Proposed economic selection indices for the Simmentaler breed in South Africa

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Abstract

The development of economic selection indices for an integrated Simmentaler production system was described. The breeding objective was defined in terms of production-, functional- and product quality traits. Criteria included in the total index were birth- and weaning weight (direct and maternal), final weight, mature cow weight, days-to-calving, backfat thickness, tenderness and marbling. The total merit index was termed as $I_T = -1.60\ BW_D - 1.95\ BW_M + 2.23\ WW_D + 1.75\ WW_M - 0.54\ FW - 2.01\ MCW - 13.21\ CD + 4.97\ BF - 2.36\ T + 12.66\ M$. The correlation between this index and the aggregate breeding objective was 0.988. The economic superiority of the progeny from the top 40% of animals selected on their ranking in the total index, relative to the average progeny, is expected to be R 119.51.

Keywords: Beef cattle, breeding objectives, product quality, growth, functional traits
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Introduction

In practice, several or many traits influence an animal's value, although they do so in varying degrees (Hazel, 1943). Information on these traits can be combined in an index by a special use of Fisher's discriminant function, as proposed by Smith (1936) and Hazel (1943). The genetic gain attainable within a group of animals by selection for several traits simultaneously is the product of the selection differential, the correlation between the aggregate breeding value (breeding objective) and the selection index, and genetic variability. The greatest opportunity of enhancing the progress from selection is by ensuring that the correlation between the breeding objective and selection index is maximised. Hazel (1943) presented a multiple correlation method of constructing optimum selection indices. However, to solve the simultaneous equations the economic parameters (relative economic values), genetic parameters (heritability, genetic correlations) and phenotypic parameters (standard deviation, correlations) of/among traits must be known (Hazel, 1943). When these traits differ in variability, heritability, economic importance and in the correlation among their phenotypes and genotypes, index selection was more effective than independent culling levels or sequential selection (Hazel & Lush, 1943; Young, 1961; Hazel *et al*., 1994).

A useful modification developed by C. R. Henderson was the separated application of the selection index in two steps (Hazel *et al*., 1994). The first step is the estimation of individual breeding values, through multitrait analysis, for each trait included in the definition of the aggregate breeding value. The second step is application of relative economic values. This separation has two important advantages. It permits use of the most complex and accurate Best Linear Unbiased Prediction (BLUP) techniques to estimate individual breeding values for each index trait, including adjustment for differing quantities of information. It then allows the economic values applied to vary with differing selection objectives, depending upon how different breeds are used in a breeding system or the particular production and marketing system, without recalculating breeding values. In this approach selection is based on a "genetic index" whereas a conventional selection index is based on the phenotype (Lin, 1990).

Formulas presented by Schneeberger *et al*. (1992) take account of the fact that traits in the objective can differ from the selection criteria used to predict the breeding values in the index, as well as the differences in the accuracy of prediction of individual breeding values. Breeding values predicted by multiple-trait animal model BLUP procedures can, therefore, be combined into an index to predict an aggregate breeding objective made up of economically important traits and their associated economic values (Schneeberger *et al*., 1992).

Although the theory of selection indices has been introduced into animal breeding more than 60 years ago and is highly developed in various forms, its application in practical breeding may not be very extensive. This is not due to constraints in selection index theory, but partly due to difficulties in the derivation of relative economic values as well as the paucity of information on the relationships among traits. Furthermore, optimal selection indices may not be extensively used since, in most genetic evaluations, not all measured traits are considered in the same multi-trait BLUP model, leading to difficulty in the construction of optimal selection indices. The method presented in this paper is indeed valid only under such a multitrait BLUP model.

Economic values have already been derived for economically important traits for the Simmentaler breed (Kluyts *et al*., 2007). Therefore, the objectives of this paper were (1) the construction of economic selection indices for the Simmentaler breed in South Africa and (2) to test the accuracy and efficiency of these indices, depending on which selection criteria are measured. It is important to note that traits included in the breeding objective were chosen on economic considerations while the choice of selection criteria depends on the cost, time and accuracy of the measurement. It was furthermore assumed that all traits were considered in a multi-trait BLUP model.

