Bioeconomic Evaluation of Embryo Transfer in Beef Production Systems: III. Embryo Lines for Producing Bulls


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ABSTRACT: A model was developed for the economic evaluation of embryos for producing bull lines for use in commercial beef production. The fundamental concept underlying the model is that a cloned and sexed embryo of known genetic characteristics for beef traits is used to produce a bull. After reaching physiological maturity, the bull is used in natural matings. Equations relating feed energy requirements and growth rates based on NRC requirements and costs and returns discounted to present value allow investigation of expected economic merits of progeny from different embryo bull lines. The model has the flexibility to determine optimal embryo characteristics for different production environments. Model sensitivity to variation in progeny sex ratios, growth rates, yield and quality grades, and herd fertility characteristics was examined. Net present values (NPV) per embryo transferred were determined at the optimal marketing age of progeny produced from mating the bull to 30 cows per year for 5 yr. Relative to the lowest NPV of $18,209 for progeny with an expected quality grade of Select and yield grade of 4 at 400 d, increments in NPV ranged from $329 to $22,708 depending on differences in expected progeny carcass grade characteristics. The difference between NPV for 100% male and 40% male sex ratios was $7,518. The NPV differences between progeny growth rates of 1.6 and .9 kg/d holding herd conception rate constant at .9 and .5 were $8,311 and $4,611, respectively. The model evaluates relative economic values of embryo lines for producing bulls, accommodating interactions among progeny characteristics, and environments.

Key Words: Econometric Models, Embryo Transfer, Net Present Value

Introduction

Increased selection intensity and reduced generation interval are potential advantages of embryo cloning and transfer (ECT; Nicholas and Smith, 1983; Seidel and Elsden, 1989). Reports in the dairy industry (Gramlin, 1981; McDaniel and Cassell, 1981; Van Vleck, 1982; Navarro-Fierro et al., 1986) have concluded that ECT is profitable only to registered cattle breeders who supply young sires for AI and merchandise surplus female animals. Most evaluations of ECT have been based on a single criterion such as the number of progeny obtained per donor, with limited assessment of consequences to the whole production system. Economic merits of ECT for producing beef bulls applying a systems approach have not been considered.

Youngs et al. (1986) demonstrated in beef cattle that after one generation of selection the improvement in yearling weight could be 29.9% greater by using ECT rather than conventional methods. Nicholas and Smith (1983) showed that selected clones in a commercial dairy herd could increase genetic merit by > 25%.

Considering that ECT techniques are becoming commercialized, there exists a danger that cloned embryos will be merchandised without evaluation of their value or optimal use. Although the value of ECT depends on the biological and economic circumstances of the consumer, a rational pricing...
system based on the potential genetic merit and the intended use of embryos is required. An ECT price discovery system requires modeling the total production system taking into consideration the overall process efficiency from the time of implantation until marketing of the end product.

Objectives of this study were to develop a model for evaluating the value of alternative embryo lines for producing bulls as herd sires in commercial beef production, considering interactions among sire progeny characteristics with economic and physical environments. Effects of sex ratios, growth rate, carcass quality and yield grades, and herd fertility on ECT were examined.

Materials and Methods

The economic value of ECT from a single embryo transfer was defined to be the net present value (NPV) of the total merit of a bull’s genotype realized from progeny. The value of a unit of genetic superiority of a bull for a beef trait realized through a single embryo implantation was expressed as a function of three factors: 1) genetic merit of the bull via progeny relative to the base, 2) frequency with which that superiority is expressed via progeny, and 3) net cash value of that merit. All costs and returns were discounted to the time of implantation to obtain the NPV of a bull from an implanted cloned and sexed embryo.

Model Concepts

An implicit assumption of the bull model is that a cloned and sexed embryo of known genetic potential for rate of gain, birth weight, mature size, and carcass characteristics may be purchased from an embryo transfer service firm. After the embryo is implanted in a recipient cow, it may develop into a bull, which is used as a herd sire in natural matings. The model assesses the relative profitability of producing alternative bulls with known genetic potentials from cloned and sexed embryos based on progeny performance. By varying the genetic potentials of bulls in the model input, embryo value differences in specific production and economic environments are obtained as output. These define break-even price differences among the embryos producing bulls.

