Multiple Trait Selection for Maternal Productivity: The Hereford Maternal Productivity Index[1]

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Introduction

Maternal productivity in beef cattle generally refers to measurement of outputs in the beef production enterprise. The primary revenue in the cow-calf segment of the industry is from the sale of weaned calves, but revenue is also derived in the salvage value of cull animals. For a more comprehensive measure of maternal productivity, inputs should also be considered, and as such maternal productivity is a composite trait influenced by several underlying cost components such as fertility, survival, maternal genetic potential, and mature size. Maternal productivity and cow efficiency are therefore complex traits that are difficult to measure, predict, and evaluate.

Cow efficiency and maternal productivity are similar traits. In general, cow efficiency is defined as the ratio of outputs to inputs per breeding female maintained within a given year. Maternal productivity can be characterized as a summation of successive cow efficiency measures with added components such as reproductive ability and longevity. Cow efficiency is simply a subset of maternal productivity without the aspect of time or repeated records. Historically, maternal productivity has been measured as a ratio of outputs (e.g., average weaning weights) divided by a measure of cow weights or feed inputs and adjusted for reproductive performance. Several studies have compared cow efficiency, and to a lesser degree maternal productivity, at the breed or crossbred type level. This has led to numerous publications defining or comparing more efficient cow types and the entire area of matching cow type to the resources available in the production unit.

An important aspect that has received little attention is the amount of variation in maternal productivity within a breed or type. Upon review, one finds clear indication of a large amount of variation within cow types for most of the component traits of maternal productivity. This means two things: 1) that one should expect a large range in maternal productivity within cow type, and 2) there is likely an opportunity to select and further enhance maternal productivity within a breed.

More recent advancements in genetic evaluation methodology provide alternatives for evaluation of traditional ratio-type and composite traits. Examples include EPD for stayability where stayability is defined as the probability that a female will wean some number of calves (i.e., survive into profitable parities) given that she becomes a dam. While genetic evaluations for these traits may be difficult to interpret, they are the forerunners of more user-friendly evaluations. Multiple trait index selection procedures allow for combining genetic evaluation and economic information for the evaluation of composite traits involving several underlying components. Application of these procedures and development of others need to be examined for accurate genetic evaluation of maternal productivity. In addition, genetic associations between maternal productivity and other economically important reproductive, production, and carcass traits are generally unknown. Knowledge of these associations is required before genetic improvement programs for maternal productivity can be implemented (Koots et al., 1994a,b).

The objectives of this report are to summarize the development of a multiple trait maternal productivity index, to describe its implementation with field data, and to summarize the Canadian Hereford Association maternal productivity index (MPI) national cattle evaluation.

Index Development

Experimental Data. Prediction and genetic evaluation of maternal productivity are difficult because properly designed research data is lacking.

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[1] The index development discussed here was taken primarily from: Mwansa, P. B., D. H. Crews, Jr., J. W. Wilton, and R. A. Kemp. 2002. Multiple trait selection for maternal productivity in beef cattle. J. Anim. Breed. Gen. 119:391-399. Financial support for this project was provided by the Canadian Hereford Association and the Agriculture and Agri-Food Canada (AAFC) Matching Investment Initiative (MII).

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Table 1. Summary statistics for maternal productivity component traits[a]

Component trait	N	Mean	SD
Birth weight, kg	3,664	36.2	4.7
Weaning weight, kg	3,664	177.4	27.9
Cow weight at weaning, kg[b]	3,609	496.4	63.2
Stayability, %[c]	751	64.7	47.8

[a] From Mwansa et al. (2002) Table 1.

[b] Weight of the cow when her calf was weaned.

[c] Probability that a female will wean three or more calves given she becomes a dam.

Today's cost of collecting such data in a research setting essentially negates any chance of developing such a project. However, Agriculture and Agri-Food Canada (AAFC) has historical data that was utilized to initially develop the MPI, in collaboration with the Canadian Hereford Association (CHA). The AAFC data were collected as part of a long term Hereford selection project conducted at the Onefour Research Substation near Manyberries, Alberta. Data on 3,664 calves born to 186 sires and 886 dams between 1964 and 1985 were available. A description of the experimental herds used for these analyses was given by Bailey et al. (1991).

Traits. Component traits were included in the MPI on the basis of their potential to contribute to high weaning weight with persistent production over a sustained herd life while considering costs. Cow-calf producers derive a majority of their income from the sale of weaned calves, and both direct (WWT) and maternal (MLK) effects on weaning weight were included on this basis. Cow weight (CWT) was included to partially account for annual maintenance costs associated with raising a calf to weaning age, and stayability (STY) was included to account for reproductive consistency. The definition of stayability was derived from and was similar to that of Snelling et al. (1995).