Materials and Methods

Henderson (1963), as quoted by Harris & Newman (1994), noted that in Hazel's (1943) approach, optimum selection toward a breeding objective ($H = \sum a_i G_i$) requires selection on an index (I) which correlates best with H. In matrix notation the unrestricted index would be $I = \mathbf{b'X}$, where $\mathbf{X}$ is a n x 1 vector of sources of information and $\mathbf{b}$ is a n x 1 vector of weighing factors to be computed. The elements of $\mathbf{b}$ are chosen as to maximise genetic gain in a total (aggregate) breeding value or breeding objective. Where ($\mathbf{a'g}_i$) is the aggregate measure of merit for individual i, $\mathbf{a}$ is a m x 1 vector of economic values (weights) and $\mathbf{g}$ is a m x 1 vector of breeding values (for animal i) for the traits in the breeding objective. Also, $\mathbf{a} = \mathbf{c'v}$, where $\mathbf{c}$ is a m x 1 vector of cumulative discounted expressions of m breeding objective traits and $\mathbf{v}$ is a m x 1 vector with uncorrected economic values for the m traits. The optimum set of selection index coefficients is those which maximise the correlation (r_{HI}) or minimise the squared deviation between the selection index and the aggregate genotype (breeding objective) (Weller, 1994). Hazel (1943) showed that maximum r_{HI} is achieved when:

$$\mathbf{Pb} = \mathbf{G}_{12}\,\mathbf{a} \qquad (1)$$

Selection index weights are then calculated as:

$$\mathbf{b} = \mathbf{P}^{-1}\,\mathbf{G}_{12}\,\mathbf{a} \qquad (2)$$

where $\mathbf{G}_{12}$ is a n x m genetic variance – covariance matrix for m traits affecting profitability and n correlated indicator traits (criteria) and incorporates the additive genetic relationships between sources of information; $\mathbf{P}$ is a n x n phenotypic (co)variance matrix of correlated indicator traits; and $\mathbf{a}$ is a n x 1 vector of relative economic values (Cunningham *et al*., 1970; James, 1982; Gibson & Kennedy, 1990; Fewson, 1993; MacNiel *et al*., 1994).

Since selection is not directly based on phenotypic measures but on predicted breeding values and since multitrait solutions from BLUP consider environmental effects, the phenotypic variance-covariance matrix (P) is not needed for index construction (Lin, 1990). Although the phenotypic correlations have no effect on the derivation of index weights (coefficients) they are required for the calculations describing the index (Amer *et al*., 1998). The only information needed, in addition to the economic values, to allow prediction of the breeding objective, is information on the genetic variances and covariances among selection criteria in the index and on genetic covariances between the selection criteria and the objective traits (Schneeberger *et al*., 1992). If predicted breeding values instead of observed phenotypic measures are used in an index, solving for the index coefficients is by equation (3) (Schneeberger *et al*., 1992):

$$\mathbf{b} = \mathbf{G}_{11}^{-1}\,\mathbf{G}_{12}\,\mathbf{a} \qquad (3)$$

where $\mathbf{b}$ is a vector of index weights (coefficients) for the predicted breeding values of the selection criteria (traits) in the index, $\mathbf{G}_{11}$ is the n x n genetic variance-covariance matrix of the n criteria in the index, $\mathbf{G}_{12}$ is the n x m genetic covariance matrix between the n selection criteria in the index and the m traits in the breeding objective and **a** is the vector of corrected economic values, expressed in South African Rand per unit of measurement, for the traits in the objective and, for this study, corrected with the discounted gene flow method described by McClintock & Cunningham (1974).

