2017

Economic selection index development for Beefmaster cattle I: Terminal breeding objective

Kathleen P. Ochsner
University of Nebraska-Lincoln, ochsnerkathleen@gmail.com

M. D. MacNeil
Delta G, Miles City, Montana

Matthew L. Spangler
University of Nebraska-Lincoln, mspangler2@unl.edu

Economic selection index development for Beefmaster cattle I: Terminal breeding objective[1]

K. P. Ochsner,* M. D. MacNeil,†‡ R. M. Lewis,* and M. L. Spangler*[2]

*Department of Animal Science, University of Nebraska, Lincoln 68583; †Delta G, Miles City, Montana 59301 and ‡University of the Free State, Bloemfontein, South Africa

ABSTRACT: The objective of this study was to develop an economic selection index for Beefmaster cattle in a terminal production system where bulls are mated to mature cows with all resulting progeny harvested. National average prices from 2010 to 2014 were used to establish income and expenses for the system. Phenotypic and genetic parameter values among the selection criteria and goal traits were obtained from literature. Economic values were estimated by simulating 100,000 animals and approximating the partial derivatives of the profit function by perturbing traits one at a time, by 1 unit, while holding the other traits constant at their respective means. Relative economic values (REV) for the terminal objective traits HCW, marbling score (MS), ribeye area (REA), 12th–rib fat (FAT), and feed intake (FI) were 91.29, 17.01, 8.38, -7.07, and -29.66, respectively. Consequently, improving the efficiency of beef production is expected to impact profitability greater than improving carcass merit alone. The accuracy of the index lies between 0.338 (phenotypic selection) and 0.503 (breeding values known without error). The application of this index would aid Beefmaster breeders in their sire selection decisions, facilitating genetic improvement for a terminal breeding objective.

Key words: beef cattle, selection index, terminal objective

 J. Anim. Sci. 2017.95:1063–1070
doi:10.2527/jas2016.1231

INTRODUCTION

The main source of long-term profitability for a beef cattle operation lies in its production efficiency, which can be improved through genetic selection. Traditionally, EBV have been the genetic tools used to select breeding livestock. While EBV are a sound selection tool, a drawback is that they represent genetic merit in only one trait while in reality multiple traits influence an animal's value (Hazel, 1943). With EBV as a sole selection tool, producers are left to individually determine their optimal use and ultimately the economic importance of each trait (Bourdon, 1998). Hazel and Lush (1942) and Hazel (1943) first introduced the concept of combining genetic evaluation and economics through selection index theory. Since then, selection indices have been implemented in the beef industry and are the recommended method of multi-trait selection in animal populations (Falconer and Mackay, 1996). Currently, Beefmaster Breeders United (**BBU**) reports ten EBV, but provides no tool for multi-trait selection. The objective of this study was to develop a selection index for terminal purpose Beefmaster cattle to increase profitability of commercial enterprises and facilitate genetic improvement of the Beefmaster breed.

MATERIALS AND METHODS

Animal Care and Use Committee approval was not obtained for this study given that the data were simulated.

Defining the Breeding Objective

The breeding objective for development of the terminal index was to increase profitability of an operation where all calves were born from mature cows, retained through the feedlot phase and sold on a grid-based pricing system. The 5 objective traits considered for the terminal index included HCW, marbling

[1]This work was supported by Beefmaster Breeders United and National Research Initiative Competitive Grant number 2011–68004–30214 from the USDA National Institute of Food and Agriculture.

[2]Corresponding author: mspangler2@unl.edu

Received November 23, 2016.
Accepted December 31, 2016.

score (**MS**), ribeye area (**REA**), 12th–rib fat (**FAT**) and feed intake (**FI**), with the latter representing the only expense related phenotype among the objective traits.

Choice of Selection Criteria

Ideally, the selection criteria would include all economically relevant traits in the breeding objective. However, in practice some traits in the objective are not readily observed, hence the need to use indicator traits for predicting traits that are economically relevant. Selection criteria should be highly correlated to the traits in the objective. Selection criteria for the terminal index were chosen from the 10 EBV currently reported by BBU and were yearling weight (**YW**), ultrasound ribeye area (**UREA**), ultrasound 12th–rib fat (**UFAT**) and ultrasound intramuscular fat (**UIMF**).

Estimation of Economic Values

A method to derive economic values is partial differentiation of a profit equation (Hill, 1974; Ponzoni and Newman, 1989; Forabosco et al., 2004). Identifying sources of income and expense in the beef cattle herd enables the development of a profit equation where profit is a function of income and expense (Ponzoni and Newman, 1989). Sources of income and expense for the terminal production system were identified and the profit was simulated for 100,000 animals using SAS 9.3 (SAS Inst. Inc., Cary, NC).