Parameter Estimation. (Co)variance components and genetic parameters were estimated for the component traits with a multivariate animal model that also included direct and maternal birth weight (BWT_d and BWT_m, respectively) using derivative free REML (Boldman et al., 1995). Appropriate contemporary group classifications were fit as fixed effects for all traits. A full maternal animal model including permanent environmental effects was used for weaning weight. In all analyses, at least three sets of covariance starting values were used, along with convergence defined at the point were the variance of the simplex function was less than 10^{-9} to reduce the probability of local maxima solutions.

Economic Weights. The multiple trait model was based on weaning weight of calves, costs associated with the weight of the cow when her calf was weaned and the impact of genetic change in survival. The combined, or aggregate, genetic value (T) to be improved (i.e., selection objective) was then defined as:

$$T = v_1 BV_{WWT} + v_2 BV_{MLK} + v_3 BV_{CWT} + v_4 BV_{STY}$$

where v_i represent net economic values derived independent of changes in the other components. The MPI is then defined as:

$$MPI = v_1 EBV_{WWT} + v_2 EBV_{MLK} + v_3 EBV_{CWT} + v_4 EBV_{STY}$$

where EBV_i represent the estimated breeding values for the component traits from the multiple trait breeding value estimation.

A gross value of \$2.58 kg^{-1} was used for WWT

Table 2. (Co)variance and genetic parameter estimates among maternal productivity components[a]

	BWT_d	BWT_m	WWT	MLK	CWT	STY
h^2	0.48 ± 0.02	0.11 ± 0.04	0.19 ± 0.04	0.18 ± 0.04	0.50 ± 0.07	0.07 ± 0.09
BWT_d	**8.4**	-0.09 ± 0.16	0.74 ± 0.02	-0.34 ± 0.09	0.67 ± 0.02	-0.82 ± 0.30
BWT_m	-0.4	**2.0**	0.09 ± 0.30	0.19 ± 0.27	-0.02 ± 0.27	0.41 ± 0.16
WWT	20.2	1.2	**88.5**	-0.42 ± 0.22	0.85 ± 0.02	-0.52 ± 0.56
MLK	-9.0	2.4	-3.6	**82.2**	-0.17 ± 0.15	-0.01 ± 0.34
CWT	64.7	-1.1	267.3	-52.0	**1120.5**	-0.48 ± 0.44
STY	-24.0	6.0	-50.0	-1.0	-162.0	**113.0**

[a] Genetic variances are on the diagonal in **bold**, genetic covariances are below the diagonal, and genetic correlations (± SE) are above the diagonal. From Mwansa et al. (2002) Table 2. Weights are in kg.

Table 3. Derived economic weights and influence of component traits[a]

Component	Economic value, \$ (v_i)	Genetic SD (σ_g)	Standardized economic weight[b]	Relative emphasis[c]
WWT, kg	2.58	9.40	24.3	0.30
MLK, kg	2.16	9.10	19.7	0.25
CWT, kg	-0.31	33.50	10.4	0.13
STY, %	2.39	10.60	25.3	0.27

[a] From Mwansa et al. (2002) Table 5.

[b] Standardized economic weight, $E_i = v_i\ \sigma_{g(i)}$.

[c] Relative influence on the index, $E = (E_i / \Sigma_4\ E)$.

(Alberta Agriculture, 1989). No reductions were included for the extra maintenance of cows because CWT was included in the model. Similarly, no adjustments were made for decreased fertility that may be associated with increased calf size because stayability, whose main component is fertility, was included in the model. The major contribution to the maternal component of weaning weight was assumed to be milk yield. Results from Miller et al. (1999) for the effect of milk yield on gross margins (accounting for increased feed requirements) indicated that a net economic value of approximately 84% of the gross value for WWT would be appropriate, leading to a value of $\$2.16\ \text{kg}^{-1}$ for MLK.