The parameters for traits and criteria used in index construction are summarized in Table 1. These parameters were provided by Breedplan International for the South African Simmentaler breed as well as from literature reports (Koots *et al*., 1994a; Gregory *et al*., 1995a; b; Barwick & Henzell, 1999; Meyer & Johnston, 2001; Devitt *et al*., 2002; Martinez-Velazquez *et al*., 2003; Cundiff *et al*., 2004). Economic values were derived by Kluyts *et al*. (2007)

The economic value (Table 1) of a trait was defined by Hazel (1943) as the amount by which profit may be expected to change for each unit of improvement in the trait concerned, independent of effects from changes in other traits included in the definition of the breeding objective. Therefore, the economic value (a) of a given trait (i) was defined as the partial derivative (δ) of the profit equation (π) with respect to the trait concerned whereby all traits (x) are assumed to take their mean (μ) values:

$$a_i = \delta\pi / \delta x_i \mid_{x = \mu} \quad (4)$$

Table 1 Economic values (corrected with the DGF method) in Rand / unit (a), heritabilities (h^2), phenotypic (σ_P) and genetic (σ_A) standard deviations for the traits and criteria used in index construction

Trait	Symbol	unit	a	h^2	σ_P	σ_A
Weaning weight –direct	WW_D	kg	2.12	0.21	26.49	12.04
Weaning weight – maternal	WW_M	kg	1.69	0.12	26.49	9.0
Final weight (600 days)	FW_H	kg	-0.65	0.32	38.05	21.47
Mature Cow weight	MCW	kg	-2.00	0.43	52.92	34.64
Calving rate	CR	%	13.27	0.17	3.47	1.43
Days to calving	CD	days	-13.27	0.08	25.0	7.07
Calving ease - direct	CE_D	%	1.48	0.13	2.02	0.73
Calving ease - maternal	CE_M	%	1.64	0.12	2.02	0.70
Dressing percentage	DP	%	17.16	0.39	1.9	1.19
Backfat	BF	mm	0.45	0.44	1.3	0.86
Tenderness	T	WBS kg	-5.03	0.29	1.3	0.70
Marbling	M	score	0.35	0.38	0.82	0.50
Criteria						
Birth weight – direct	BW_D	kg		0.42	4.32	2.80
Birth weight – maternal	BW_M	kg		0.08	4.32	1.23
Scrotal circumference	SC	cm		0.36	2.70	1.62

The mean genetic correlations among traits provided by Breedplan International for the South African Simmentaler breed and synthesized from literature reports by Koots *et al*. (1994b), Graser *et al*. (1994), Nitter *et al*. (1994) and Johnston & Bunter (1996) are summarized in Table 2.

Williams (1962a) labelled the Smith-Hazel index as an estimated index since the phenotypic and genetic parameters required for index construction are never known absolutely. The index has to be derived by use of sample estimates (Williams, 1962b). Sampling errors associated with estimation from a small data set could, therefore, affect the reliability of the index. Harris (1964) noted that, in practice, it was possible to detect some estimates that are not reasonable (impossible), i.e., where the estimates are outside the parameter space. Examples are (1) negative estimates of additive genetic variance, (2) estimates of the additive genetic variance that are greater than the estimates of phenotypic variance (heritability estimates greater than 1.0) and (3) estimates of the additive genetic correlation which are greater than 1.0 in absolute magnitude. Sales & Hill (1976a; b) studied the effects of sampling errors on the efficiency of selection indices and concluded that the loss of efficiency is small even for estimates far from the correct value. Methods to improve the

