ABSTRACT: A deterministic beef efficiency model (BEM) was used to evaluate life-cycle herd efficiency (LCHE) in cow-calf beef production systems using four breed groups of beef cattle. The breed groups were Beef Synthetic #1 (SY1), Beef Synthetic #2 (SY2), Dairy Synthetic (DS), and purebred Hereford (HE). The LCHE was defined over the lifetime of the herd as the ratio of total output (lean meat equivalent) to total input (feed equivalent). Breed differences in LCHE were predicted with the larger/slower maturing DS being most efficient at each age of herd disposal and reproductive rate. This was mainly because, at any average age at culling, the dams of DS breed group were less mature and so had been carrying relatively lower maintenance loads for shorter periods and positively influencing LCHE. Higher LCHE was predicted with improvement in reproductive performance if there were no associated extra costs. However, this declined sharply if there was a delay in marketing of offspring. As average age at culling increased from 4 to 6 yr, efficiency declined sharply, but it began to recover beyond this age in most breed groups. We concluded that the slower maturing DS breed group may be more efficient on a herd basis in cow-calf systems and that improvements in reproductive rate not associated with extra costs improve life-cycle efficiency. Culling cows soon after their replacements are produced seems efficient.

Key Words: Beef Cattle, Production, Efficiency, Evaluation
Be

Synthetic #2 (SY2). The SY1 population was a Synthetic #1 (SY1), Dairy Synthetic (DS) and Beef breed groups were purebred Hereford (HE), Beef Alberta, were used to estimate these parameters. The Growth data of four beef breed groups kept at the inflection parameter, and B is an integration constant. Mature weight, k is the maturing index, m is the function, Y is the weight at time t, A is the asymptotic error than Brody’s (Brody, 1945) function. In this using the Richards (Richards, 1959) function, Y = A(1 – Be^kt)^m, which was found to give less prediction error than Brody’s (Brody, 1945). In this function, Y is the weight at time t, A is the asymptotic mature weight, k is the maturing index, m is the inflection parameter, and B is an integration constant. Growth data of four beef breed groups kept at the University of Alberta beef cattle ranch, at Kinsella, Alberta, were used to estimate these parameters. The breed groups were purebred Hereford (HE), Beef Synthetic #1 (SY1), Dairy Synthetic (DS) and Beef Synthetic #2 (SY2). The SY1 population was a composite of Charolais, Angus, and Galloway. The DS population contained approximately ½ dairy breeding (Holstein, Brown Swiss, and Simmental) and the rest from traditional British and continental beef breeds. The SY2 group was a recently synthesized composite with approximately ½ Hereford, 10% dairy, and the remainder from other beef breeds. Estimates of the growth traits of each breed group are presented in Table 1.

The herd submodel was developed following the methods of Taylor et al. (1985). It assumes a stable equilibrium herd structure and generates the numbers of animals from the different gender, age, and physiology subclasses over any specified production cycle. Hence, a conceptual “average cow” with the production characteristics of the herd is simulated. The submodel traces and categorizes the number of offspring produced by this cow over its lifetime in the herd (see Naazie et al., 1997, for details). The herd is then essentially the number of average cows, their offspring, and the breeding bulls. This simplification is effective and allows evaluation of complex situations in a simple manner (Taylor et al., 1985). Reproductive rate was defined as the proportion of calves surviving to weaning and replacements were assumed to be produced in the herd. The reproductive rate, the offspring sex ratio at birth, and the fact that at least one female offspring has to be produced as a replacement, if the herd is to sustain itself, are used to calculate the minimum number of years a cow must stay in the herd for the herd to be sustainable. Culling the conceptual cow, therefore, implies the herd is being culled or replaced. The cow’s productive life is the difference between the ages at first calving and its average culling age, and, unless a replacement has been produced (i.e., age at culling is greater than the minimum number of years required to produce a replacement), culling is not permitted by the model because the herd will not be sustainable.