The conceptual structure of the model is similar to that of a steer model described by Ruvuna et al. (1992a); hence, only essential components and features of the bull model are described. The model may be partitioned into three hierarchical components. The first is related to biological functions of bull growth from the time of embryo implantation to the time of physiological maturity, the time at which the bull may be used for natural matings to produce progeny for commercial beef production. The second is the progeny component, whereby the bull is used as a herd sire in natural matings. The third component evaluates profitability of the ECT bull based on progeny performance. Although the first two components are biological, the third considers profitability of the bull line as a function of production costs and market returns discounted to present value using the NPV criterion. A proportion of heifer progeny may be retained for herd replacements and the surplus, together with steer progeny, are reared and sold for beef at the market age and weight determined by the model to maximize NPV. The intermediate inputs and outputs generated by the model during evaluation are feeds in terms of NE for maintenance and growth, milk suckled by calves from birth to weaning, and weight gains and body weights, which are accrued on a daily basis.

Parameters for body weights, growth rates, and carcass traits of the progeny are a function of the genetic characteristics of the breed, the bull, and the production environment in which the progeny are kept. Expected values of ADG are estimated and updated daily, based on energy content of herd feed available per animal per day and genetic potential. The herd NE per animal per day available is an input to the model. If energy intake exceeds maintenance requirements, the animal gains weight at a rate determined by the energy in the feed surplus to maintenance. If the resulting daily gain exceeds the maximum genetic potential, feed intake is constrained to the level yielding the maximum permissible growth. The calculations to determine the balance between energy available, energy requirements, and growth are made daily, using equations derived from NRC (1984) and reported by Ruvuna et al. (1992a).

Feed intake of a calf from birth to weaning is assumed to be from dam’s milk. This allows assessment of feed cost preweaning by costing milk suckled, without the complications of evaluating the most economical way to feed a calf. In addition, this approach provides the flexibility to examine differences in lactation yield of recipients and natural dams as a separate problem. A provision is provided in the model that allows for preweaning supplementary or creep feeding.

Input parameters of expected progeny phenotypic values for birth weight (EBWT), growth rate (EWG), and mature size (WMA) are estimated by combining breeding values with nonadditive effects from parental information in Equation [1].

\[ EP_i = BBV_i (1 + HI_i + HM_i) \]  \[1\]

where \( EP_i \) is the expected phenotypic value of progeny for the \( i \)th trait (EBWT, EWG, WMA); BBV
Table 1. Default heterosis parameters

<table>
<thead>
<tr>
<th>Trait</th>
<th>Direct heterosis (%)</th>
<th>Maternal heterosis (%)</th>
<th>Phenotypic standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birth wt</td>
<td>3.8 to 4.0</td>
<td>1.7</td>
<td>4.73 kg</td>
</tr>
<tr>
<td>Preweaning growth</td>
<td>4.6 to 5.0</td>
<td>1.0</td>
<td>10.1 kg/d</td>
</tr>
<tr>
<td>Weaning wt</td>
<td>3.6 to 5.0</td>
<td>4.7 to 6.0</td>
<td>29.93 kg</td>
</tr>
<tr>
<td>Postweaning growth</td>
<td>8.5 to 9.0</td>
<td>1.1</td>
<td>11.1 kg/d</td>
</tr>
<tr>
<td>Mature wt</td>
<td>2.5 to 3.5</td>
<td>3.5</td>
<td>51.87 kg</td>
</tr>
</tbody>
</table>

Sources: Cundiff et al. (1964); Cundiff (1973); Dinkel and Busch (1973); Woldehawariat et al. (1977); Omar (1984); and Asbury et al. (1986).

is the expected progeny breed breeding value; and HI and HM are expected percentage of individual and maternal heterosis, respectively. Each BBV is obtained from the expected breeding value of sire and dam and adjusted to the parental population genetic base using Equation [2].

$$BBV_i = \frac{1}{2}(BP_{si} + EBV_{si}) + \frac{1}{2}(BP_{di} + EBV_{di})$$

where BP is breed population genetic base for sire (s) and dam (d), respectively; EBV is estimated breeding value of sire (s) and dam (d), respectively, expressed as a deviation from the breed base population.