Table 2 Mean genetic correlations (r_g) among 16 traits

	WW_M	YW	FW	MCW	CR	CD	CE_D	CE_M	DP	BF	T	M	BW_D	BW_M	SC
WW_D	-0.16	0.75	0.70	0.40	-	-	-0.21	-	-	-0.05	-	-	0.66	-0.05	0.19
WW_M	*	-	-	-	-	-	-	-	-	-	-	-	-0.14	0.39	0.19
YW		*	0.80	0.50	-	-	-0.29	-	-	-0.10	-	-	0.52	-	0.39
FW			*	0.75	-	-	-	-	-	-0.15	-	-	0.55	-	0.15
MCW				*	-	-	-0.23	-	-	-0.15	-	-	0.35	-	0.10
CR					*	-0.97	-	-	-	-	-	-	-	-	0.63
CD						*	-0.10	-0.20	-	-0.20	-	-	-	-	-0.20
CE_D							*	-0.30	-	-	-	-	-0.74	-	-
CE_M								*	-	-	-	-	-	-0.60	-
DP									*	0.30	-	0.25	-	-	-
BF										*	-	0.24	-0.27	-	-
T											*	-0.31	-0.01	-	-
M												*	0.31	-	-
BW_D													*	-0.35	0.04
BW_M														*	-0.07

estimates of parameters to increase the efficiency of index selection were proposed by Hayes & Hill (1980; 1981) and Tai (1989), while Tai (1986) proposed a method to construct a confidence interval for the expected response to multi-trait selection. Foulley & Ollivier (1986) proposed a method to test the coherence of variance-covariance matrices. However, on a large data set, the genetic variance-covariance matrix among traits (i.e. variance-covariance matrix among genetic values of the traits) provides a reasonable estimate of the variance-covariance matrix among the estimated genetic values (Lin, 1990). With the use of a small data set, the variance-covariance matrix of true genetic values may be very different from the variance-covariance matrix of genetic estimates, thus affecting the efficiency of the derived index. According to Lin (1990) this is a problem associated with the use of a small data set rather than a problem of theoretical derivation.

Although it was assumed that parameters were estimated on a large data set, and the genetic variance-covariance matrix among genetic values of the traits will, therefore, provide a reasonable estimate of the variance-covariance matrix among the estimated genetic values, matrices were tested for coherence with the method of Foulley & Ollivier (1986). According to Foulley & Ollivier (1986) matrices will be coherent if:

- for any linear combination of selection objectives H = a'g,
  $\sigma^2_H > 0$
- and for any predictor I = a'g,
  $\sigma^2_I / \sigma^2_H = \lambda, \quad 0 \leq \lambda \leq 1$

Since the heritability of a trait is a ratio of variances ($h^2 = \sigma^2_A / \sigma^2_P$), variances are squared deviations, and a correlation between two variables is a simple function of the covariance of the variables and their standard deviations (Equation 6) (Bourdon, 1997), the variances and covariances to include in the matrices ($\mathbf{G}_{11}$ and $\mathbf{G}_{12}$) were computed from the data in Tables 1 and 2 with the use of Equations 5 and 7.

$$\sigma^2_A = h^2 \cdot \sigma^2_P \qquad (5)$$

$$r_{X,Y} = \text{cov}\ (X,Y) / \sigma_X\ \sigma_Y \qquad (6)$$

$$\text{cov}\ (X,Y) = r_{X,Y} \cdot \sigma_X\ \sigma_Y \qquad (7)$$

Where $r_{X,Y}$ = the genetic correlation between variables X and Y; cov (X,Y) = the covariance between variables X and Y and σ_X and σ_Y are the genetic standard deviations for X and Y, respectively.