The efficiency submodel obtains the predicted feed intakes from the growth and feed intake submodel and the numbers of animals in various subclasses from the herd submodel and computes the total input to and output from the herd and, hence, LCHE. All inputs were converted to their equivalents in feed (Mcal of ME) and all output to their equivalents in steer lean meat production (g lean meat/kg of mature weight). Hence, the total input was made up of the feed intake of the market offspring from birth to time of sale or slaughter, that of the culled breeding bulls and dams, the extra feed for pregnancy and lactation, the extra feed for environmental corrections, the breeding costs

<table>
<thead>
<tr>
<th>Breed Group</th>
<th>Mature weight (A), kg</th>
<th>B</th>
<th>k x 10^-3</th>
<th>m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hereford</td>
<td>587.3 ± 12.7</td>
<td>.9036</td>
<td>1.0239</td>
<td>.6873</td>
</tr>
<tr>
<td>Beef synthetic 1</td>
<td>610.8 ± 16.4</td>
<td>.9891</td>
<td>1.1006</td>
<td>.6374</td>
</tr>
<tr>
<td>Beef synthetic 2</td>
<td>639.3 ± 25.2</td>
<td>.9917</td>
<td>.8518</td>
<td>.6136</td>
</tr>
<tr>
<td>Dairy synthetic</td>
<td>706.6 ± 45.4</td>
<td>.9979</td>
<td>.5543</td>
<td>.4926</td>
</tr>
</tbody>
</table>

aThe Richards function is given by Y = A(1 – Be^kt)^m.
(feed equivalent), and the initial cost of the stock (feed equivalent). The initial cost of the herd was expressed as a product of the cost per kilogram of live weight and the weight of the animal, using prices published by Alberta Agriculture (1989). The breeding cost (defined as the net cost of maintaining the breeding male over its lifetime per calf produced by that male) was estimated on the basis of the breeding practices at the University of Alberta beef research ranch. Bulls were used as yearlings, and 75% of them were culled; the other 25% were used again at 2 yr of age, and all were then culled. The average cost of feed per bull was therefore calculated as .75 times the feed consumed to 1 yr plus .25 times the feed consumed to 2 yr. The value of the bull at slaughter was similarly weighted. Each bull was mated to 25 cows and, hence, could produce $0.75 \times 25$ (first year) plus $0.25 \times 50$ calves, where $r$ was the reproductive rate. The cost of carrying an additional two bulls per 100 cows per year as an insurance for the availability of bulls was also included.

Total output was estimated by converting the lean meat output of various types of animals to their equivalent in steer lean meat and summing. Slaughter records of the University of Alberta beef cattle ranch were used to compute the proportions of various classes of animals and their carcass grades at slaughter. The proportions obtained were weighted by the average price of the different grades of beef reported by Alberta Agriculture from 1985 to 1989 (inclusive) to obtain the relative value of the different classes of animals (see Neazie, 1992, for details). Any extra milk was also converted to its equivalent in lean meat, although this was not significant in cow-calf systems of production. Equivalent outputs could then be summed.

The model was designed so that LCHE could be estimated at all possible degrees of maturity of the market offspring. Because offspring meant for the meat market are usually the main output of the beef enterprise, the point was to determine whether there are optimal degrees of maturity at which such offspring should be culled from the herd to improve efficiency. Comparisons were made on the basis of degree of maturity because it best represents an animal’s state of development (Taylor, 1985; Taylor et al., 1985). Comparisons at the same age or weight usually imply comparison of animals at different metabolic states, whereas at the same degree of maturity, animals are at approximately the same body condition and metabolic state (Taylor, 1985; Taylor et al., 1985). The current model lacks the generality of general systems models, such as the Texas A&M University model (Sanders and Cartwright, 1979), and has no routines for tracking individual animals over time. It also does not accommodate different mating systems or diet optimization but allows the investigation of life-cycle efficiency under various scenarios. However, as much as possible, all traits were estimated rather than assumed. Hence, the mature weight was estimated asymptotically by a growth function, which, together with the fact that these animals are raised solely on range, perhaps prolongs the length of time an animal takes to attain mature weight.