Under the dominance model, percentage of heterosis expressed by a progeny is estimated by multiplying maternal and individual F1 heterosis estimates by the relative F1 heterozygosity level of the dam and progeny, respectively (F1 heterosis x percentage of F1 heterozygosity of progeny; maternal heterosis x percentage of F1 heterozygosity of dam). The default individual and maternal heterosis parameters used were the midrange values of ranges reported in Table 1. Weight of a steer or a heifer at market age from a bull obtained from ECT is estimated using Brody’s (1945) growth equations for asymptotic growth. The fundamental concept underlying the model is that equations representing growth rates and weights are a function of feed and genotype. Feed requirements are dependent on genetic levels of growth potential. The potential growth rates and weights may or may not be reached, depending on adequacy of feed available.

Economic Expressions

The model calculates two major cost components. The first is for costs associated with bull ownership from the time of embryo implantation to physiological maturity at 55% of WMA (Omar, 1984; Doren, 1989). The second is for costs of progeny from birth to market age. Other costs input to the model include a per-cow annual cost specific to a herd to account for costs such as health, labor, and incidentals and a marketing cost to cover transportation and loading. Income is generated from progeny sales, production of herd replacements, and bull salvage value.

Economic value of an embryo for producing a bull is expressed as net returns from progeny of the bull discounted to the time of embryo implantation. The NPV criterion is used to define the economic merit of alternative embryos of various characteristics for different production systems. A deterministic model in terms of structure, functions, and biological and economic parameters follows.

$$NPV = -EIC - HCC - (CB \times DISC^{-t_2} + FC_g \times DISC^{-t_{1m}} \times Pp - (FC_w \times DISC^{-t_{3m}}) \times Pm \times Pp \times [\sum (Bm \times PBj - NCj \times HCC)] + (1 - S) \times FC_{gfr} \times DISC^{-t_0 + t_{fr} + j - 1} + (1 - S) \times FC_{gfr} \times DISC^{-t_0 + t_{fr} + j - 1} + (1 - S) \times FC_{gfr} \times DISC^{-t_0 + t_{fr} + j - 1}$$

where NPV = net present value of a sexed male embryo; EIC = initial embryo and implantation costs; HCC = herd annual cost per cow; CB = costs at birth of bull calf; DISC = (1 + D/100) and D is annual discount rate or real interest rate; FCg = feed cost incurred at time t0 associated with a bull fetus during gestation; Pp = probability of embryo survival from implantation to birth; FCw = feed cost incurred at time t1m associated with a bull fetus during gestation; Pm = probability of bull calf survival from birth to reproductive maturity; y =

Table 1. Default heterosis parameters
years the bull is used for mating (5 yr); Bm = bull maintenance (feed, health, and labor) cost/year; PBj = probability of bull survival from yearj to the next yearj + 1 j = 1, ..., y, = \prod_{i=1}^{j} P_i, where P_i = probability of bull survival in a specified yeari; NCj = number of cows maintained and mated to bull in the jth yr; CR = probability of conception to natural service in mating season (herd fertility); CBo = progeny cost at birth (dollars); S = sex ratio of progeny as a proportion of male calves; FCgi = feed costs associated with the fetus during gestation; i = m, f; FCwi = progeny feed cost incurred at time tgi to produce beef income from sales at time t3i. Includes additional feed to support maternal milk for calf growth from birth to weaning; i = m, f; FCmi = progeny feed cost incurred at time tgi to produce income from sales at time t3i. Includes feed to support growth from weaning to marketing; i = m, f; Pm = probability of progeny survival implantation to birth; EBF = breed value of replacement heifer progeny; Pr = probability of female progeny used as replacement (else sold for beef); EWmi = expected progeny weight at marketing (kilograms); i = m, f; SP = sale price per kilogram, considering quality and yield grades; MC = marketing cost (dollars/animal); BUSV = bull salvage value; t0 = time from implantation date to first natural mating (year); t2 = gestation length (year); t6m = average time (weighted by daily feed energy for bull calf growth to reproductive maturity) at which feed costs FCm are incurred (year); t5i = average time (weighted by daily feed energy for fetal growth) at which feed costs FCgi are incurred from time of conception to birth; i = m, f (year); t5i = time from mating to receipt of income from sale of steer or heifer progeny at market age; i = m, f (year); t4i = average time (weighted by daily feed energy for growth to weaning) at which feed costs FCwi are incurred from the time of mating to weaning; i = m, f (year); and t5i = average time (weighted by daily feed energy for calf growth to marketing) at which feed costs FCmi are incurred from the time of mating to marketing; i = m, f (year).