As stated above, the optimum set of selection index coefficients are those which maximise the correlation (r_{HI}) or minimise the squared deviation between the selection index and the aggregate genotype (breeding objective). Therefore, according to Groen *et al.* (1994), the accuracy of index selection is a function of the correlation (r_{HI}) between the aggregate genotype and the index and is calculated as:

$$r^2_{HI} = \sigma^2_I / \sigma^2_H \qquad (8)$$

Where σ^2_I and σ^2_H are the variances of the index and the breeding objective respectively and since $\mathbf{Pb} = \mathbf{G}_{12}\ \mathbf{a}$ (from Equation 1) it follows that these variances are:

$$\sigma^2_I = \mathbf{b'Pb} = \mathbf{b'G}_{12}\ \mathbf{a} \qquad (9)$$

$$\sigma^2_{\mathbf{H}} = \mathbf{a'G}_{22}\ \mathbf{a} \qquad (10)$$

Where $\mathbf{G}_{22}$ is the m x m genetic variance-covariance matrix of the m traits in the breeding objective. Equation 9 is, however, only correct when assuming that fixed effects are known (Schneeberger *et al.*, 1992).

According to Amer *et al.* (1998) responses (Ř) in each breeding objective trait (j) can be calculated using:

$$\check{R}_j = i\ \beta_{j\,I}\ \sigma_I = i\ [(\mathbf{b'}\ \mathbf{G}_{12\,j}) / \sigma_I\ ] \qquad (11)$$

Where i is the selection intensity, $\beta_{j\,I}$ is the genetic regression of the j th recorded trait (criterion) on the index, **b'** is a row vector of index coefficients, $\mathbf{G}_{12\,j}$ is the j th column of matrix $\mathbf{G}_{12}$ and σ_I the standard deviation of the index which is the square root of the variance, $\mathbf{b'G}_{12}\ \mathbf{a}$ (from Equation 9). Response in profit ($\check{R}\pi_j$) due to genetic change in each trait (j) with selection intensity (i) can then be calculated as:

$$\check{R}\pi_j = \check{R}_j \cdot a_j \qquad (12)$$

Where a_j is the economic value of trait j.

Criteria (Table 1) to include in the index will be all the traits in the breeding objective except CR, SC, CE_D, CE_M and DP. Birth weight direct (BW_D) and birth weight maternal (BW_M) were included as criteria in the index. These criteria were chosen to assist in the prediction of calving ease.

The genetic variance-covariance matrix ($\mathbf{G}_{11}$), with variances on diagonal and covariances off-diagonal, of the criteria (WW_D, WW_M , FW, MCW, CD, BF, T, M, BW_D, BW_M) in the index as well as the genetic covariance matrix ($\mathbf{G}_{12}$) between the selection criteria (WW_D, WW_M, FW, MCW, CD, BF, T, M, BW_D, BW_M) in the index and the traits (WW_D, WW_M, FW, MCW, CD, CE_D, CE_M, DP, BF, T, M) in the breeding objective were then constructed.

Since there are a limited number of herds with breeding seasons where breeding values for CD can be derived, an alternative index (I_A) was constructed that includes SC instead of CD as fertility criterion.

Since there are at present only a limited number of herds/animals with breeding values for scanned traits (backfat, tenderness and marbling) a primary index (I_P) was developed with traits usually measured in a cow-calf production system (based on the results summarized in Table 3) to be used until more information on these scanned traits are available. This primary index includes only WW_D, WW_M, MCW and CD as criteria.

Results and Discussion

According to Kluyts *et al.* (2007) the breeding objective ($H = \sum a_i G_i$) for the South African Simmentaler breed was defined as:

$$H = 2.12WW_D + 1.69WW_M - 0.65FW - 2.00MCW - 13.27CD + 1.48CE_D + 1.64CE_M + 17.16DP + 0.45BF - 5.03T + 0.35M$$

Therefore, let the vector of economic values be:

a' = [2.12 1.69 -0.65 -2.00 -13.27 1.48 1.64 17.16 0.45 -5.03 0.35]

Matrices were tested with the method of Foulley & Ollivier (1986) and they satisfy the criteria of coherence since σ^2_H = 14639.61 and λ = 0.9753.