### Evaluations with the Model

The traditional cow-calf system of production is one in which there is an equal male-female sex ratio at birth and a cow is allowed to remain in the herd as long as she produces a calf annually. The logic of such a system is to minimize the cost of replacing females. To investigate the breed effect, the mean age at culling and the mean reproductive rates reported by Berg et al. (1990) and Arthur et al. (1993) were employed to simulate base life-cycle efficiencies. The mean reproductive rates (calf crop weaned) reported by Berg et al. (1990) were .75 for HE, SY1, and SY2, and 0.77 for the DS. The mean ages at culling were 3.7 for HE, 4.5 for SY1, and 5.2 for DS (Arthur et al., 1993). The mean age at culling was 4.2 yr for all three, and this was assumed as the culling age for SY2. The reproductive rates were approximated to .8 and assumed to be what is attainable under “normal conditions,” and the breed groups were then compared at this reproductive rate and three different ages at culling: 6, 8, and 10 yr. The mature weights of the synthetic breed groups relative to that of the HE were considered in computing the outputs. It was also assumed that all breed groups had the same lean meat content of 33% of live weight at any stage of maturity (Taylor et al., 1985). The SY1 group is reputed to have a lean meat content of 38%, but differences employing this figure were minor and are not reported.

To investigate the effect of average age at culling on LCHE, a mean reproductive rate of .8 was assumed, as above, and the age at culling was then varied from a minimum equivalent to the age at which the dam’s replacement would have been produced (see Neazie et al., 1997) to a maximum of 10 yr. The 10-yr maximum was thought to be reasonable because the pattern of change in efficiency would have been established by then and because few animals live beyond this age in a beef herd. For example, the mean age at disposal was 4.2 yr (Arthur et al., 1993) for the breed groups of this study, and, by 10 yr of age, a maximum of only 3.3% of the cows remained in the herd. To determine what would happen to LCHE if reproductive rates were improved, a mean culling age of 6 yr was used, and the reproductive rate was varied from .5 to 1.0. It was assumed further that such improvements in reproductive rate would be achieved at a cost, whether in terms of improved management, better feeding, or use of biotechnology. To determine at what point such costs will not be reasonable, they were expressed as a percentage of total feed costs.
Results and Discussion

Breed Effects on Life-Cycle Efficiency

Figure 1a indicates the degree of maturity of each of the four breed groups with respect to age in days. The DS and the SY2 had heavier mature weights and were slower in maturing than the HE and the SY1 (see Table 1 for growth traits). In general, the breed groups are 31 to 35% mature at weaning (6 mo), 43 to 50% mature at 1 yr, 52 to 60% at 18 mo, and 58 to 69% mature at 2 yr. Figure 1b represents the cumulative feed intake per unit of mature body weight (Mcal ME/kg of mature weight) for the same breed groups. The fastest maturing breed group, SY1, had the lowest energy intake per kilogram of mature size at any degree of maturity, whereas the slowest maturing breed group, DS, had the highest.

The breed group comparisons for LCHE are shown by Figure 2 for the base efficiencies, employing the estimated breed production characteristics reported by Berg et al. (1990) and Arthur et al. (1993). A degree of maturity of offspring at slaughter of $\mu = .4$ was identified as the point of maximum efficiency, and most comparisons were made at this stage. However, the differences in LCHE from $\mu = .3$ to .5 are small for all breed groups, and efficiency could be maximized by selling offspring to feedlots at weaning when they are 31 to 35% mature.

The differences among breed groups ranged from a minimum of less than 1% to a maximum of 25%, and the difference between the best and the poorest breed group at the point of maximum efficiency (degree of maturity of offspring at slaughter, $\mu = .4$) was 24%. At conventional slaughter points of $\mu = .7$ to .85, there was little difference among the breed groups, but, as pointed out earlier, the use of a growth function to fit growth data of animals on range has manifested in a delay in the attainment of any level of maturity. For example to attain a $\mu$ of .8, offspring of the fastest and slowest maturing breed groups would require 2.7 and 5.2 yr, respectively (Figure 1). Offspring destined for the meat market are hardly ever retained in the herd beyond 2 yr; hence, some caution should be exercised in interpreting the results when $\mu > .7$.

