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DEVELOPMENT OF A MULTIPLE TRAIT SELECTION INDEX FOR FEEDLOT TRAITS IN BEEF CATTLE INCLUDING FEED EFFICIENCY

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ABSTRACT: A multiple trait index including residual feed intake was constructed to improve net feedlot income in market progeny. The selection objective was defined as $H = v_1E_1 + v_2E_2 + v_3E_3$. where aggregate genetic merit (H) was a linear function of daily DMI (E_1, kg/d), ADG (E_2, kg/d), and slaughter weight (E_3, kg) in market progeny. Regression of steer (n = 426) net income on traits in the objective yielded the vector of economic weights (**v**) with elements v_1 = $-21.49, v_2 = $183.73, and v_3 = $-0.27. The selection criterion was defined as $I = b_1X_1 + b_2X_2 + b_3X_3$ where index value (I) was a linear function of residual feed intake (X_1, kg/d), ADG (X_2, kg/d), and adjusted 365-d weight (X_3, kg) of bulls tested between weaning and yearling. Residual feed intake was defined as the difference between actual intake and that predicted by phenotypic regression (R^2 = 0.69, residual SD = 0.58 kg/d) of daily DMI on ADG, metabolic mid-test weight, and on-test gain in ultrasound subcutaneous fat depth and longissimus muscle area. The matrix of genetic covariances of traits in the criterion with those in the objective (**G**) was estimated from recent reports in the literature and the matrix of phenotypic (co)variances among traits in the criterion (**P**) was estimated from a group of yearling Angus bulls with test data. Selection index weights were obtained from the solution $\mathbf{b} = \mathbf{P}^{-1}\mathbf{G}\mathbf{v}$ with elements: b_1 = -10.12, b_2 = 24.79, and b_3 = -0.09. Index values of Angus bulls (n = 99) adjusted to a mean of 100 (SD = 7.81) ranged from 80.1 to 115.7. Phenotypic correlation estimates for index values with bull daily DMI, ADG, 365-d weight, and residual feed intake were -0.22, 0.53, 0.01, and -0.74, respectively. The phenotypic correlation estimate for index value with end of test scrotal circumference (0.16) was low but favorable. Therefore, higher index values were obtained for bulls with lower daily dry matter consumption, lower residual feed intake, higher ADG, and slightly larger scrotal circumference.

Key Words: Beef Cattle, Feed Efficiency, Selection

Introduction

Beef cattle selection programs have traditionally focused on output traits related to reproductive rate, growth performance and(or) carcass composition. Recently, there has been a renewed interest in genetic characterization of traits related to inputs of beef production, mainly those of feed, which account for the largest proportion of non-fixed costs. Breed differences and genetic parameters for measures of feed efficiency have been well characterized in most cases (Koots et al., 1994a). Several recent studies (e.g. Archer et al., 1999; Arthur et al., 2001a,b) have been devoted to residual feed intake (**RFI**), defined as the difference between actual intake and that predicted by phenotypic regression of intake on body weight and growth rate (Koch et al., 1963), and in some cases also on various measures of body composition (e.g., Basarab et al., 2003). There is a lack of research, however, investigating potential implementation of multiple trait selection programs including RFI. One potential reason for this is the relative lack of estimates of covariances of RFI with other economically important traits (Archer et al., 1999), as well as the costs associated with collection of individual feed intake data (Archer et al., 2004).

With adequate centralized data collection systems typical of beef postweaning test centers and decreasing cost of hardware, feed intake measurement can be more cost effective. The challenge remains to develop multiple trait selection models which include feed efficiency. The objectives of this study, therefore, were to propose a three-trait index of yearling bull test phenotypic data with the objective to increase feedlot profitability of market progeny, and to estimate the associations of the index with other traits commonly measured in bull tests.

Materials and Methods

Charolais and crossbred, Charolais-sired steers (n = 426) produced from 1999 to 2002 at the Agriculture and Agri-Food Canada Onefour Research Substation were fed following weaning (200 d of age) until prior to harvest (455 d of age) at the Lethbridge Research Centre feedlot which is equipped with hardware to record daily feed intake (GrowSafe Systems, Ltd., Airdrie, AB). Individual daily feed intake was measured during the final 112-d portion of the feeding period wherein steers consumed a diet consisting of 75% rolled barley, 20% barley silage, and 5% supplement. Further details regarding the experimental protocol can be found in Crews et al. (2003). Revenue per steer in the feedlot sector was calculated by multiplying final live weight by a ten-year average price ($1.59/kg) for fed steers weighing approximately 575 kg. Cost estimates included total feed costs plus average live weaned calf price ($2.03/kg) multiplied by adjusted 205-d weaning weight. Total feed costs were estimated as total DMI during the 112-d feeding period adjusted to a feeding period of length equal to harvest age minus 205 d. Net feedlot revenue (**NFR**) was then defined as revenue minus costs.

