A prototype national cattle evaluation for sustained reproductive success in Hereford cattle[1]

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ABSTRACT: The objective of this research was to develop a prototype system for national cattle evaluation that would facilitate selection for improved fertility of daughters from Hereford sires. Raw data for this analysis were the birth dates of calves as reported by breeders to the American Hereford Association. Records from females entered this analysis with the reporting of a birth date for their first calf. At that time, females were required to be in contemporary groups of at least 3 animals and to have at least 2 additional paternal half-sibs also represented in the data. To explicitly define "sustained reproductive success," the philosophy taken was that a female that maintained a calving interval of 425 d or less would be considered successful. Females failing to meet this criterion were considered to be at the end of their successful lifetime. Data were analyzed using methodology for survival analysis with grouped data. Fixed contemporary groups were modeled as being time dependent, reflecting the females exposed for breeding in the same herd-year-season. Sire effects were time independent and considered random. Also included in the analysis were time-independent covariates for maternal weaning weight and total maternal calving ease from the national cattle evaluation of the American Hereford Association. Records from females still successfully in production at the time of this analysis, those that were transferred, those with calving intervals less than 280 d, and those that were successful until becoming donor dams for embryo transfer were considered censored. A total of 36,866 females contributed to this analysis, with 14,143 of these having censored records. The median number of females in a contemporary group was 6. A total of 3,323 sires had daughters with records. The median number of daughters per sire was 7. Heritability of sustained reproductive success on the underlying scale estimated from these data was approximately 0.05. Additional data accumulated over time will improve this genetic evaluation. Sustained reproductive success is important to the commercial beef industry, and results from this evaluation are expected to enhance the assessment of economic value of Hereford seedstock.

Key words: beef cattle, genetic evaluation, reproduction, survival analysis

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INTRODUCTION

Dickerson (1970) contended that improving reproduction in beef cattle should be a major objective to increase production efficiency. The practice of culling nonpregnant females is a commonly recommended management tactic to increase production efficiency (Dziuk and Bellows, 1983; Azzam and Azzam, 1991). In many herds, it is the primary factor that determines the length of the productive life or longevity. To improve the genetic potential for successful reproduction, the Red Angus Association of America adopted an EPD for the probability that a cow calves annually through 6 yr of age. Use of this EPD has produced a positive genetic trend in it (Red Angus Association of America, 2010). However, inefficient use of contemporary group information and partial records are 2 problems that may limit current genetic evaluations for reproductive success. These problems can be addressed by using survival analysis to account for time-dependent contemporary groups and censored records (Ducrocq and Sölkner, 1994, 1998).

Cow longevity interests beef producers because of its effect on their profitability. Increasing the probability that a cow calves every year affects both the income

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and expense of the commercial cow-calf producer. Income is increased because more mature cows are in production. Increasing the age at which cows are culled reduces the expense because fewer heifers are needed to replace open cows. With fewer heifers needed as replacements, income is further increased because more calves can be sold. The countervailing concern is that older cows are at greater risk of mortality without their salvage value being returned. However, ages at which this loss is most likely to occur are well beyond the age at which most cows fail to sustain reproductive success (Núñez-Dominguez et al., 1992). Therefore, sustained reproductive success, in large part, determines longevity and longevity drives production efficiency. Thus, our goal was to produce a genetic evaluation indicative of sustained reproductive success.

MATERIALS AND METHODS

Animal Care and Use Committee approval was not obtained for this study because the data were accumulated by the American Hereford Association (**AHA**) as part of their breed improvement program.

Ten years ago, the AHA made a commitment to whole-herd reporting. This commitment has resulted in a starting point for accumulating the data needed for a genetic evaluation of fertility. To capitalize on this investment and make the resulting genetic evaluation as applicable as possible to the commercial industry, these records were examined to determine the age at which a female no longer calves annually (i.e, to find the number of parities after which each female first fails to reproduce annually with an imposed 60-d calving season).

Females considered in this analysis were born between 2001 and 2007, and only primiparous females entered the analysis. All females included in this analysis had at least 1 calf with a reported birth date and were required to have at least 2 paternal half-sibs with similar records. Heifers in a yearling contemporary group were assumed to remain members of that contemporary group until the time of their first breeding, with age at first calving (before 24 mo, 24 to 27 mo, 28 to 34 mo, and 35 to 38 mo) used to further stratify the yearling contemporary groups. Only females that calved for the first time before 39 mo of age contributed to this genetic evaluation. A genetic evaluation of heifer calving rate was conducted separately (D. W. Moser, Department of Animal Sciences and Industry, Kansas State University, Manhattan, personal communication). Here, females were required to first calve as members of primiparous contemporary groups of 3 or more individuals. An animal is a member of only 1 contemporary group in many genetic evaluations. However, culling policies and environmental factors change over time. Thus, after their first calving, cows were regrouped annually into new contemporary groups defined by herd and year.