The economic weight for CWT was based on the extra feed required by a heavier cow, reduced by the salvage value of that heavier cow. The estimated feed requirement for a 500 kg cow producing 5 kg of milk per day is $12.3\ \text{kg d}^{-1}$ (Alberta Agriculture, 1989). This is approximately [(12.3/500) × 100] 2.46% of body weight. The feed associated with a 1 kg change in cow weight was therefore assumed to be $0.0246\ \text{kg d}^{-1}$. On an annual basis, this was (365 × 0.0246) $8.979\ \text{kg yr}^{-1}$. At $\$0.07\ \text{kg}^{-1}$ (Alberta Agriculture, 1989), the extra feed cost was $\$0.63\ (\text{kg yr})^{-1}$. The salvage value associated with cow weight was based on an estimated 25% replacement rate and a salvage value of $\$1.28\ \text{kg}^{-1}$ (Koots and Gibson, 1998). Salvage revenue was then (0.25 × \$1.28) $\$0.32\ (\text{kg yr})^{-1}$. Net economic value was then equal to (\$0.32 - \$0.63) $\$\text{-}0.31\ (\text{kg yr})^{-1}$.

The definition of stayability used in this study was the probability that a female would have three or more calves given that she became a dam. An equivalence of stayability to fertility was used to derive the relative economic weight of this component. Fertility rates of 81% for 2-yr-old heifers and 90% for 3-year-old cows (Koots and Gibson, 1998) resulted in the probability of having a third calf of 0.81 × 0.90 = 0.729. Increasing fertility by 1% gives a probability of 0.82 × 0.91, which is an increase in stayability of 1.72% resulting from the 1% increase in fertility. The value of a unit increase in stayability was then estimated as 1.72 times that of one unit increase in fertility. Koots and Gibson (1998), using an economic model which also included cow weight, milk yield and growth rate, estimated a value for cow value of \$14.72 per genetic SD. This economic value was assumed to be equivalent to \$14.72 × 1.72 = \$25.30 per genetic SD of stayability. With the estimated genetic SD reported later in this study, the economic value for stayability was then (\$25.30 / 10.6) $\$2.39\%^{-1}$.

Combining EBV and corresponding economic values for each of the component traits into a linear function gives the index:

$$\text{MPI} = 2.58\ \text{EBV}_{\text{WWT(kg)}} + 2.16\ \text{EBV}_{\text{MLK(kg)}} - 0.31\ \text{EBV}_{\text{CWT(kg)}} + 2.39\ \text{EBV}_{\text{STY(\%)}}$$

MPI Characteristics. The MPI was constructed as a weighted linear combination of multiple trait EBV. There was a range from -96 to +89 for animals in the experimental data set. The actual and standardized weights for the EBV are given in Table 3, along with the relative emphasis placed on individual component traits. From parameters and economic weights estimated for the experimental data, the MPI places 30% relative emphasis on WWT, 25% on MLK, 13% on CWT, and 27% on STY. The number of traits considered here and the limit on the scope of the selection program to the production of a weaned calf make comparisons with other studies considering carcass traits (e.g., MacNeil et al., 1994 and Koots and Gibson, 1998) difficult.

Table 4. Summary statistics for field data components of the MPI (n = 487,565[a])

Component[b]	Mean	Minimum	Maximum	Phenotypic SD
BWT, lb	90.25	45	150	11.46
WT205, lb	553.40	162	1082	96.95
CWT, lb	1468.95	772	2120	269.74
STY, %[c]	62.60	0	100	44.45

[a] Total animals in the evaluation. Maximum numbers of animals with records = 256,668.

[b] BWT = birth weight (lb), WT205 = adjusted 205-d weaning weight (lb), CWT = weight of cow at weaning of her calf (lb), STY = stayability = probability that a female will wean three or more calves given that she became a dam (%).

[c] Stayability was adjusted in the case of 2- and 3-year old females to account for their not having had the opportunity to produce three calves. Stayability raw score was multiplied by 100 (%) for the purposes of this table.

MacNeil et al. (1984) found relative economic values that were higher for female fertility than for direct or maternal weaning weights when considering weaning weight as the market endpoint. Cow weight had a negative economic value in that study and the relative value was approximately half that of direct and maternal weaning weights, similar to this study.

Genetic Trend in Components Due to MPI Selection. All component traits in the index would be expected to show positive (i.e., increasing) genetic trend due to sire selection on the MPI. Expected genetic changes are a function of the magnitude and sign of the genetic correlation among the component traits in the index as well as the economic values. The expected genetic change in CWT with simulation (Mwansa et al., 2002) was approximately 24% of the genetic SD, while expected change in WWT was approximately 44%. This comparison shows that although MPI selection would be expected to increase CWT, the magnitude of that change would be moderated relative to increases in growth potential. The extent of change in CWT as a result of the positive genetic correlation with WWT was reduced but not removed by the negative economic weight on CWT.