A multiple trait linear regression model (SAS Ver. 8.3, SAS Inst., Inc., Cary, NC) and stepwise procedures were used to identify key component traits in the steers that were related to NFR, and to estimate partial regression coefficients for the final model which were then equated to the marginal economic value of the component traits. Steer traits in the final model included daily DMI (**SFI**), ADG (**SDG**), and final live weight (**SWT**).

Data from Angus bulls which had completed a postweaning test at the Beef Development Center in Millican, TX were also used in this study. This bull test facility was equipped with a feed intake recording system (GrowSafe Systems, Ltd., Airdrie, AB) that was used to measure individual daily feed intake of bulls during an 84-d period. Feed intake data were converted to daily DMI (**BFI**) using DM analysis of composited feed ingredient samples. For this study, data from Angus bulls (n = 99) in test 1 as described by Lancaster et al. (2005) were used. Additional raw data available on bulls included serially-measured (14-d) live weight, adjusted 365-d weight (**BYW**), end-of-test scrotal circumference (**BSC**), and ultrasound measures of subcutaneous fat depth, and longissimus muscle area at the start and end of the test. Gain in ultrasound fat (**FGN**) and muscle area (**MGN**) were computed from start- and end-of-test measurements. Linear regression of serial live weight on test day was used to compute ADG (**BDG**), and mid-test live weight$^{0.75}$ (**BMW**). Residual feed intake of bulls (**BRFI**) was defined as the difference between actual DM intake and that predicted by phenotypic regression (R^2 = 0.69, residual SD = 0.58 kg/d) of BFI on BDG, BMW, FGN, and MGN (Arthur et al., 2001a,b; Basarab et al., 2003). The BRFI phenotype was therefore phenotypically independent of the traits in the prediction.

Using multiple trait selection index methods (e.g., Cameron, 1997), economic weights for SFI, SDG, and SFW in the selection objective and appropriate phenotypic and genetic (co)variance matrices were used to compute weighting factors for BRFI, BDG, and BYW in the selection criterion. Briefly, the selection objective was defined as $H = v_1E_1 + v_2E_2 + v_3E_3$, where aggregate genetic merit (**H**) was a linear function of SFI (E_1), SDG (E_2), and SFW (E_3) breeding values with economic weights from regression described above. The selection criterion was defined as $I = b_1X_1 + b_2X_2 + b_3X_3$ where index value (**I**) was a linear function of BRFI (X_1), BDG (X_2), and BYW (X_3) with appropriate weighting factors from the solution to the selection index equations, $\mathbf{b} = \mathbf{P}^{-1}\mathbf{G}\mathbf{v}$. In these equations, **P** is a symmetric (3 × 3) matrix of phenotypic (co)variances among traits in the criterion measured on bulls. The (3 × 3) matrix **G** contained genetic covariances of bull traits in the criterion with steer traits in the objective. Post-multiplication of the matrix product $\mathbf{P}^{-1}\mathbf{G}$ by the vector **v** containing economic weights for steer traits in the objective yields the vector **b** containing phenotypic weights for bull traits in the criterion. Genetic covariances in **G** were derived from the recent literature (e.g., Koots et al., 1994a,b; Archer et al., 1999; Arthur et al., 2001a; Crews et al., 2003) because experimental data to estimate parameters among traits measured on bulls and their market progeny were not available. Phenotypic (co)variances in **P** were estimated from the Angus bull data described previously. Matrix inversions and algebra for the selection index methods were computed using OCTAVE, an interpreted matrix language component of the Linux (Red Hat Ver. 8.0, Research Triangle Park, NC) operating system. Index values (I) were computed for all Angus bulls and adjusted to a mean of 100. Simple correlations of the adjusted index value with component traits and BSC were computed to quantify their phenotypic associations.

Results and Discussion

Table 1 contains summary statistics for the relevant traits measured on Angus bulls during postweaning test.