Bull costs in Equation [31 consist of embryo and implantation costs (EIC), birth costs due to dystocia (CB), and feed energy costs for gestation (FCgi), birth to weaning (FCmi), and weaning to reproductive maturity (FCm). After reproductive maturity, the annual bull cost (Bm) and maintenance cost of cows to which the bull is mated are input to the model and accumulated in Equation [4] over the bull’s herd life. Alternatively, the overall cost of raising and maintaining a bull may be input directly to the model if prior estimates are assumed. This has the advantage of reducing the run-time required for the model to complete an evaluation.

The major progeny costs are categorized into birth costs due to dystocia (CB), and feed energy costs for gestation (FCgi), birth to weaning (FCmi), and weaning to marketing (FCm) in Equation [5].

At marketing age, females are either sold for beef or enter the herd as replacements at value of breed characteristics (Equation [6]). Income in Equation [7] is derived from progeny sales as a function of weight (EWm) and carcass quality (Qm) and yield (Ym) grades at marketing. The terms Qm and Ym at a specific market age (Dm) are defined relative to mean market values as characteristics of breed and line of embryo. In the model, mean breed quality grade (Q) and yield grade (Y) are, respectively, initialized to 4 (Choice) and 3, and mean market age (AGE) to 450 d, which are consistent with literature values (Wilson et al., 1969; Crouse et al., 1974a,b). The equations used to represent relationships of quality and yield grades with age were described by Ruvuna et al. (1992a).

An assumption was that progeny are normally distributed around the breed values of Q and Y. The expected proportion of progeny in each quality and yield grade class was generated assuming a bivariate normal distribution of Q and Y values. Default parameters for standard deviations were 4.775 for Q and 7.344 for Y and a covariance of .0772 between Q and Y. These values were summarized from the literature (Breidenstein et al., 1963; Wilson et al., 1969; Crouse et al., 1974a,b; Koch et al., 1985). The proportion of progeny in an interval was approximated by the area under the curve between the lower and upper boundaries of each quality and yield grade class.

Table 2. Default input parameter values used in the model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biological and herd management parameters</td>
<td></td>
</tr>
<tr>
<td>Average weaning age, d</td>
<td>205</td>
</tr>
<tr>
<td>Quality grade&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4</td>
</tr>
<tr>
<td>Yield grade&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3</td>
</tr>
<tr>
<td>Economic Parameters</td>
<td></td>
</tr>
<tr>
<td>Cost of embryo, sexing, and implantation, $</td>
<td>0</td>
</tr>
<tr>
<td>Bull maintenance cost per year, $</td>
<td>100</td>
</tr>
<tr>
<td>Bull salvage value, $</td>
<td>1,200</td>
</tr>
<tr>
<td>Probabilities</td>
<td></td>
</tr>
<tr>
<td>Embryo survival implantation to birth, %</td>
<td>90</td>
</tr>
<tr>
<td>Bull fertility, %</td>
<td>90</td>
</tr>
<tr>
<td>Bull progeny survival birth to marketing, %</td>
<td>90</td>
</tr>
<tr>
<td>Sex ratio as proportion of male progeny</td>
<td>1</td>
</tr>
<tr>
<td>Probability of female calf for replacement, %</td>
<td>0</td>
</tr>
<tr>
<td>Bull survival birth to mating age, %</td>
<td>90</td>
</tr>
<tr>
<td>Bull survival in a specified year, %</td>
<td>100</td>
</tr>
</tbody>
</table>

<sup>a</sup>Quality grade 3 = Select; 4 = Choice; 5 = Prime.  
<sup>b</sup>Yield grade scale 1, 2, 3, 4.
Although the model allows $5 \times 5$ classes of $Q \times Y$, the classes were collapsed into nine classes to conform to the current pricing system (Ruvuna et al., 1992b). For each class, price was multiplied by the proportion of progeny and summed over all $Q$ and $Y$ classes to obtain a weighted price per kilogram. Varying expected breed mean $Q$, $Y$, and AGE to depict genotypic differences in quality and yield grades relative to age provided a method to examine differences in NPV associated with differences in quality and yield grades. Table 2 contains the prices and biological parameters in addition to those in Table 1 of Ruvuna et al. (1992) that were assumed for this study as direct inputs to the model.