Simulation of several selection scenarios (Mwansa et al., 2002) was used to quantify expected genetic trend by varying the accuracy of the MPI due to differences in information density. Simulation demonstrated that without sufficient grandprogeny data, little genetic change would be expected in MLK. With more data from grandprogeny, comparable increases in both WWT and MLK would be expected. The simulation(s) indicated that, obviously, appropriate family structures are needed to achieve genetic change in relationship to the relative economic values. The accuracy of the index is reduced significantly with reduced information on grandprogeny. The MPI as described can be implemented flexibly, with economic values changed in computations of index values as economic scenarios change. The assumption of linearity is probably reasonable, as long as economic values are periodically updated. Based on the development of the MPI, the Canadian Hereford Association recommended that pilot and release runs be conducted, evaluated, and released. The remainder of this report is focused on the second release run of the CHA maternal productivity index national cattle evaluation.

The 2003 CHA MPI National Cattle Evaluation

Field Data Considerations. Unlike experimental data from genetic resource herds, national cattle evaluation using field data requires unique consideration of the bias that is often inherent to breed association field data. Data up to January 1, 2003 was used for the most recent MPI evaluation. The Canadian Hereford Association maintains performance and pedigree data in the Total Herd Evaluation (THE) database (www.hereford.ca) which was provided to implement the release run.

Prior to analysis, birth and weaning weights were adjusted for age of dam and (for weaning weight), age at measurement (BIF, 2002). Contemporary groups were formed on the basis of subclasses defined similarly to those used for the Hereford North American Cattle Evaluation (NACE). Contemporary groups for all traits were restricted to have at least 2 records on animals from different sires, as well as other restrictions generally utilized in national cattle evaluation procedures (e.g., BIF, 2002). The component trait models genetic parameters from the study by Mwansa et al. (2002) were assumed constant for the CHA field data, although phenotypic variances appropriate to the CHA field database were re-estimated. Table 4 summarizes the 2003 MPI evaluation relative to the component traits.

Table 5. Summary of MPI component trait EPD (n = 487,565)

Component	Mean	Minimum	Maximum
WWT, lb	2.07	-36.97	54.19
MLK, lb	2.00	-32.24	34.04
CWT, lb	1.24	-104.05	108.09
STY, %	0.27	-11.11	9.53

The usual multiple trait Best Linear Unbiased Prediction (BLUP) procedures were used to compute breeding values (EBV) for the component traits which were then assembled into the MPI as previously described:

$$\text{MPI} = 1.17\ \text{EBV}_{\text{WWT(lb)}} + 0.98\ \text{EBV}_{\text{MLK(lb)}} - 0.14\ \text{EBV}_{\text{CWT(lb)}} + 2.39\ \text{EBV}_{\text{STY(\%)}}$$

where the economic values for the component traits were adjusted for application to WWT, MLK and CWT EBV which were measured and computed in pounds instead of kilograms. Because STY was a probability (range 0 to 1.00), no adjustment was made to the economic value compared to the study by Mwansa et al. (2002).

Component Trait EPD. Although breeding values are used to calculate the MPI, Table 5 summarizes EPD for the component traits. These EPD are comparable to those published as part of the 2003 Hereford NACE, except that the MPI run did not include data from American Hereford Association except for those across-country registered animals with data in Canada. It is important to note that the MPI is a within-country national cattle evaluation at present, but an international MPI evaluation is certainly possible.

Mean EPD in the evaluation are not forced to sum to or average zero, so variability exists with respect to the central tendency of genetic values. The actual MPI values released to the CHA membership (www.hereford.ca) were computed using WWT and MLK breeding values from the Hereford NACE, so some discrepancies are expected between these results and those released.

Maternal Productivity Index and Maternal Productivity Ratio. The MPI computed as described above reflects expected revenue differences among animals in the evaluation. Mwansa et al. (2002) reported a range of -\$96 to +\$89 for animals in the developmental AAFC data set. As shown in Table 6, the range in raw MPI values in the CHA field database was -\$96.10 to +\$119.16, with an average MPI of +\$9.70. At the request of CHA, an MPI ratio was developed to force the average and standard deviation of annual MPI values to be constant at 100 and 25, respectively. Therefore, the maternal productivity ratio (MPR) was defined as:

$$\text{MPR} = 100 + (\text{MPI}_i - \hat{\mu}_{\text{MPI}})\left[\frac{25}{\sigma_{\text{MPI}}}\right]$$

where MPI_i is the raw MPI value for animal i, $\hat{\mu}_{\text{MPI}}$ is the raw MPI mean (9.70 in the 2003 evaluation), and σ_{MPI} is the raw MPI standard deviation (19.07 in the 2003 evaluation). This computation forces the MPR to have a mean of 100 and a variance of 625 in each evaluation year. Response to reporting MPI and MPR values by CHA has been positive.