Table 1. Summary statistics for traits measured on Angus bulls (n = 99) during postweaning test

Trait[a]	Mean	Minimum	Maximum	SD
BFI, kg/d	8.40	6.31	11.58	1.06
BDG, kg/d	1.40	0.75	2.32	0.26
BMW, kg	94.1	77.7	110.7	7.13
BYW, kg	438.9	330.4	542.5	42.32
FGN, mm	0.30	-0.69	0.76	0.26
RGN, cm^2	25.7	4.6	51.8	8.86
BRFI, kg/d	0.00	-1.58	1.33	0.58
BSC, cm	35.0	30.0	45.0	2.60

[a] BFI = daily DMI, BDG = ADG, BMW = metabolic mid-test weight, BYW = adjusted 365-d weight, FGN = on-test gain in ultrasound fat depth, RGN = on-test gain in ultrasound longissimus muscle area, BRFI = residual feed intake, BSC = end-of-test scrotal circumference.

As noted previously, BRFI was computed so as to be phenotypically independent of body size, ADG, and body composition as measured by gains in ultrasound fat depth and longissimus muscle area. The correlation (data not reported in tabular form) of BFI with MGN (0.42) was higher than that with FGN (0.18). These results suggest that adjustment of residual feed intake for body composition in bulls may depend more on adjustment for muscle deposition than fat deposition, although the RFI estimation model R^2 was minimally increased by the addition of body composition measurements compared to a more traditional base RFI model including only weight and growth rate. Conversely, Basarab et al. (2003) showed that base RFI was more related to gain in empty body fat than to gain in empty body protein in steers. It may be that restricted fat deposition in bulls on test accounts for part of the apparent discrepancy between these results.

The regression of steer net revenue on SFI, SDG, and SWT yielded the economic weights in the vector **v** with elements v_1 = -21.49, v_2 = 183.73, and v_3 = -0.27. Basarab et al. (2003) calculated a difference of $45.60 in 120-d feeding costs between steers with the highest (i.e., least efficient) and lowest (i.e., most efficient) RFI values. The marginal value of SFI, therefore, would be negative which is supported by the present study. The higher economic value for SDG apparently reflects the impact of weight gain during steer finishing relative to feed intake and slaughter weight, but also the relatively low variability of the trait. In the presence of measures of DMI and ADG, the marginal economic value of SWT was lower.

Phenotypic covariances in the matrix **P** can be derived from values in Table 1 for bull traits in the selection criterion. It should be noted, however, that if data and pedigree structure were sufficient, an index of EPD could be constructed based on bull EPD expressed on the appropriate market progeny scale and economic values in **v** (Cameron, 1997). Due to the lack of suitable data to obtain EPD among the Angus bulls in this study and because the index was to be used as a marketing tool for the bull test, we extend the criterion to include traits on bulls with the objective to improve aggregate genetic merit of their progeny. The inverse of **P**, used to solve for the index weights in **b** was obtained as:

$$\mathbf{P}^{-1} = \begin{bmatrix} 2.933 & -0.244 & 0.003 \\ & 21.853 & -0.074 \\ \text{Symm.} & & 0.001 \end{bmatrix}$$

with elements in rows (and columns) 1, 2, and 3 corresponding to BRI, BDG, and BYW, respectively. Diagonal elements of **P** were phenotypic variances, with symmetric off-diagonals equal to covariances. Table 2 summarizes genetic parameters for bull and steer traits relevant to the index.

Table 2. Phenotypic variance, heritability (h^2) and additive genetic SD (σ_G) for bull[a] and steer[b] traits in the index

Trait	Var(P)[c]	h^2	σ_G
BRFI	0.342	0.39	0.365
BDG	0.066	0.28	0.136
BYW	1791.2	0.33	24.31
SFI	0.996	0.51	0.713
SDG	0.060	0.46	0.166
SFW	3783.9	0.40	38.90

[a] Bull traits: BRFI = residual feed intake, BDG = ADG, BYW = 365-d weight.

[b] Steer traits: SFI = daily DMI, SDG = ADG, SFW = final live weight.

[c] Phenotypic variance.

Phenotypic variances in Table 2 were obtained from the Angus bull measurements. Heritabilities assumed for the bull traits were from Arthur et al. (2001a) who studied Angus bulls in Australia, with the exception of BYW, which was not reported in that study. The heritability of 0.33 assumed for BYW was the weighted average estimate reported by Koots et al. (1994a). Heritability estimates for steer traits were extracted from Crews et al. (2003) who reported on the same steers used in this study to derive the economic weights.