The bull salvage value (BUSV) in Equation (8) is an input to the model. For this study, EIC was set to 0 and, therefore, the model provides a method to examine embryo and implantation break-even prices considering differences in genetic superiority of clonal bull embryos and feed availability.

**Sensitivity Analysis**

Sensitivity of NPV to alternative quality and yield grades, sex ratios, growth potential, and herd fertility was examined. It was assumed that all feed requirements were met. Biological parameters were held to default values (Table 2, Ruvuna et al., 1992b), and NPV were computed by allowing combinations of parameters under investigation to vary within ranges consistent with literature values. Three quality grades (Select, Choice, Prime) and three yield grades (2, 3, 4) were combined with three age classes (400, 450, 500) at which $Q/Y$ combinations may be attained. These were used in the model to characterize and evaluate 27 progeny genotypes for carcass characteristics. Four growth rates (9, 1.14, 1.4, 1.6 kg/d) were evaluated in combination with five herd conception rates (.5, .6, .7, .8, and .9). The sex ratios examined were 40, 50, 60, 80, and 100% male. Progeny sex control was considered because of its economic importance to the efficiency of beef production and also because of the feasibility of future technologies to control sex in natural matings (Taylor et al., 1985). These technologies include identification and abortion of male or female pregnancies or methods of selectively disabling sperm bearing either X or Y chromosomes.

In the evaluations, a bull was assumed to be produced from a sexed embryo and used in natural matings for 5 yr. The number of cows mated (NCJ) was initialized to 30 per year.

**Results and Discussion**

*Returns in Relation to Quality and Yield Grades*

Table 3 shows market ages at which NPV was maximized for progeny genotypic combinations of carcass yield and quality grade at ages of 400, 450, and 500 d. Quality grade (Q) and yield grade (Y) combinations are designated by (Q/Y). Progeny with an expected quality grade of Q3 (Select) and yield grade of Y4 at 400 d of age provided the lowest NPV of $18,209 at the optimal slaughter age of 450 d. The highest NPV was $40,917 for progeny with an expected quality grade of Q5 (Prime) and yield grade of Y2 at age 400 d when slaughtered at the optimal age of 550 d. Holding quality grade constant at Q3 and increasing yield grade from Y2 to Y4 reduced NPV by $10,223, $9,976, and $9,731, for progeny achieving Q/Y combinations at an expected mean age of 400, 450, and 500 d, respectively. Conversely, holding yield grade constant at Y2 and increasing quality grade from Q3 to Q5 increased NPV by $12,485, $12,291, and $11,985, respectively. An interesting result is that NPV for progeny with combinations of yield grades Y3 and Y4 with quality grades Q4 and Q5 at 400, 450, or 500 d of age was maximized when progeny were slaughtered at the optimal age of 500 d. The lowest optimal market age of 450 d was for progeny with quality grade Q3 and yield grade Y3 or Y4. Although NPV varied, age differences for given mean quality and yield grades did not alter the optimal marketing age. The large NPV differences suggest that using clonal embryo lines to produce herd bulls may be viable for commercial beef production, if embryos with the appropriate genetic potential in specific production environments can be identified.

Table 3. Net present value in relation to progeny differences in quality and yield grades and age

<table>
<thead>
<tr>
<th>Expected Q/Y</th>
<th>Progeny age at expected Q/Y</th>
<th>400 d</th>
<th>450 d</th>
<th>500 d</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NPY</td>
<td>AGE</td>
<td>NPY</td>
<td>AGE</td>
</tr>
</tbody>
</table>

*Q/Y = quality grade/yield grade, Quality grade 3 = Select, 4 = Choice, 5 = Prime. Yield grade scale 1, 2, 3, 4.*  
*NPV = not present value.*  
*AGE = age at slaughter.*
Figure 1. Net present value in relation to sex ratio at different marketing ages.