The vector of index coefficients (**b**) was then computed using Equation 3 ($\mathbf{b} = \mathbf{G}_{11}^{-1}\,\mathbf{G}_{12}\,\mathbf{a}$) as:

$$\mathbf{b'}_T = [2.23 \quad 1.75 \quad -0.54 \quad -2.01 \quad -13.21 \quad 4.97 \quad -2.36 \quad 12.66 \quad -1.60 \quad -1.95]$$

These index coefficients can now be multiplied with each EBV and summed to obtain the index value for an animal. Animals can then be ranked according to these index values and selection based on these rankings.

The total merit index (I_T) for an integrated Simmentaler production system is:

$$I_T = -1.60\,BW_D - 1.95\,BW_M + 2.23\,WW_D + 1.75\,WW_M - 0.54\,FW - 2.01\,MCW - 13.21\,CD + 4.97\,BF - 2.36\,T + 12.66\,M$$

The variances of the index (equation 9) and breeding objective (equation 10) were calculated as 14278.18 and 14639.61 respectively. With Equation (8) the accuracy (r^2_{HI}) of the derived economic selection index, in predicting the breeding objective, was computed as 0.9753. The correlation (r_{HI}) between this index and the breeding objective is then 0.988.

The alternative index (I_A) (that includes SC and not CD as fertility criterion) for an integrated Simmentaler production system is:

$$I_A = 12.53\,BW_D + 13.18\,BW_M - 0.33\,WW_D + 0.46\,WW_M - 0.50\,FW - 2.00\,MCW + 15.90\,SC + 43.69\,BF - 11.69\,T - 31.89\,M$$

The variance of the alternative index was 6640.149. It was, however, only 45.4% accurate in predicting the breeding objective. The correlation (r_{HI}) between this index and the breeding objective was only 0.674.

To test the effect of individual criteria on the efficiency of the index (I_T), these criteria were deleted one at a time from the index. The efficiency of these sub-indices was then compared to the efficiency of the overall index. These results are summarized in Table 3.

Table 3 Reduction in accuracy of the sub-index, compared to the total index (I_T), when individual criteria were dropped from the index

	I_T	Criteria									
		WW_D	WW_M	FW	MCW	CD	BF	T	M	BW_D	BW_M
r^2_{HI}	0.9753	0.9619	0.9623	0.9731	0.8412	0.4164	0.9748	0.9745	0.9741	0.9747	0.9745
Reduction		0.013	0.013	0.002	0.134	0.559	0.001	0.001	0.001	0.001	0.001

From Table 3 it is clear that most individual criteria have only a small influence on the efficiency of the index. However, when MCW or CD is dropped from the index the resultant sub-indices are only 84.1 % or 41.6% accurate, respectively, compared to the 97.5 % of the total index with these criteria included. Since dropping certain traits have a small influence on the efficiency of the index the possibility to construct the total index without these traits (criteria) was investigated. However, when criteria were dropped from the index the index weights (coefficients) of the remaining criteria changed. For instance when WW_D was dropped from the index the index weights (b-values) for BW_D and BW_M changed from negative values to high positive values of 4.87 and 3.50, respectively. These values are even higher than the values assigned (in this sub-index) to WW_M and FW of 1.26 and 0.08 respectively. Although these indices may be just as efficient economically as the total index it may be unacceptable because the positive weights assigned to birth weight may compromise CE_D and CE_M. It was, therefore, decided to retain the total index.

Responses in each breeding objective trait were calculated using Equation (11) and the response in profit due to genetic change in each trait was then calculated with Equation (12). It was assumed that the selection intensity is equal to 1. This can also be seen as the expected economic superiority, over the average progeny, of the progeny from the top 40% of animals selected on their ranking in the total index. Note that i is approximately equal to 1 when 40% of animals are selected (i = 0.966; Falconer & Mackay, 1996). These results are summarized in Table 4.

A primary index (WW_D, WW_M, MCW and CD) was constructed with the vector of index coefficients:

$$\mathbf{b}'_P = [1.54 \quad 1.57 \quad -2.23 \quad -13.33]$$

The variance (σ^2_I) of this index (I_P) was computed at 14161.95. The accuracy of I_P is 96.74% and correlation with the objective 0.984. The expected responses when selection is based on this index are also summarized in Table 4.