The raw data for this analysis were birth dates of the reported calves. To explicitly define “sustained reproductive success,” the philosophy taken was that a female that maintains annual calving would be considered successful. This philosophy was codified as a rule requiring a calving interval of 425 d or less to be considered successful. The interval of 425 d was chosen because it allowed a cow to become bred early in a 60-d breeding season in one year and relatively late in the breeding season the next year without “failing.” If age at first calving was less than 24 mo, an allowance of an additional 30 d was made for the common practice of breeding yearling heifers to calve ahead of the cow herd. Thus, if a female calved first before it was 2 yr old, then its first calving interval could be 425 + 30 d and still be considered successful.

An integer value from 1 to 7 describes the phenotype of each female, indicating the number of years it was successful at calving annually. For some females, the number of parities over which they were reproductively successful is known to be greater than only a certain amount. However, the number of parities to failure is unknown for these females, and their records were considered right censored (Kachman, 1999). Here, cows that became donors, as evidenced by the registration of an embryo transfer calf within the year after their last calf, and cows that were transferred while otherwise being deemed successful were considered censored. Females deemed successful as of January 1, 2010, were also considered censored.

The statistical approach used in analyzing these data was that of survival analysis as implemented by Ducrocq and Sölkner (1994, 1998). Because reproductive successes were numbers of parities with relatively few possible integer values, the approach of Prentice and Gloeckler (1978) for discrete or grouped data, as discussed by Ducrocq (1999) and Ducrocq et al. (2010), was used in these analyses. Grouped data models are a special case of proportional hazard models in which failure times are grouped into intervals $T_i = [a_{i-1}, a_i]$, where $i = 1$ to r, with $a_0 = 0$ and $a_r = +\infty$. All failure times falling into the T_i interval are recorded as t_i (Mészáros et al., 2010). A detailed description and derivation of mixed models for discrete response variables is given in Ducrocq (1999). The initial model used was

$$\lambda_{ijk}(t) = 1 - \exp\{-\exp[\boldsymbol{C}_i(t) + \mathbf{u}_j + \xi_k]\},$$

wherein $\lambda(t)$ represents the hazard function (instantaneous probability of reproducing) for a cow at parity t; $\boldsymbol{C}_i(t)$ represents the time-dependent contemporary group effects; and $\mathbf{u}_j$ represents the time-independent random effect of sire of female assumed to be normally distributed, with mean 0 and variance $\mathbf{A}\sigma_u^2$, where $\mathbf{A}$ is the additive relationship matrix between sires and σ_u^2 is the sire variance; $\xi_k = \log(-\log\alpha_k)$, and

$$\alpha_k = \exp\left[\int_{\tau_{k-1}}^{\tau_k} \lambda_0(\omega)\mathrm{d}\omega\right],$$

where λ_0 is the baseline hazard function, ω is the conditional probability of success in parity τ_k, and τ_k is parity k.

Inspection of the results from this model (not shown) indicated effects of voluntary culling based on maternal performance and effects of involuntary culling for failure to rebreed resulting from dystocia. To remove effects not related to the innate reproductive ability of the cow, the model was augmented with time-independent linear covariates for total maternal calving ease EPD and maternal weaning weight EPD. Results from this augmented model provided an evaluation of sires that was complementary to their breeding values for production traits. Equations [9] and [19] of Yazdi et al. (2002) were used to calculate the effective heritability and reliability of the genetic evaluation of each sire, respectively.

RESULTS AND DISCUSSION

Length of productive life of a cow, as defined by the time from first calving to death or culling, may be affected by both voluntary and involuntary disposal. Traditional analyses of length of productive life have modeled the difference between age at first calving and age at disposal as the dependent variable (e.g., Forabosco et al., 2002; Szabó and Dákay, 2009). Here, the focus is toward improving reproductive potential as a means of increasing production efficiency and profitability by addressing a primary cause of voluntary disposal, culling of open cows (Arthur et al., 1992; McDermott et al., 1992). If open cows are not culled, they represent a substantial opportunity cost and reduction in efficiency. However, the AHA whole-herd reporting system does not explicitly require reporting of the reproductive status of each cow or information regarding the success or failure of each insemination, and the decision to cull or retain an open female is made by its owner. Thus, the data were manipulated to reflect herd life under a management system that included a 60-d calving season (i.e., a maximum intercalving period of 425 d) and absolute culling of cows not calving during that period. If data indicating success of failure of each insemination to establish pregnancy were available, an approach to fertility similar to that of González-Recio et al. (2005) could be an alternative to the strategy used in this research.