Comparison of High Versus Low MPI Groups

Given the breeding objective of the MPI to increase the genetic potential of Herefords to consistently wean heavy calves over a sustained productive life while maintaining input costs, it was of interest to compare the MPI and its component traits between groups with high versus low values with respect to the index (Crews, 2002). The comparisons reported here are based on a pilot MPI evaluation provided to CHA prior to the release of the full 2003 run. The pilot run was based on a slightly different set of animals, which can be considered a subset of the population described above for the 2003 MPI evaluation.

Grouping and Analysis Method. Two MPI groups were defined, where animals with MPI more than two standard deviations above the overall mean (4.48) were classified into the high group (n = 17,328) Animals with MPI more than two standard deviations below the mean were classified into the low group (n = 11,496). Component trait EPD were compared between the groups by expressing within-group mean, minimum,

Table 6. Summary statistics for the raw MPI and MPI ratio (MPR) from the 2003 CHA evaluation

Index	Mean	Minimum	Maximum	SD
MPI	9.70	-96.09	119.16	19.07
MPR	100.00	-38.56	243.37	25.00

Table 7. Summary c

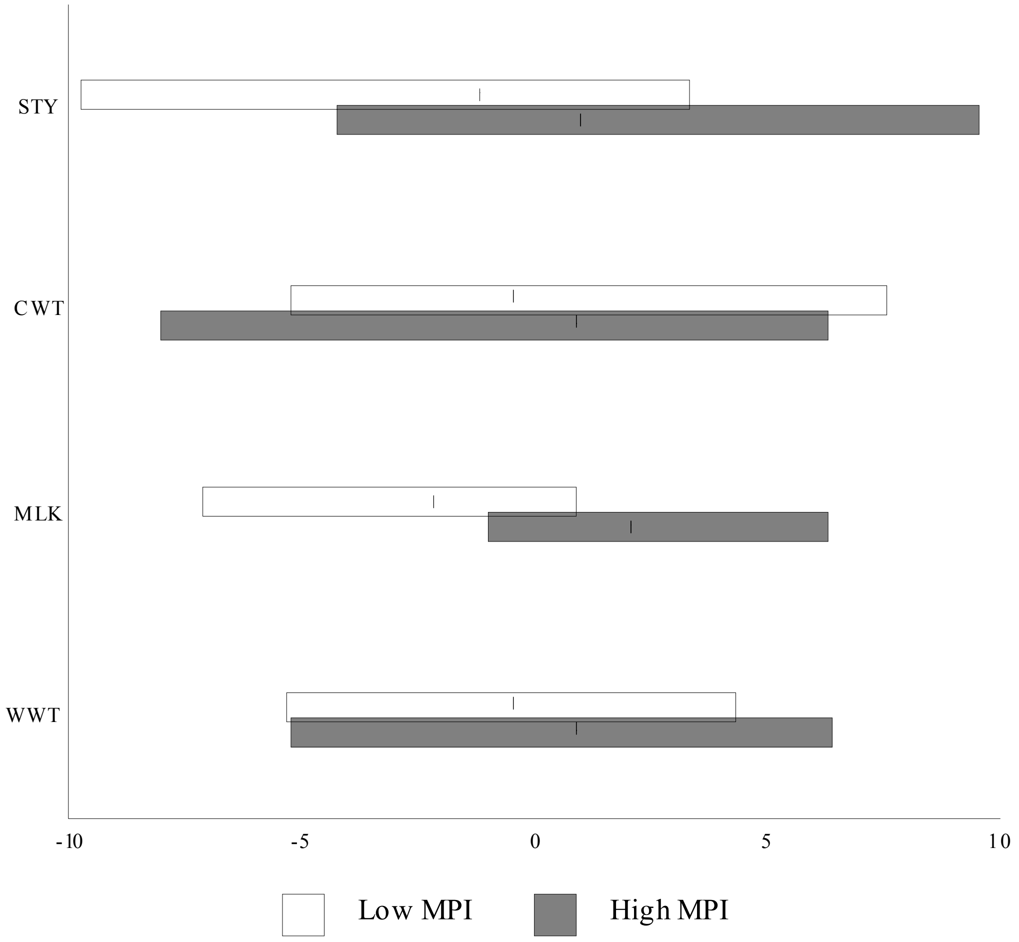
	Low MPI group (n = 11,496)			High MPI group (n = 17,328)		
Trait	Mean	Minimum	Maximum	Mean	Minimum	Maximum
WWT, kg	-1.65	-40.63	35.39	9.12	-39.95	52.21
MLK, kg	-11.32	-37.13	4.51	11.05	-4.98	32.71
CWT, kg	-4.79	-78.08	120.39	17.49	-122.01	101.52
STY, %	-1.83	-15.17	5.02	1.49	-6.63	14.56
MPI, $	-43.81	-127.86	35.00	55.13	44.00	148.69