In the assumed production and marketing system, half of the calves were fed through a calf-fed system and half were fed through a yearling system. For the calf-fed system it was assumed that calves were sent to the feedlot directly after weaning for a 211 d finishing period before harvest. The yearling system assumed that after weaning calves entered into a 315 d growing period prior to being sent to a feed yard for a 90 d finishing period. It was assumed that all replacement females were obtained from outside the herd. Income was derived solely from the marketing of animals for slaughter on a grid based system. Phenotypes for HCW, MS, REA, and FAT were simulated from a random normal distribution with the means (SD) based on literature values of 320 (38.8) kg, 5.4 (0.9) marbling score units, 76.5 (9.3) cm^2 and 1.2 (0.32) cm, respectively (Moser et al., 1998; Wheeler et al., 2006). The genetic relationships between traits were accounted for by a Cholesky decomposition applied to the phenotypic covariance matrix between all objective traits considered.

The 5-yr (2010 to 2014) average price for steers and heifers at slaughter was obtained from the Livestock Marketing Information Center (LMIC, 2015) and used as the base price for all slaughter animals. The base price was \$3.858/kg with a SD of \$0.642/kg. Premium and discount values based on yield grade (**YG**), quality grade (**QG**) and HCW were obtained from United States Department of Agriculture- Agricultural Marketing Service (USDA-AMS, 2015) and are presented in Table 1. Quality grade of each carcass was assigned based on simulated marbling score (e.g., 5.0 = Sm^0 = Low Choice), and each animal received a premium or discount accordingly. It was assumed that animals sent to slaughter are 30 mo of age or younger and thus age was not considered as a contributing factor to QG. The standard USDA equation for yield grade (Murphey et al., 1960) was used, after adjusting the intercept for the average KPH fat percentage. The resulting equation was: YG = 3.0 + 0.984 × FAT - 0.0496 × REA + 0.00838 × HCW. Weight discounts were applied to animals for which the simulated carcass weight was under 272 kg or over 409 kg. Carcass price was calculated as the sum of base carcass price, YG premium/discount, QG premium/discount and weight discount (if applicable). Income for each animal was calculated by multiplying the carcass price (\$/kg) by the weight of the animal in kg.

Expenses for the production system assumed in development of the terminal index were feed, veterinary labor, medicine, bedding, marketing, custom operations, fuel, repairs, processing, and yardage. A 5-yr (2010 to 2014) average and SE of prices for feedstuffs used in the production system were calculated using information ob-

Table 1. Premiums and discounts for carcass sales based on 5-yr average (2010 to 2014)

Category	Adjustment[1] (\$/kg)
USDA Quality Grade	
Prime	0.402
Choice	0
Select	-0.195
Standard	-0.480
USDA Yield Grade	
1.0–2.0	0.092
2.0–2.5	0.048
2.5–3.0	0.045
3.0–4.0	0
4.0–5.0	-0.228
> 5.0	-0.386
Carcass weight (kg)	
< 227	-0.702
227–250	-0.483
250–272	-0.061
272–409	0
409–431	-0.005
431–454	-0.006
> 454	-0.511

[1]U.S. Department of Agriculture Agricultural Marketing Service. Values reflect adjustments to the base carcass price.

Table 2. Diet composition and prices of feedstuffs based on a 5-yr average (2010 to 2014)

Ingredient	Inclusion[1] (% DM)	Price[2] ($/kg)	SD ($/kg)	Correlation[3]
Feedlot Diet Composition				
Dry-rolled corn	43.8	0.211	0.051	1.00
Wet distillers grains + solubles	43.8	0.200	0.048	1.00
Alfalfa hay	7.5	0.200	0.042	0.84
Urea	1.1	0.663	0.050	0.72
Limestone	1.9	0.028	0.002	0.92
Potassium	0.8	0.648	0.071	0.65
Salt	0.6	0.289	0.011	0.84
Trace minerals	0.43	0.877	0.037	0.18
Rumensin	0.03	19.575	3.915	0.40
Tylan	0.02	17.775	3.555	0.40
Vitamins	0.02	2.950	0.360	0.40
Winter Yearling System Diet Composition				
Prairie hay	74	0.140	0.022	0.66
Corn	20	0.211	0.051	1.00
44% protein supplement	6	0.436	0.060	0.87
Summer Yearling System Diet Composition				
Summer Grazing	75	0.105	0.022	0.90
Prairie Hay	19	0.140	0.022	0.66
Corn	5	0.211	0.051	1.00
44% protein supplement	1	0.436	0.060	0.87

[1]Based on Barron Lopez (2013).

[2]USDA National Agricultural Statistics Service.