Following the method of van Arendonk (1986), this new genetic evaluation was intended to provide breeders with new information that is complementary to existing evaluations for production traits. In addition to contemporary group effects, the analytical model was intended to account for voluntary disposal of females caused by poor performance as dams (Ducrocq et al., 1988b) and failure to rebreed in a timely manner because of environmental effects of dystocia (Rogers et al., 2004; Tarrés et al., 2005; Szabó and Dákay, 2009). To the extent that these traits are genetically correlated with sustained reproductive success, this approach may be less than optimal and a multivariate analysis would be preferred. However, this preferred approach can be computationally demanding and infeasible (Tarrés et al., 2006; Van Melis et al., 2010). Further, estimates of the additive genetic variance of longevity have been insensitive to the magnitude of genetic correlations with indicator traits (Tarrés et al., 2006; Van Melis et al., 2010). Here, the estimated heritability of sustained reproductive success estimated was virtually identical despite whether the model included the linear covariates.

A total of 36,866 females contributed to these analyses. Of these, 14,143 (38.4%) had records that were right censored. Of those females whose records were considered censored, 76 were due to reported intercalving periods less than 280 d, 4,212 were due to transfer between herds, and the remainder remained successfully in production at the end of 2009.

In forming contemporary groups, females subjected to perceptibly the same environmental circumstances during the inferred breeding season were considered members of a contemporary group. Initially, heifers were assigned to contemporary groups for sustained reproductive success based on their age at first calving and yearling contemporary group. There were 3,978 heifers that first calved at less than 24 mo of age, 28,356 heifers that first calved at 24 to 27 mo, 2,739 heifers that first calved at 28 to 34 mo, and 1,793 heifers that first calved at 35 to 38 mo. The median number of females in primiparous contemporary groups was 6, with an interquartile range from 4 to 11 (Figure 1A). Subsequently, contemporary groups were formed from all multiparous females in the same herd-year. Despite attrition over parities, the median number of cows in subsequent contemporary groups remained at 6, with a slightly expanded interquartile range from 3 to 13 (Figure 1B). In an evaluation in which contemporary groups were assigned early in life and any subsequent contemporary group definition subdivided the original groups, the original groups could only become smaller. However, considering females of various ages exposed to similar circumstances at the time of breeding as contemporaries in time-dependent groups results in more parsimonious parameterization; thus, the precision of all parameter estimates is increased (Ducrocq et al., 1988a).

A total of 3,014 sires with at least 1 daughter had a known failure time. Shown in Figure 2 is the distribution of paternal half-sib family sizes for daughters with uncensored records. An additional 309 sires were represented in the data, but only by daughters with censored records. Overall, the median and mean paternal half-sib family sizes were 7 and 11, respectively. The effective heritability of sustained reproductive success estimated from these data was approximately 0.05. Robertson (1959) indicated the optimal family size for the estimation of heritability with data arising from half-sib families to be approximately $4/h^2$. Thus, the present low estimate of heritability suggests that more accurate genetic evaluations might be obtained if fam-