and maximum EPD as deviations from the overall mean in standard deviation units to remove scale effects (Crews, 2002)

Table 7 contains a summary of EPD for the component traits of the MPI by group. The ranges and SD of components reflected the phenotypic range and genetic parameters used in the multiple trait evaluation model described previously. Therefore, for example, STY EPD were closer to and more closely distributed around zero than EPD for CWT, which had a higher phenotypic mean, variance, and heritability.

Within the high MPI group, mean component EPD were positive, although the minimum and maximum EPD reflect that animals with both negative and positive EPD were represented in the group. Further, the mean component trait EPD in the low MPI group were uniformly negative. Again, however, the range

Figure 1. Comparison of mean and range of component trait EPD between high and low MPI groups. Standardized range and mean EPD are expressed in standard deviation units for direct (WWT) and maternal (MLK) weaning weight, cow weight (CWT), and stayability (STY).



included both negative and positive EPD. This would be expected because the weights assigned to individual traits were not of the same sign or magnitude. These results suggest that no individual component trait was equivalent to the MPI, and that increasing selection for the MPI would result in selected animals with a wide range of component EPD.

To further compare the groups, scale effects were removed be expressing the mean, minimum and maximum within-group component trait EPD as differences from the overall mean component EPD in standard deviation units (Figure 1).

The difference in standardized means was 1.34, 4.29, 1.39, and 2.14 SD for WWT, MLK, CWT, and STY, respectively. The ranges in standardized EPD, equivalent to the difference between maximum and minimum standardized EPD, were 11.47, 7.24, 14.25, and 13.68 SD for WWT, MLK, CWT, and STY, respectively in the high MPI group. The standardized ranges for the low MPI group were 9.50, 8.00, 12.65, and 13.03 SD for WWT, MLK, CWT, and STY, respectively. These results indicate that from 8 to more than 14 SD of variation existed for the component traits. However, the standardized ranges in component traits were similar between the groups. As shown in Figure 1, 82% of the range in WWT EPD included animals that were assigned to the high and low MPI groups. This overlap in standardized range indicates that direct weaning weight did not effectively separate animals designated as high versus low relative to the index. Similar results were noted for CWT, where 74% of the range in CWT EPD included EPD within the ranges of the low and high groups. Further, there was 39 and 14% overlap in group ranges for STY and MLK EPD, respectively. Therefore, differences in MLK and STY EPD tended to more closely correspond to differences in the MPI compared to the other component traits (WWT and CWT). However, none of the component traits provided animal rankings equivalent to those based on the MPI, which reflects the multiple trait nature of this index. Validation of the MPI with an economic comparison of animals in low versus high MPI groups has yet to be completed.

Conclusions and Implications

A maternal productivity index was developed with the breeding objective to increase the genetic potential of beef cattle to consistently wean heavy calves over a sustained productive life while maintaining input costs. Selection for maternal productivity in beef cattle using the MPI, which incorporates EBV for direct and maternal weaning weight, cow weight, and survival weighted by their independent economic values, would be expected to result in positive genetic change for all component traits. This index would be of general use in varying production environments using economic weights reflecting those particular environments. Genetic values for the component traits varied widely and similarly among animals with different index values, which appeared to be more closely related to genetic differences in maternal weaning weight and stayability than in preweaning growth or cow weight. Results suggest that selection for the MPI would not be equivalent to selection for any of the component traits alone. The components of the MPI were specifically chosen on the basis of ease of implementation for national cattle evaluation and their association with the overall breeding objective, although it has been noted that cow weight is the component phenotype with the most sparse information in field data. Questions still need to be addressed related to adjustment of stayability for length of productive life such that young and older cows are not assigned biased records due to age, and accounting for the repeated records possible with cow weight.

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