[3]Correlation with the price of corn. Based on Barron Lopez (2013).

tained from the USDA–National Agricultural Statistics Service (USDA-NASS, 2015). The correlation between corn prices and other feedstuffs was included in the simulation to ensure that the relationship between prices did not deviate from their true relationship in the industry. Prices for each feed ingredient were simulated from a random normal distribution as a function of the average price, SE and correlation with the price of corn. Feed intake was simulated from a random normal distribution with a mean of 8.59 kg and SD of 1.09 kg (Rolfe et al., 2011). Feed costs for animals fed through the calf-fed system were simulated assuming animals were consuming the feedlot diet outlined in Table 2 for 211 d. Cattle in the yearling system were fed the winter yearling system diet for 198 d, the summer yearling system diet for 117 d and the feedlot diet for 90 d (Table 2).

Veterinary labor, medicine, bedding, marketing, custom operations, fuel, repairs, processing, and yardage were considered fixed while building the profit equation because they did not vary based on the biological merit of an individual animal (Table 3). Veterinary and medicine costs were estimated by calculating a 5-yr average from data provided by D. W. Gillings (Christiansen Land and Cattle Ltd., Kimball, SD, personal communication). Means and SE of other

Table 3. Price of other costs in terminal system based on average prices from 2010 to 2014

Expense object	Average cost (US$/head per yr)	SE of cost
Veterinary and Medicine[1]	19.220	4.464
Bedding[2]	0.49	0.12
Marketing[2]	10.407	3.534
Custom Operations[2]	30.877	11.915
Fuel[2]	53.463	10.636
Repairs[2]	42.190	9.208

[1]D. Gillings, Christiansen Land and Cattle Ltd., Kimball, SD, personal communication.

[2]Barron Lopez (2013).

costs including bedding, marketing, custom operations, fuel, repairs, processing, and yardage were obtained from Barron Lopez (2013). Total cost of the production system was calculated as a sum of feed costs and other costs through all phases of production.

Calculating Selection Index Coefficients

Hazel (1943) first introduced the selection index equations to calculate index coefficients (**b**) for each of the selection criteria:

$$b = P^{-1}Gv$$

where **P** is a $n \times n$ matrix of the phenotypic (co)variances among the n traits measured and available as selection criteria, **G** is a $n \times m$ matrix of the genetic (co)variances among the n selection criteria and m objective traits, and **v** is an $m \times 1$ vector of economic values for all objective traits. This method was used to calculate economic index coefficients to be applied to phenotypic measures for the terminal index. Genetic co-variances were calculated from the genetic SD and genetic correlations. Phenotypic co-variances were calculated using the phenotypic SD and phenotypic correlations between traits. The heritability, genetic variances and phenotypic variances of the objective traits and selection criteria used to calculate the P and G matrices were extracted from literature and are presented in Table 4. Phenotypic correlations among the selection criteria, and genetic correlations between the selection criteria and objective traits, needed for back-calculation of the co-variances were extracted from scientific literature and are presented in Table 5.

For an index designed for a beef breed association index coefficients should be applied to EBV. Not only is this more practical, but literature supports the argument that index coefficients applied to EBV are more accurate (Schneeberger et al., 1992; Bourdon, 1998). From a practicality standpoint, phenotypic

Table 4. Genetic and phenotypic parameters for selection criteria and objective traits

Trait[1]	h^2	σ_α^2	σ_p^2	Source
YW, kg	0.40	480.982	1,202.455	Moser et al. (1998)
UREA, sq. cm	0.29	16.501	56.900	Moser et al. (1998)
UIMF, %	0.38	0.176	0.470	MacNeil and Northcutt (2008)
UFAT, cm	0.39	0.012	0.031	MacNeil and Northcutt (2008)
FI, kg	0.39	0.275	0.705	Arthur et al. (2001)
HCW, kg	0.59	520.010	881.373	Moser et al. (1998)
REA, sq. cm	0.39	19.008	48.738	Moser et al. (1998)
FAT, cm	0.27	0.019	0.070	Moser et al. (1998)
MS[2], score	0.55	0.203	0.360	Gregory et al. (1995)

[1]Selection criteria: YW = yearling weight, UREA = ultrasound ribeye area, UIMF = ultrasound intramuscular fat percentage, UFAT = ultrasound rib fat. Objective traits: FI = feed intake, HCW = hot carcass weight, REA = ribeye area, FAT = 12th–rib fat, MS = marbling score. h^2 = heritability, σ_α^2 = genetic variance, σ_p^2 = phenotypic variance.

[2]Marbling score units where 4.0 = Sl^0 and 5.0 = Sm^0.