From Table 4 it can be seen that, with selection on I_T, all the traits changed in the desired direction except WW_D and made a positive contribution to profit. The largest contribution came from the functional traits (fertility) and mature-cow-weight. Ponzoni & Newman (1989) also concluded that, under most circumstances the trait making the greatest positive contribution to genetic gain in economic units was calving day (CD). WW_D, on the other hand, will be reduced with 1.48 units (kg). The main reason for this decrease is the relative high genetic correlation between WW_D and MCW (r_G = 0.4) and the relatively high negative economic value of MCW. In their study, Nitter *et al.* (1994) showed positive economic responses for growth and reproduction whereas the economic response in carcass value, maintenance and calving difficulty were negative. When selection is based on I_P the expected response in total profit will be almost the same as with selection on I_T. There are, however, no changes expected in the quality traits (dressing percentage, marbling and tenderness) with selection on I_P. The alternative index is clearly the least efficient economically. With I_A relatively more emphasis is placed on weight traits (BW_D and BW_M) than on fertility traits as compared with the other indices. These heavier weights placed on early growth resulted in a reduction in calving ease (direct and maternal). It is furthermore concluded that CD cannot be excluded from the index. It is also clear from these results that, the higher the variance of the index the greater is the expected economic response when selection is based on that specific index.

Table 4 Properties of indices, expected responses (Ř) in traits (per unit) and expected economic superiority or expected response in profit (Řπ in Rand) of the progeny from animals selected on different indices (I_T = total index, I_A = alternative index and I_P = primary index)

Index	I_T		I_A		I_P	
Trait	Ř	Řπ	Ř	Řπ	Ř	Řπ
WW_D	-1.48	-3.138	-2.143	-4.543	-1.479	-3.136
WW_M	0.84	1.42	1.224	2.069	0.844	1.426
FW	-8.647	5.62	-12.634	8.212	-8.111	5.272
MCW	-20.232	40.464	-29.629	59.258	-20.327	40.654
CD	-5.577	74.007	-1.099	14.583	-5.599	74.299
CE_D	0.141	0.209	-0.082	-0.122	0.143	0.212
CE_M	0.118	0.194	-0.084	-0.137	0.111	0.182
DP	0.029	0.498	0.106	0.819	0	0
BF	0.263	0.118	0.385	0.173	0.214	0.096
T	-0.021	0.106	-0.031	0.156	0	0
M	0.027	0.010	0.040	0.014	0	0
Accuracy (%)	97.53		45.40		96.74	
r_{HI}	0.988		0.674		0.984	
Total (R)		119.51		81.48		119.01

Conclusions

The primary index constructed in this study is not the same as a sub-index. Sub-indices can be constructed for sub-systems (e.g. cow-calf system) of the integrated system, by setting the economic values of certain traits to zero (Amer *et al*., 1998). The primary index is defined for the total breeding objective of an integrated system but include only criteria usually measured in a cow-calf production system. The intention is that this index is to be used as a first index until more information, especially on scanned (product quality) traits, becomes available.

Many of the properties and constraints of these indices are related to a pure-breeding situation, and may not be the case when modelling a scenario involving a terminal or maternal crossbreeding situation.

In this article a detailed description of the development of an economic selection index was presented. Although these indices were developed specifically for the Simmentaler breed in South Africa, the methods employed can be used to develop indices for different breeds and/or different production systems within the same breed. Only small changes in the economic values, definition of the breeding objective, and correlation structure between traits and criteria are necessary.

Application of these principles and results is necessary if the beef cattle industry is to maximise the exploitation of genetics and to improve its relative competitive position. This approach may have wide ranging benefits, not only for the beef cattle industry, but also for consumers.

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