Life cycle herd efficiency seemed to be higher, the slower the breed matured. The DS breed group, which was clearly the slowest to mature (Figure 1), was also the most efficient. The SY1 breed group had the lowest efficiency when offspring were slaughtered before 20% maturity, but, thereafter, the Hereford was the worst, up to 80% maturity. At the point of maximum efficiency, the DS breed group was 24, 20, and 12% more efficient than the Hereford, SY1, and SY2, respectively. The breed group comparisons at the same mean culling ages (6, 8, and 10 yr) and reproductive rate ($r = .8$) were similar to those estimated using their natural production characteristics; the LCHE was highest for DS. In this case, the differences in

Figure 1. Degree of maturity and mean cumulative energy consumptions (Mcal/kg of mature weight) to specific degrees of maturity of the four breed group (a) degree of maturity with age in days and (b) cumulative feed consumption (Mcal/kg of mature weight) with degree of maturity.
with size, such as gestation and lactation, dystocia, and postweaning rate of gain, preclude size itself from having a major effect on life-cycle production efficiency. Morris and Wilton (1976) concluded that little difference exists among breeds when the cost of replacement and the salvage value of the culled cow are considered. Experimental work, comparing cattle of different sizes at the same finish (% fat), seems to confirm these conclusions (Smith et al., 1976; Barber et al., 1981; Kempster et al., 1982; Stewart and Martin, 1983). However, most of the experimental studies compare efficiency over some portion of the life of the slaughter offspring without examining the entire production system, and most usually impose some resource constraint (either feed or space). Differences in management costs between breed groups could influence life-cycle efficiency, but such differences were assumed to be minimal in the current study.

In contrast to the above findings, other researchers concluded that breeds do exhibit differences in efficiency. For example, Blaxter (1968) and Taylor and Young (1966) argued that individual differences in rate of maturing were likely to be associated with differences in production efficiency. In experimental studies, Cundiff et al. (1981, 1984) reported significant differences in efficiency between large and small breed groups compared at the same marbling or fat trim points. They reported that breed groups reaching these end points faster were more efficient because of lower energy requirement for maintenance. It seems likely that even though the mature size per se will not influence breed differences, the overall effect of differences in maturing rate, mature size, and feed intake do have an effect on breed differences in life-cycle feed efficiency.

The unexpectedly low LCHE of the faster maturing breed groups in this study can be explained by their maturing rates (Taylor and Young, 1966; Blaxter, 1968; Taylor et al., 1985) and are in line with the results of the sensitivity analysis (Naazie et al., 1997). The degree of maturity of the dam was the trait to which the model was most sensitive. It should be recalled that increasing the dam's degree of maturity by 10% resulted in a reduction in LCHE. Dams are culled on an age basis (not on a "same maturity" basis), and, at any age of herd disposal, the faster maturing dams are relatively more mature and have been carrying a relatively larger maintenance load for a longer period of time. Because the dam's intake is by far the major input to the herd, the more mature dams of these breed groups at any average culling age would make these breed groups less efficient. By contrast, the slow maturing breed groups would be the least mature at any culling age and would therefore be more efficient. It is also important to note that the results in Figure 3 were obtained using the natural production characteristics of these breeds groups, with the DS group having the highest longevity of 5.2 yr, whereas the HE, SY1, and SY2 had 3.7, 4.5, and 4.2 yr, respectively. Hence, DS (about 80% mature) had the longest productive life but was still as young as or younger than the rest of the groups (e.g., SY1 is about 87% mature at 4.5 yr). Even at the same culling age, all breed groups would have been subject to approximately the same productive life, making the slower maturing breed groups more productive and also more efficient. For example, if the herd is turned over at 5 yr of age, SY1 dams would be 91% mature, and DS would be only 80% mature. But, both of these breed groups would have had a 4-yr productive life, if they were mated to calve first at 2 yr as usually happens, making the slower maturing DS relatively more productive.

Therefore, under the assumptions of this study, the large-sized, slow maturing DS breed group was predicted to be advantageous in terms of LCHE in cow-calf systems.