Table 5. Genetic correlations (above diagonal) between selection criteria and objective traits, and phenotypic correlations (below diagonal) between selection criteria

Trait[1]	YW	UREA	UIMF	UFAT	FI	HCW	REA	FAT	MS
YW		0.44[7]	0.31[7]	0.03[3]	0.5[10]	0.61[3]	0.6[3]	0.32[2]	-0.2[11]
UREA	0.41[3]		-0.25[7]	0.04[3]	0.44[9]	0.41[3]	0.66[3]	-0.11[8]	-0.3[8]
UIMF	0.03[7]	-0.08[7]		0.36[7]	0.53[9]	0.25[2]	0.23[4]	0.33[6]	0.47[4]
UFAT	0.13[3]	0.11[3]	0.17[7]		0.29[9]	0.27[4]	-0.24[6]	0.69[3]	0.45[6]
FI						0.66[9]	0.21[9]	0.49[9]	0.5[9]
HCW							0.12[3]	-0.1[3]	0.25[2]
REA								-0.05[3]	-0.21[2]
FAT									0.35[2]

[1]Selection criteria: YW = yearling weight, UREA = ultrasound ribeye area, UIMF = ultrasound intramuscular fat percentage, UFAT = ultrasound rib fat; Objective traits: FI = feed intake, HCW = hot carcass weight, REA = ribeye area, FAT = 12th–rib fat, MS = marbling score.

[2]Koots et al. (1994).

[3]Moser et al. (1998).

[4]Reverter et al. (2000).

[5]Devitt and Wilton (2001).

[6]Kemp et al. (2002).

[7]Stelzleni et al. (2002).

[8]Bergen et al. (2005).

[9]Nkrumah et al. (2007).

[10]Arthur et al. (2001).

[11]Within the range of estimates reported by Koots et al. (1994).

measures will rarely be available for all animals on all traits included in the selection criteria. Sex-limited traits and traits such as carcass merit cannot be measured directly on all breeding animals. Initial selection decisions are often made before an animal expresses all the traits which determine its overall genetic merit. Additionally, Bourdon (1998) raised 2 serious drawbacks in applying index weighting factors to phenotypic values for an individual. First, this method lacks accuracy because it does not incorporate information on relatives. Second, it is biased because it does not account for genetic differences among contemporary groups. These issues can be overcome by using EBV instead of individual phenotypic performance. Another benefit of using index coefficients to be applied to EBV is that the phenotypes entering into genetic evaluation are adjusted for heterosis effects, which may be especially important in a composite breed like Beefmaster.

Schneeberger et al. (1992) presented a method to calculate a vector of index coefficients to be applied to EBV for the selection criteria in the index. The equation to estimate index coefficients to be applied to EBV is:

$$b = G_{11}^{-1} G_{12} v$$

where $\mathbf{G_{11}}$ is a $n \times n$ matrix of genetic (co)variances among the n selection criteria, $\mathbf{G_{12}}$ is a $n \times m$ matrix of the genetic (co)variances among the n selection criteria and m objective traits and $\mathbf{v}$ is an $m \times 1$ vector of economic values for all objective traits. Index coefficients to be applied to EBV for selection criteria were calculated using this method. For each selection index, it was ensured that a positive definite (co)variance matrix existed.

Estimating Index Accuracy

Following the notation of Van Vleck (1993), the accuracies of the indices that utilize phenotypic measures were calculated as:

$$r_{HI} = \frac{\boldsymbol{b'Gv}}{\sqrt{(\boldsymbol{b'}\mathbf{P}\boldsymbol{b})(\boldsymbol{v'Cv})}}$$

where **b'Gv** represents the covariance between the index and aggregate genotype, **b'Pb** represents the index variance, and **v'Cv** represents the aggregate genotype variance. **C** is an $m \times m$ genetic (co)variance matrix among the objective traits.

For indices that utilize EBV as the selection criteria, the following equation was used to calculate the accuracy of the index:

$$r_{HI} = \frac{\boldsymbol{b'G_{12}v}}{\sqrt{(\boldsymbol{b'}\mathbf{G}_{11}\boldsymbol{b})(\boldsymbol{v'Cv})}}$$

where $\boldsymbol{b'G_{12}v}$ represents the covariance between the index and aggregate genotype and $\boldsymbol{b'}\mathbf{G}_{11}\boldsymbol{b}$ represents the index variance. The substitution of $\mathbf{G_{11}}$ for **P** in calculating the index variance is accompanied by several assumptions. In presenting the index coefficient equations using EBV as the selection criteria, Schneeberger et al. (1992) explained that $\mathbf{G_{11}}$ is the genetic (co)variance matrix of the selection criteria which is assumed to be known without error. However, EBV would never be known with complete certainty given the heterogeneity of the residual variance. Thus, the index accuracy estimated herein would be the 'best case scenario' presuming that the accuracy of each EBV included in the index for each animal was unity.