The non-symmetric matrix **G** relates traits in the criterion with traits in the objective and in this case, consists of elements equal to the genetic covariances of BRFI, BDG, and BYW with SFI, SDG, and SFW. Because the traits in the objective and criterion are dissimilar, each element of **G** is defined as

$$g_{ij} = \Gamma_{ij} h_i h_j \sigma_i \sigma_j$$

where g_{ij} is the element in the ith row and jth column of **G**, Γ is the genetic correlation, h is the square root of heritability, and σ is phenotypic SD (Cameron, 1997). Subscripts i and j refer to trait i in the criterion and trait j in the objective, respectively.

Genetic correlations of bull traits with steer traits were derived from literature sources (Table 3) and then the nine elements of **G** were computed using heritability and phenotypic SD estimates reported in Table 2.

Table 3. Genetic correlations of bull traits with steer traits

Bull trait (i)[a]	Steer trait (j)[b]	Γ_{ij}[c]
BRFI	SFI	0.60
	SDG	0.00
	SFW	0.00
BDG	SFI	0.50
	SDG	0.75
	SFW	0.70
BYW	SFI	0.50
	SDG	0.50
	SFW	0.75

[a] Bull traits: BRFI = residual feed intake, BDG = ADG, BYW = 365-d weight.

[b] Steer traits: SFI = daily DMI, SDG = ADG, SFW = final live weight.

[c] Genetic correlation.

Genetic correlations involving BRFI were generally similar to those in Arthur et al. (2001a) where RFI had a positive genetic correlation with feed intake, but near zero genetic correlations with ADG and live weight. The remaining genetic correlations were derived based on: 1) observing that similar postweaning traits measured in bulls and steers (e.g., BDG and SDG) have been reported to have genetic correlations of approximately 0.75 (e.g., Devitt and Wilton, 2001; Crews et al., 2004), and 2) dissimilar trait pairs (e.g., BYW and SFI) may likely have genetic correlations of magnitude equal to that if they had been measured on the same animals (Koots et al., 1994b), but should be reduced by the fact they were measured in animals of different gender and under different management schemes (Crews et al., 2004). For example, the genetic correlation between BYW and SFI was assumed to be 0.50 which is the product of the genetic correlation between yearling weight and feed intake (0.76; Koots et al., 1994b) and the genetic correlation of bull yearling weight with steer yearling weight (0.66; Devitt and Wilton, 2001), or 0.76 × 0.66 = 0.50. A similar procedure was used for the remaining trait pairs to obtain assumed genetic correlations in Table 3.

Solution to the equations $\mathbf{P}^{-1}\mathbf{Gv}$ yielded the vector of selection criterion or index weights (**b**) with individual elements b_1 = -10.12, b_2 = 24.79, and b_3 = -0.09. The elements in **b** were used to calculate index values, defined as I = -10.12(BRFI) + 24.79(BDG) + -0.09(BYW). Because producers consigning bulls to the test preferred to report index values similar to more traditional ratios, 100 was added to the index value as a deviation from the index mean, adjusting the index mean to 100. The mean, minimum, maximum, and SD of the adjusted index were 100, 80.1, 115.7, and 7.81, respectively. The index weight was negative for BRFI, positive for BDG, and near zero for BYW. The result that a negative weight was obtained for BRFI is consistent with the desired selection trend to decrease feed intake. The increases in efficiency gained through decreasing BRFI is expected to also result in a negative genetic trend for feed intake in steer progeny. Both of these would be considered favorable. Also intuitive was the positive weight on BDG. The relative contribution of BYW in this index was relatively low which may reflect the smaller economic value of SFW in the objective, but may also reflect that measurement of BYW adds little more information to the index in the presence of BRFI and BDG. From Cameron (1997), the contribution of BYW to selection response in the objective as

$$1-\sqrt{1-\frac{b_3^2}{(\mathbf{b'Pb})P_{3,3}^{-1}}}$$

where b_3 is the element of **b** corresponding to BYW and $P_{3,3}^{-1}$ is the third diagonal element of $\mathbf{P}^{-1}$, gives 0.09, indicating that removal of BYW from the criterion would reduce the accuracy of the criterion by 9%. Comparatively, removal of BRFI from the criterion would reduce accuracy of the criterion by 34% which was more than for BYW or BDG (27%). This result emphasizes the importance of including RFI in the selection criterion.