Sex Ratio

Sex ratio (S) was defined as the proportion of male progeny. Its effect on NPV was obtained by varying S from 1 (all males) to .4. The assumption was that all progeny were sold for beef. Figure 1 and Table 4 show the NPV for different sex ratios at different marketing ages. The NPV was defined by the market age with greatest NPV for each sex ratio examined. The NPV tended to be stable with respect to age at slaughter as they approached optimum (Figure 1). The NPV ranged from $29,230 for 100% males to $21,712 for 40% males. The difference in NPV ($7,518) was a result of sex differences in growth rate and carcass characteristics. For all values of S < 1, the optimal market age was 550 d, indicating that sex ratio did not affect optimal market age but affected the NPV due to sex differences in carcass characteristics (Ruvuna et al., 1992a). At a sex ratio of .5, the NPV of male progeny was $5,887 higher than that of female progeny. Optimal market age may differ for other combinations of growth rate and mature size (Ruvuna et al., 1992b).

Table 4. Net present value at optimum marketing age in relation to sex ratio

<table>
<thead>
<tr>
<th>Sex ratio</th>
<th>NPV&lt;sub&gt;a&lt;/sub&gt;, $</th>
<th>NPV&lt;sub&gt;b&lt;/sub&gt;, $</th>
<th>NPV&lt;sub&gt;c&lt;/sub&gt;, $</th>
<th>NPV&lt;sub&gt;d&lt;/sub&gt;, $</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>0</td>
<td>28,392</td>
<td>28,392</td>
<td>29,230</td>
</tr>
<tr>
<td>.8</td>
<td>3,242</td>
<td>22,516</td>
<td>25,758</td>
<td>28,598</td>
</tr>
<tr>
<td>.6</td>
<td>6,484</td>
<td>16,832</td>
<td>23,518</td>
<td>24,154</td>
</tr>
<tr>
<td>.5</td>
<td>8,104</td>
<td>13,991</td>
<td>20,074</td>
<td>21,712</td>
</tr>
<tr>
<td>.4</td>
<td>9,725</td>
<td>11,149</td>
<td>20,674</td>
<td>21,172</td>
</tr>
</tbody>
</table>

<sup>a</sup>NPV<sub>f</sub> = net present value of female progeny.
<sup>b</sup>NPV<sub>m</sub> = net present value of male progeny.
<sup>c</sup>NPV<sub>fm</sub> = net present value of male & female progeny.
<sup>d</sup>NPV<sub>t</sub> = total net present value including NPV<sub>fm</sub> and bull salvage value.

Optimal NPV with a herd conception rate (CR) of .9 was $33,804, $32,153, $29,231, and $25,493 for growth rates of 1.6, 1.4, 1.14, and .9 kg/d, respectively. Because the model for NPV is linear in CR, there was a linear decrease in NPV of $5,983, $4,900, $4,575, and $4,160 for each .1 decrease in CR at growth rates of 1.6, 1.4, 1.14, and .9 kg/d, respectively. The NPV increased with potential for growth. The difference between NPV for the highest and lowest growth rates of 1.6 and .9 kg/d was $9,312 at CR = .9 and $4,619 at CR = .5.

These results demonstrate the critical importance of herd fertility, as a management factor, on the potential for realizing profit differences associated with embryos of varying genetic potential. For example, the combination of CR = .8 with a 1.14 kg/d growth rate yielded a higher NPV ($24,656) than the combination of CR = .7 with a growth rate of 1.6 kg/d ($23,638).

The results of this study must be interpreted with respect to the assumptions on which they were based. No breeding or pregnancy costs other than those for feed requirements for prenatal growth, preweaning growth, and postweaning growth were included. The relationships between feed prices and other environmental factors were assumed constant for all sets of parameter values examined. Feed availability and intake were assumed unlimited.

Implications

The bull model was developed as a decision aid to examine optimal use of embryo cloning and transfer for producing bull lines for use as herd sires in commercial beef production. The model was constructed such that different embryo characteristics could be examined and matched with different production systems to determine the appropriate embryo for a given economic and physical environment. The enhanced economic merit realized will depend largely on the genetic superiority of clonal lines for beef traits within the production environment.

Literature Cited