Estimating Index Sensitivity

Economic selection index coefficients are seldom known without error because of uncertainties in (co) variances and in economic values. One way to determine the sensitivity of indices to the (co)variances and economic values assumed is to calculate the efficiency of the index. The efficiency (E_u) is given as:

$$E_u = \frac{R_{H_u}}{R_{H_t}} = \frac{b'_u G_{12_t} v}{\sqrt{b'_u G_{11_t} b_u}} \times \frac{1}{\sqrt{b'_t G_{12_t} v}}$$

where R_{Hu} is the response expected from the 'used' values, R_{Ht} is the response expected from the 'true' values, b_u are index coefficients derived from 'used' values and b_t are 'true' index coefficients. The 'used' index coefficients are based on current belief, while the 'true' index coefficients are assumed to be optimum. In reality, there are potential uncertainties associated with the assumed phenotypic and genetic parameter estimates and economic values which is why it is important to calculate the efficiency and determine the impact of inadvertently using incorrect index coefficients.

Sensitivity to absolute changes in genetic correlations between objective traits and selection criteria of ± 0.2 and ± 0.4 were calculated. These changes in genetic correlations are equivalent to those investigated by Simm et al. (1986). It is important to note that in some cases these changes resulted in a change of sign. In instances where these changes would have resulted in a correlation greater than unity, the genetic correlation was assumed to be 1. Sensitivity to a 50% increase or decrease in the magnitude of the economic value of each trait in the breeding objective was also investigated. This also follows the methods of Simm et al. (1986), who calculated the efficiency of 2 selection indices following an increase or decrease of 50% in the economic value of each trait in the aggregate breeding value.

Two alternative sets of index coefficients were derived to test the implication of assuming half of the animals were fed through a calf-fed system while the other half were fed through a yearling system. One set of index coefficients were calculated assuming all calves were fed through a calf-fed system. The other set of index coefficients were calculated assuming all calves were fed through a yearling system. The correlation between these 2 indices was calculated.

Table 6. Economic values, relative economic values (REV) and relative emphasis placed on individual objective traits

Trait[1]	Economic value ($/trait unit)	Genetic SD[2] (σ_a)	REV (per σ_a)	Relative emphasis (%)
FI, kg	-57.05	0.52	-29.66	19.3
HCW, kg	4.00	22.80	91.29	59.5
REA, sq. cm	1.92	4.36	8.38	5.5
FAT, cm	-50.51	0.14	-7.07	4.6
MS, units[3]	37.80	0.45	17.01	11.1

[1]FI = feed intake, HCW = hot carcass weight, REA = ribeye area, FAT = 12th–rib fat, MS = marbling score.

[2]From additive genetic variances in Table 4.

[3]Marbling score units where 4.0 = Sl^0 and 5.0 = Sm^0.

RESULTS AND DISCUSSION

Economic Values

Economic values, relative economic values (**REV**) and the proportion of emphasis placed on each objective trait are presented in Table 6. As expected, the REV estimated for HCW, MS, and REA were positive. Twelfth rib fat was characterized by a negative economic value because increased FAT also increased numerical YG, and consequently reduced the carcass value when YG exceeded 4.0. Since FI is an expense related trait, in was no surprise that the economic value for this trait was strongly negative. Hot carcass weight received 59.5% of the emphasis, implying that selection based on the index will result in the most gain in HCW. Feed intake received the next greatest emphasis at 19.3%.

Amer et al. (2001) defined 5 breeding objectives for beef cattle in Ireland and used these to derive selection sub-indexes for which separate sets of REV were reported. One of the sub-indexes proposed was a production sub-index, aimed to improve carcass value in a terminal objective. Breeding objective traits in the production sub-index included weaning weight (**WW**), winter and summer FI (expressed in effective energy units), HCW, carcass fat score (expressed on a 15-point scale), and carcass conformation score. To enable comparisons of results from the current study to results reported by Amer et al. (2001), the REV were converted to US dollars using the June 2016 exchange rate. The REV of HCW was 10.38. Moreover, the relative emphasis placed on HCW was 64%, which closely aligns with the relative emphasis placed on HCW in the present study. Amer et al. (2001) reported REV (relative emphasis) for summer FI, winter FI and carcass fat score of -0.20 (1%), -0.62 (4%) and -1.58 (10%), respectively. These values are consistent with results of the current study.

Barron Lopez (2013) estimated the REV of eleven breeding objective traits aimed at improving the efficiency of general purpose beef cattle. The objective traits included were milk production, average daily gain, mature weight, dressing percentage, FAT, kidney-pelvic-heart fat, REA, MS, calving difficulty, heifer pregnancy, and gestation length. The REV of the carcass traits FAT, REA, and MS were -6.90, 9.31, and 11.023, respectively. These values are very similar to those reported herein for the same carcass traits. Relative emphasis placed on FAT, REA, and MS by Barron Lopez (2013) was 12%, 17%, and 20%, respectively. Again these results are comparable to results in the present study, although these three carcass traits received a proportionately lower percentage of the relative emphasis due to the fact that this was general purpose breeding objective and included more traits. In comparison, REV for carcass weight, carcass conformation score, carcass fat score, gestation length, and calving difficulty reported by Amer et al. (1998) for terminal sires were 15.0, 7.3, 4.4, 3.2, and 7.8, respectively.