To further characterize the index, correlations with bull traits are reported in Table 4.

Table 4. Phenotypic correlations of the index with bull traits

Bull trait[a]	r_P[b]	*P*-value
BRFI	-0.74	<0.001
BFI	-0.22	0.029
BDG	0.53	<0.001
BYW	0.01	0.897
BSC	0.16	0.121

[a] BRFI = residual feed intake, BFI = daily DMI, BDG = ADG, BYW = 365-d weight, BSC = end-of-test scrotal circumference.

[b] Phenotypic correlation.

Phenotypic correlation estimates ($P < 0.03$) of index value with BRFI, BFI, and BDG were -0.74, -0.22, 0.53, respectively. These results suggest that higher index values were obtained for bulls with lower daily DMI, lower residual feed intake, and higher ADG. The correlation of index value with 365-d scrotal circumference was low (0.16) indicating only a marginal ($P < 0.13$) association although the sign of the correlation was favorable. The mean BSC of bulls with index values below100 (34.74 cm) was similar ($P < 0.30$) to that of bulls with index values above 100 (35.26 cm). There was essentially no association ($r = 0.01$; $P > 0.89$) between index value and BYW.

Implications

The design of selection programs should not only consider the multiple traits that are economically important to beef production, but also that profitability is a function of both revenues and costs. The recent increase of available individual feed intake data from traditional bull tests can be used to develop index selection tools that consider growth and saleable weight outputs, but also feed inputs. The index proposed here is an example multiple trait selection tool that is expected to increase growth rate and decrease feed intake during the feedlot phase of market progeny from centrally tested sires with feed efficiency phenotypes.

Literature Cited

Archer, J. A., E. C. Richardson, R. M. Herd, and P. F. Arthur. 1999. Potential for selection to improve efficiency of feed use in beef cattle: A review. Aust. J. Agric. Res. 50:147-161.

Archer, J. A., S. A. Barwick, and H.-U. Graser. 2004. Economic evaluation of beef cattle breeding schemes incorporating performance testing of young bulls for feed intake. Aust. J. Exp. Ag. 44:393-404.

Arthur, P. F., J. A. Archer, D. J. Johnston, R. M. Herd, E. C. Richardson, and P. F. Parnell. 2001a. 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.

Arthur, P. F., G. Renand, and D. Krauss. 2001b. Genetic and phenotypic relationships among different measures of growth and efficiency in young Charolais bulls. Livest. Proc. Sci. 68:131-139.

Basarab, J. A., M. A. Price, J. A. Aalhus, E. K. Okine, W. M. Snelling, and K. L. Lyle. 2003. Residual feed intake and body composition in young growing cattle. Can. J. Anim. Sci. 83:189-204.

Cameron, N. D. 1997. Selection Indices and Prediction of Genetic Merit in Animal Breeding. CABI, New York.

Crews, D. H., Jr., N. H. Shannon, B. M. A. Genswein, R. E. Crews, C. M. Johnson, and B. A. Kendrick. 2003. Genetic parameters for net feed efficiency of beef cattle measured during postweaning growing versus finishing periods. Proc West. Sec. Amer. Soc. Anim. Sci. 54:125-128.

Crews, D. H., Jr., E. J. Pollak, and R. L. Quaas. 2004. Evaluation of Simmental carcass EPD estimated using live and carcass data. J. Anim. Sci. 82:661-667.

Devitt, C. J. B, and J. W. Wilton. 2001. Genetic correlation estimates between ultrasound measurements on yearling bulls and carcass measurements on finished steers. J. Anim. Sci. 79:2790-2797.

Koch, R. M., L. A. Swiger, D. Chambers, and K. E. Gregory. 1963. Efficiency of feed use in beef cattle. J. Anim. Sci. 22:486-494.

Koots, K. R., J. P. Gibson, C. Smith, and J. W. Wilton. 1994a. Analyses of published genetic parameter estimates for beef production traits. 1. Heritability. Anim. Breed. Abstr. 62:309-338.

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

Lancaster, P. A., G. E. Carstens, D. H. Crews, Jr., and S. A. Woods. 2005. Evaluation of feed efficiency traits in growing bulls and relationships with feeding behavior and ultrasound estimates. Proc. West. Sec. Amer. Soc. Anim. Sci. 56 (current proceedings).