**Effect of Reproductive Rate**

The effect of changing the reproductive rate \( r \) from .5 to 1.0 on LCHE is shown by Figure 3 for an average culling age of 6 yr. The results were similar in trend for all breed groups but varied slightly in magnitude and stage of occurrence. In any breed group, improving \( r \) improved LCHE as long as the offspring were marketed or slaughtered early enough. For the HE and SY2 breed groups, this implied not retaining offspring beyond 70% maturity in the herd. For the SY1, offspring should not be retained beyond 75% maturity, and, for the DS breed group, the offspring should not be retained beyond 65% maturity.
Figure 3. Influence of reproductive rate on the life-cycle efficiency (g equivalent lean/Mcal ME) at the same culling age of 6 yr in four breed groups (a) Hereford, (b) Beef Synthetic #1, (c) Beef Synthetic #2, and (d) Dairy Synthetic.
This implies that, for all the breed groups, market offspring should be culled and sold to feedlots or slaughtered before 4 yr of age. This is, of course, not a limitation because most beef animals are slaughtered before 2 yr of age. The differences were substantial especially for SY1 breed group. In the SY1 breed group, increasing reproductive rate from .8 to 1.0 improved efficiency by 8.8%. This difference is of practical significance because a reproductive rate of .8 approximates what is obtained under field conditions. The values for other breed groups were 6.6, 7.2, and 7.5% for the DS, SY2, and HE, respectively.

The results compared favorably with the conclusion of Dickerson (1978) that an approximately 10% improvement in biological efficiency could be expected in lamb or beef cattle as a result of a 20% increase in the number of offspring due to genetic improvement. Fennessy and Thompson (1989), working with farmed red deer, obtained 5 to 9% improvement in efficiency for a 10% increase in r. The differences obtained in the current study ranged from 3.9 to 6.5% for a 10% increase in the reproductive rate. These were in general similar to those of Taylor et al. (1985), although they did not find as rapid a decline in efficiency beyond the peak as that reported in this study. Their results indicated an increase of 4 to 5% at the point of maximum efficiency for a proportionate increase of 10% in r without crossover in efficiency curves. The crossover in efficiency curves, especially when \( \mu > .7 \), seems anomalous, but it should be remembered that when market offspring are not sent to market at the appropriate time, efficiency is lost. This is because they begin to lose value on account of their age but also because they begin to consume excessively more than they produce. Hence, the more there are (i.e., the higher the reproductive rate), the bigger the loss in efficiency.

The current results, therefore, agree reasonably well with the few published estimates. However, if the cost of achieving such reproductive increases exceeded 15% of dam costs, LCHE was reduced in all cases. Taylor et al. (1985), investigating the effects of reducing dam feed costs, also reported marked influences on overall efficiency. This suggests that it is probably not wise to incur too much cost in trying to achieve higher reproduction. Thus, if for the same level of costs the reproduction can be improved, it will result in improvement in LCHE.

**Effect of Average Age at Culling on Life-Cycle Efficiency**

The influence of age at culling on LCHE is shown by Figure 4 for each breed group. These values were evaluated for a reproductive rate of .8. For clarity in the diagrams, results for ages at culling of 8 and 9 yr were not included. In general, the life-cycle efficiency declined as the cows were maintained longer in the herd. However, beyond 6 yr of age, the decline in efficiency was minimal and indeed in some breed groups (HE and SY1) efficiency began to recover, depending on slaughter age of the offspring. In general, maximum efficiency was obtained if offspring were slaughtered between 30 to 60% mature, usually at 40% maturity. At the latter degree of maturity, the SY1 breed group recovered in efficiency enough to make disposal at 10 yr of age 4 to 9% more efficient than at 4 yr of age. Hence, for this breed group, these results suggest that it might be worthwhile retaining cows as long as possible, provided offspring are culled before they were 60% mature. As indicated earlier, market offspring need not always be slaughtered but can be sold to feedlots. However, in this particular instance, early herd disposal at 4 yr was far more efficient than at later ages irrespective of the maturity level of the market offspring at slaughter.