Buchanan et al. (2016) conducted a study evaluating the economic impact of bovine respiratory disease (**BRD**) in a typical feedlot finishing operation. Traits included in the breeding objective were BRD incidence, HCW, YG, camera marbling score, dry matter intake, days to harvest, and WW. For HCW, YG, camera marbling score, and dry matter intake Buchanan et al. (2016) reported REV (relative emphasis) of 191.98 (31%), -13.59 (5%), 24.50 (9%) and -60.71 (10%), respectively. Hot carcass weight received the second highest emphasis, following BRD incidence rate. The negative REV for YG reported by Buchanan et al. (2016) supports both the negative REV for FAT and the positive REV for REA reported herein. The REV reported for camera marbling score is similar in direction to the REV for MS reported in the current study. The negative REV for dry matter intake is comparable to the REV for FI derived herein.

Index Coefficients

Index coefficients for phenotypic measures of YW, UREA, UFAT, and UIMF were 0.74, 0.08, -31.04, and 13.32, respectively. Terminal index coefficients to be applied to EBV for YW, UREA, UFAT, and UIMF were 1.72, 0.81, -36.60, and 12.38, respectively. The correlated responses in goal traits were 0.42 kg., 21.17 kg., 4.28 cm^2, 0.05 cm, and -0.15 units for FI, HCW, REA, FAT, and MS, respectively.

Enns and Nicoll (2008) developed a selection index for New Zealand beef cattle with an economic breeding objective aimed at increasing net income per cow lifetime. The selection criteria included WW, YW, number of calves weaned, and average lifetime body weight of calf weaned. Index weighting factors for each trait changed depending on the number of calves weaned by the dam. The index coefficient of YW for a yearling out of a cow that had weaned one calf was 0.63, which is similar in sign to the index coefficient derived for YW in the current study.

Barron Lopez (2013) estimated index coefficients for a variety of indices designed to improve the efficiency of general purpose beef production. In total 13 selection criteria traits were considered including average daily gain, mature weight, FAT, REA, MS, calving difficulty, heifer pregnancy, birth weight, WW, YW, HCW, yearling height, and maternal weaning weight. The estimates of index coefficients reported for YW ranged from 0.03 to 0.64. For the index that Barron Lopez (2013) recommended to improve the proposed breeding objective, index coefficients for FAT, REA, and MS were -53.0, 1.92, and 25.3, respectively. These carcass trait index coefficients are in agreement with the index coefficients presented herein.

Index Accuracy

The accuracy of the terminal index to be used for EBV lies between 0.338 and 0.503. The lower bound of the accuracy estimate assumes that phenotypic measures are the selection criteria. The upper bound of the accuracy estimate assumes that EBV known without error are the selection criteria. We would expect the true accuracy of the index to lie somewhere between the 2 accuracies presented herein that were produced by assuming the index was comprised of either phenotypic measures or by EBV that are known without error.

Index Sensitivity

The sensitivity to changes in genetic correlations is reported as the efficiency of the index after adding 0.2 or 0.4, or after subtracting 0.2 or 0.4, from the genetic correlations between the objective traits and selection criteria, one at a time. A change of ± 0.2 in the genetic correlations resulted in efficiencies ranging from 0.97 to 1.00, with the exception of correlations involving HCW. Selection efficiencies resulting from the ± 0.2 adjustment of correlations between HCW and other traits ranged from 0.85 to 0.97. The increased sensitivity of HCW to changes in its correlation with other traits was due to the fact that it had the largest REV of all traits considered.

A change of ± 0.4 in the values of the correlations resulted in selection efficiencies ranging from 0.94 to 1.00, with the same exception as before. Efficiencies resulting from the adjustment ± 0.4 in genetic correlations between HCW and other traits ranged from 0.23 to 0.93. The efficiency 0.23 resulted from subtracting 0.4 from the 'true' genetic correlation between YW and HCW, and indicates that this index is sensitive to uncertainties in genetic correlations between these 2 traits. To further this sensitivity, 0.3 was subtracted from the 'true' genetic correlation between YW and HCW; the resulting efficiency was 0.57. The genetic relationship between HCW and YW is known to be moderate to strong and positive (Koots et al., 1994). Decreasing this genetic correlation by more than 0.2 assumes a genetic relationship that is not biologically reasonable. Consequently, it can be concluded that the index is insensitive to realistic changes in the assumed genetic correlation between these 2 traits.

