weight on test as independent variables to circumvent the use of ratios. The ratio of gain to feed assumes that the biological relationship is represented by a linear function (gain = rate of feed conversion times feed, plus error) whose intercept passes through the origin; this is unrealistic biologically (Tanner, 1949; Weil, 1962; Meyer and Garrett, 1967).

Linear Contrasts of Combinations of Breed-Types. The average difference between crossbreds and straightbreds was slight (P > .05), indicating that heterosis for intrinsic efficiency of ADG was absent (Table 4). The British breeds (Angus and Hereford) and their cross tended to be slightly more efficient (1.1 g gain/kg feed) than the dairy breeds (Holstein and Jersey) and their cross; even though this difference was nonsignificant, this trend is of interest. The comparison of Brahman-dairy crosses (Brahman × Jersey and Brahman × Holstein).
not significant. Therefore, the results suggest patterns.

Heterosis for efficiency of weight gain of cattle is not improved by crossbreeding (Brahman-British crosses) compared with straightbreds (British). Brahman-British crosses also were compared with straightbreds Angus and Hereford; this difference was small and nonsignificant.

Conclusions

The results indicate that heterosis for intrinsic efficiency of weight gain of cattle is not significant. Therefore, the results suggest that crossbreeding to utilize the effects of heterosis will not improve intrinsic efficiency of feed conversion of growing cattle. Also, the results indicate that efficiency of feed conversion as determined by different statistical procedures may not reflect the same biological phenomenon.

Efficiency in the present study was estimated over an interval of 24 mo; most other studies covered an interval of about 6 mo. Breed-types could change in magnitude and rank of efficiency of ADG over this wide time interval due to differences in maturation patterns. Also, only one diet was used; interactions among breed-types, diet and time interval could not be tested but may, if present, affect general conclusions and comparisons of results from those of other studies. Therefore, comparing rankings of breed-types from various experiments should include consideration of the statistical procedures, the nature of efficiency determined and the experimental protocol.

Implications

Differences among breeds and heterosis for intrinsic efficiency of weight gain of beef cattle appear to be small, if they are present at all. The present and previous results imply that any differences among breeds or heterosis for efficiency of feed conversion may be due primarily to differences in size (weight), degree of maturity, body composition, appetite and environmental factors and not due to differences in inherent digestive, metabolic and conversion processes that constitute intrinsic factors. Therefore, selection for efficiency of ADG based on gain/feed (or feed/gain) ratios may have correlated effects on size, maturity and(or) appetite but not on intrinsic efficiency.

Literature Cited