The differences in efficiency ranged from less than 1 to 53% depending on the breed group and the degree of maturity of the offspring at slaughter. At the point of maximum efficiency (degree of maturity, \( \mu = .4 \)), culling the herd at 4 yr of age was up to 9.5% more efficient than at 5 yr of age depending on breed group. Relative to disposal at 6 yr of age, culling at 5 yr was up to 6.4% more efficient at the point of maximum efficiency. However, culling at 6 yr of age was only \(-0.8, -1.5, 4, \) and 2.5% more efficient than at 7 yr of age in HE, SY1, SY2, and DS breed groups, respectively, indicating that the trend in efficiency was reversing for most of the breed groups by this age at culling. These results were similar in some respects to those of Taylor et al. (1985), who reported a maximum difference of 15% at the point of maximum efficiency and 8% between life-cycle efficiency at 5 and 7 yr of age at culling. In the present study, maximal differences at the point of maximum efficiency (\( \mu = .4 \)) were 8.5, 13, 12, and 19% for the HE, SY1, SY2, and DS breed groups, respectively. However, the efficiency curves derived by Taylor et al. (1985) were relatively unchanging at the maximum (very platykurtic), and efficiency continuously declined with increasing age at culling. Results similar to those of Taylor et al. (1985) were also reported by Fennessy and Thompson (1989) for red deer, but the changes in efficiency with the length of residence in the herd were smaller in their study. They attributed this to the fact that the hind was much more mature at first calving than cattle, and the efficiency at first calving would be smaller than that for cattle. Subsequent changes in life-cycle efficiencies would then be expected to be smaller as well.

The decline in life-cycle efficiency from year to year (in the 1st 6 yr of this study) was probably attributable to the fact that the dams were getting older and were eating more but contributing less to the output. As explained by Taylor et al. (1985), when a dam is young, she utilizes her feed intake both for reproduction and productive growth because her carcass is still of prime value. However, as she ages,
Figure 4. Influence of age at culling on the life-cycle efficiency (g equivalent lean/Mcal ME) in the four breed groups (reproductive rate = .8) (a) Hereford, (b) Beef Synthetic #1, (c) Beef Synthetic #2, and (d) Dairy Synthetic.
Figure 5. Proportionate share of the dam in (a) input to the herd, (b) output from the herd (evaluated when offspring degree of maturity at slaughter = .4), and (c) the degree of maturity of the dam at each culling age.
her carcass is less valuable, and she consumes more feed that is not being used for productive growth. Hence, she consumes more feed and produces relatively less output, both from her salvage value and the offspring she is producing. The reversal of the trend in efficiency beyond 6 yr of age at culling differed noticeably from the results of Taylor et al. (1985). This was probably the result of a difference in the treatment of the value of cull cow (dam) meat. Taylor et al. (1985) employed a function \( P_{d(n)} = 1.02 - 0.02n \), where \( P_{d(n)} \) was the price of dam meat at her nth calving, that decreased with age (number of calvings) to predict the value of cull cow meat. As the value of the culled cow declined, her contribution to the total output declined at a fairly constant rate as the age at which she was culled increased. In the current study, however, the value of a culled cow meat remained constant over some age ranges, 2 to 3 yr, 4 to 5 yr, and 6 yr or older. Beyond 6 yr of age, no more penalty was incurred in the value of lean from a culled cow, and the contribution of the dam to the output tended to stabilize and not decline as in the study of Taylor et al. (1985). This effect is reflected in Figure 5, which indicates the contribution of the dam to both input and output, depending on her age at culling (values were evaluated at offspring degree of maturity = .4). It can be seen that even though the proportion of input due to the dam is decreasing at a fairly constant rate for each breed group, the decline in the contribution of the dam to output is less rapid beyond 6 yr of age. This improvement in the dam's contribution to output together with the increased number of offspring probably made the dam's maintenance cost less important, and hence the improvement in efficiency beyond 6 yr of age.

Conclusions

The following predictions were made with the model under the assumptions of no restriction in ME intake and no differences in the management costs among the breed groups.

1. Large breed differences in life-cycle herd efficiency were predicted at any average age at herd disposal; the trend favored the slower maturing breed groups.

2. Improvement in life-cycle herd efficiency with improvement in reproductive rate was predicted provided that the associated costs of attaining this improvement were minimal.

3. Life-cycle herd efficiency was predicted to decline with increase in age at culling up to 6 yr. Beyond 6 yr, efficiency began to recover in the faster maturing breed groups, and the decreases in the slow maturing groups became marginal.

Implications

Predictions from the current model indicate that maintaining a cow in the herd as long as possible is probably not an efficient option. These predictions support earlier findings that a cow should be culled as soon as her replacement is produced. Life-cycle efficiency will be improved if reproduction is improved, but such improvement in reproduction should not be achieved at a cost. Breed groups were predicted to vary in life-cycle efficiency, as a function of differences in maturing rates.

Literature Cited