The sensitivity to changes in economic values is reported as the efficiency of the index after a 50% increase or decrease in the economic value of each objective trait, one at a time. Efficiency values ranged from 0.84 to 1.00. The index was the most sensitive to a 50% decrease in the economic value of HCW. The same rationale applies here as for the sensitivity of HCW to changes of genetic correlation. Aside from the sensitivity of HCW to the decrease in economic value, all other efficiencies calculated for the terminal index were above 0.97. This result indicates that the index is relatively insensitive to wide changes in economic values.

The correlation between 2 alternative sets of index coefficients (1 assuming all calves were fed through a calf-fed system and the other assuming all calves were fed through a yearling system) was 0.99. Based on this result, it can be concluded that the index coefficients are relatively insensitive to which system was used. Therefore, the index coefficients presented can be applied regardless of the choice of a calf- or yearling-fed system.

Conclusions

In the terminal objective considered for this study, decreasing FAT and FI while increasing HCW, REA, and MS would increase profitability. Hot carcass weight and FI are the top 2 drivers of profit, implying that improving feed efficiency is crucial to increasing the profitability of an operation with a terminal objective, more so than simply improving carcass quality alone. Given the suite of EBV currently available to Beefmaster breeders, this would correspond to a selection index based on EBV with positive coefficients for yearling weight, and ultrasonically measured REA and intramuscular fat percentage. Ultrasonically measured FAT EBV would have a negative index coefficient.

Multitrait selection is critical given that more than one trait impacts overall profitability of a beef cattle operation. The most efficient way to conduct multitrait selection is by using an economic selection index. Although the index from the current study was proven to be robust to changes in the assumed genetic correlations and economic values, care should be taken relative to the application of the index in production systems that might vary in terms of production goals. In example, the terminal index assumed herein does not contemplate the retention of females for the purposes of breeding. Using the index from the current study in a commercial production scenario where breeding females are retained would not be advised given the potential differences in goal traits. For a terminal objective in Beefmaster herds, selection based on the economic selection index presented herein would improve the profitability of commercial beef enterprises.

LITERATURE CITED

Amer, P. R., R. Crump, and G. Simm. 1998. A terminal sire selection index for UK beef cattle. J. Anim. Sci. 67:445–454. doi:10.1017/S1357729800032859

Amer, P. R., G. Simm, M. G. Keane, M. G. Diskin, and B. W. Wickman. 2001. Breeding objectives for beef cattle in Ireland. Livest. Prod. Sci. 67:223–239. doi:10.1016/S0301-6226(00)00201-3

Arthur, P. F., J. A. Archer, D. J. Johnston, R. M. Herd, E. C. Richardson, and P. F. Parnell. 2001. Genetic and phenotypic variance and covariance components for feed intake, feed efficiency, and other postweaning traits in Angus cattle. J. Anim. Sci. 79:2805-2811. doi:10.2527/2001.79112805x

Barron Lopez, J. A. 2013. Selection Objective for Improving Efficiency of Beef Cattle. PhD Diss. Univ. of Nebraska, Lincoln.

Bergen, R., S. P. Miller, and J. W. Wilton. 2005. Genetic correlations among indicator traits for carcass composition measured in yearling beef bulls and finished feedlot steers. Can. J. Anim. Sci. 85:463–473. doi:10.4141/A05-013

Bourdon, R. M. 1998. Shortcomings of current genetic evaluation systems. J. Anim. Sci. 76:2308–2323. doi:10.2527/1998.7692308x

Buchanan, J. W., M. D. MacNeil, R. C. Raymond, A. R. McClain, and A. L. Van Eenennaam. 2016. Variance component estimates for Charolais-sired fed cattle and the relative economic impact of bovine respiratory disease. J. Anim. Sci. doi:10.2527/jas.2016-1001

Devitt, C. J., and J. W. Wilton. 2001. Genetic correlation estimates between ultrasound measurements of yearling bulls and carcass measurements on finished steers. J. Anim. Sci. 79:2790–2797. doi:10.2527/2001.79112790x

Enns, R. M., and G. B. Nicoll. 2008. Genetic change results from selection on an economic breeding objective in beef cattle. J. Anim. Sci. 86:3348–3357. doi:10.2527/jas.2006-566

Falconer, D. S., and T. F. C. Mackay. 1996. Introduction to Quantitative Genetics, Ed 4. Longmans Green, Harlow, Essex, UK.

Forabosco, F., A. Groen, R. Bozzi, J. Van Arendonk, F. Filippini, P. Boettcher, and P. Bijma. 2004. Phenotypic relationships between longevity, type traits, and production in Chianina beef cattle. J. Anim. Sci. 82:1572–1580. doi:10.2527/2004.8261572x

Gregory, K. E., L. V. Cundiff, and R. M. Koch. 1995. Genetic and phenotypic (co)variances for growth and carcass traits of purebred and composite populations of beef cattle. J. Anim. Sci. 73:1920–1926. doi:10.2527/1995.7371920x

Hazel, L. N. 1943. The genetic basis for constructing selection indexes. Genetics 28:476–490.

Hazel, L. N., and J. L. Lush. 1942. The efficiency of three methods of selection. J. Hered. 33:393–399.

Hill, W. G. 1974. Prediction and evaluation of response to selection with overlapping generations. Anim. Prod. 18:117–139. doi:10.1017/S0003356100017372

Kemp, D. J., W. O. Herring, and C. J. Kaiser. 2002. Genetic and environmental parameters for steer ultrasound and carcass traits. J. Anim. Sci. 80: 6: 1489-1496. doi:10.2527/2002.8061489x

Koots, K. R., J. P. Gibson, and J. W. Wilton. 1994. Analyses of published genetic parameter estimates for beef production traits. 2. Phenotypic and genetic correlations. Anim. Breed. Abstr. 62:825–853.

Livestock Marketing Information Center (LMIC). 2015. http://www.lmic.info/. (Accessed 10 August 2015.)

MacNeil, M. D., and S. L. Northcutt. 2008. National cattle evaluation system for combined analysis of carcass characteristics and indicator traits recorded by using ultrasound in Angus cattle. J. Anim. Sci. 86:2518–2524. doi:10.2527/jas.2008-0901

Moser, D. W., J. K. Bertrand, I. Misztal, L. A. Kriese, and L. L. Benyshek. 1998. Genetic Parameter Estimates for Carcass and Yearling Ultrasound Measurements in Brangus Cattle. J. Anim. Sci. 76:2542–2548. doi:10.2527/1998.76102542x

Murphey, C. E., D. K. Hallett, W. E. Tyler, and J. C. Pierce, Jr. 1960. Estimating yields of retail cuts from beef carcasses. J. Anim. Sci. 19:1240 (Abstr.).

Nkrumah, J. D., J. A. Basarab, Z. Wang, C. Li, M. A. Price, E. K. Okine, D. H. Crews, Jr., and S. S. Moore. 2007. Genetic and phenotypic relationships of feed intake and measures of efficiency with growth and carcass merit of beef cattle. J. Anim. Sci. 85:2711–2720. doi:10.2527/jas.2006-767

Ponzoni, R. W., and S. Newman. 1989. Developing breeding objectives for Australian beef cattle production. Anim. Prod. 49:35–47. doi:10.1017/S0003356100004232

Reverter, A., D. J. Johnston, H. U. Graser, M. L. Wolcott, and W. H. Upton. 2000. Genetic analysis of live-animal ultrasound and abattoir carcass traits in Australian Angus and Hereford cattle. J. Anim. Sci. 78:1786–1795. doi:10.2527/2000.7871786x

Rolfe, K. M., W. M. Snelling, M. K. Nielsen, H. C. Freetly, C. L. Ferrell, and T. G. Jenkins. 2011. Genetic and phenotypic parameter estimates for feed intake and other traits in growing beef cattle, and opportunities for selection. J. Anim. Sci. 89:3452–3459. doi:10.2527/jas.2011-3961

Schneeberger, M., S. A. Barwick, G. H. Crow, and K. Hammond. 1992. Economic indices using breeding values predicted by BLUP. J. Anim. Breed. Genet. 109:180–187. doi:10.1111/j.1439-0388.1992.tb00395.x

Simm, G., C. Smith, and J. H. D. Prescott. 1986. Selection indices to improve the efficiency of lean meat production in cattle. Anim. Prod. 42:183–193. doi:10.1017/S000335610001789X

Stelzleni, A. M., T. L. Perkins, A. H. Brown, Jr., F. W. Pohlman, Z. B. Johnson, and B. A. Sandelin. 2002. Genetic parameter estimates of yearling live animal ultrasonic measurements in Brangus cattle. J. Anim. Sci. 80:3150–3153. doi:10.2527/2002.80123150x

USDA-AMS. 2015. http://www.ams.usda.gov/. (Accessed 6 July, 2016.)

USDA-NASS. 2015. https://quickstats.nass.usda.gov/. (Accessed 24 June, 2015.)

Van Vleck, L. D. 1993. Selection index and introduction to mixed model methods for genetic improvement of animals: The green book. CRC Press, Inc. Boca Raton, FL.

Wheeler, T. L., L. V. Cundiff, L. D. Van Vleck, G. D. Snowder, R. M. Thallman, S. D. Shackelford, and M. Koohmaraie. 2006. Preliminary results from cycle VIII of the cattle germplasm evaluation program at the Roman L. Hruska U.S. Meat Animal Research Center. Germplasm Evaluation Program Progress Report No. 23. Clay Center, NE.