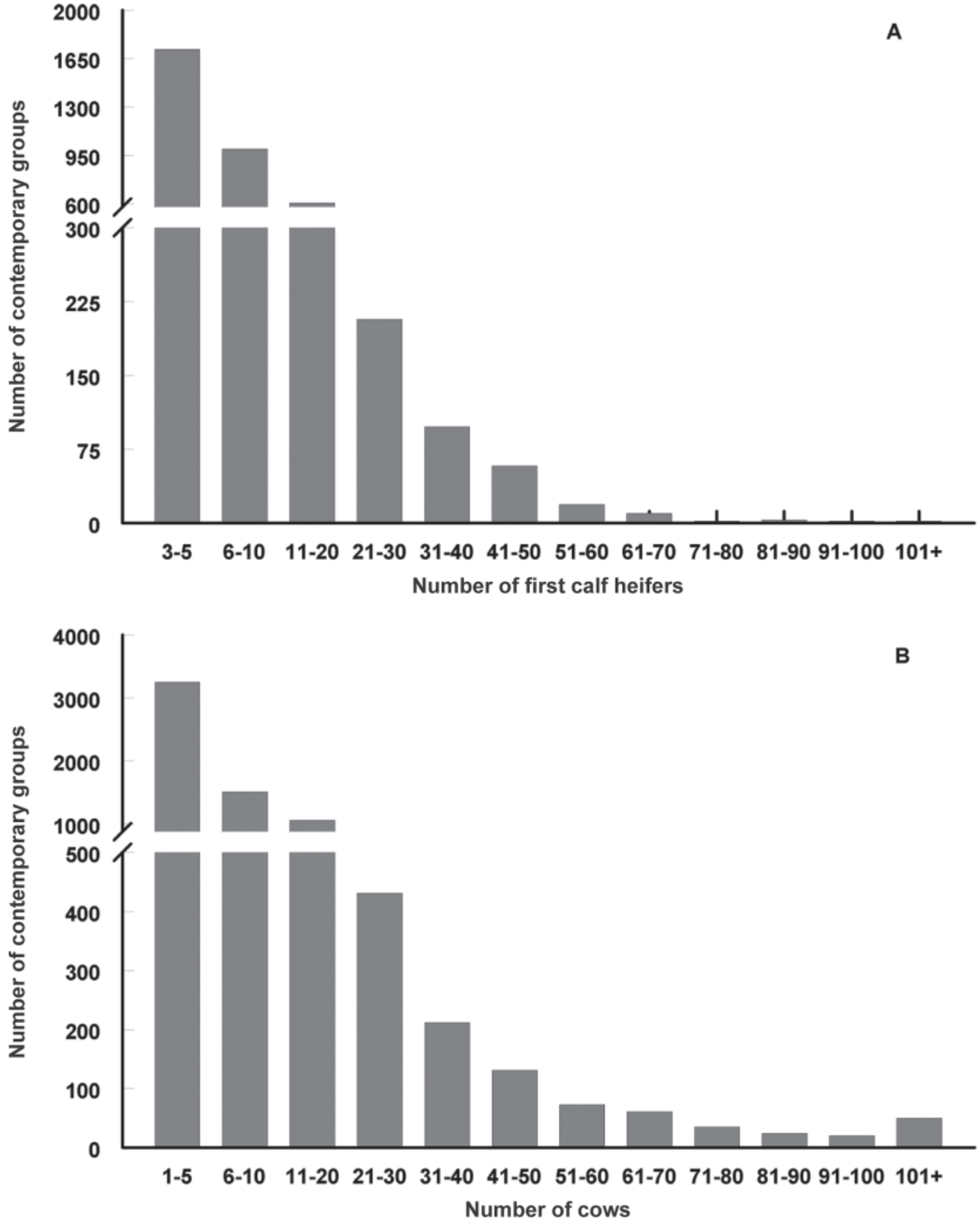

Figure 1. Distribution of contemporary groups as a function of the number of primiparous heifers (A) and multiple-parity cows (B) in them.

ily sizes were larger, perhaps through greater use of AI in the Hereford breed. However, it is noteworthy that a greater genetic advance may be achieved at somewhat more modest family sizes and a greater number of sires evaluated (Robertson, 1957). Other estimates for conceptually related traits of cows range from slightly more than 0.20 to about 0.02 in both beef (Snelling et al., 1995; Donoghue et al., 2004; Rogers et al., 2004) and dairy (Ducrocq et al., 1988b; Vollema and Groen, 1998) cattle.

Results of this genetic evaluation can be presented on 4 alternative scales—risk ratio (**RR**), sign-reversed EBV expressed in genetic SD units, time to 50% failure (**FT**), and percentage of daughters sustaining successful reproductive performance through their fourth calf (**S4**)—to aid understanding. Thus, an average sire would have RR = 1, SD = 0, FT = 817 d, and S4 = 12.9%. A sire with more fertile daughters would have an RR less than 1, a positive SD, and greater values for FT and S4. A sire with fewer fertile daughters would have an RR greater than 1, a negative SD, and smaller values for FT and S4. The relationships between these measures of breeding value are shown in Figure 3. For sires with 25 or more daughters included in the data, the range of SD was from −2.4 to +1.3.

Reliability (a measure of accuracy) of the EBV is based on the number of records and the genetic variance. A sire must have approximately 90 daughters

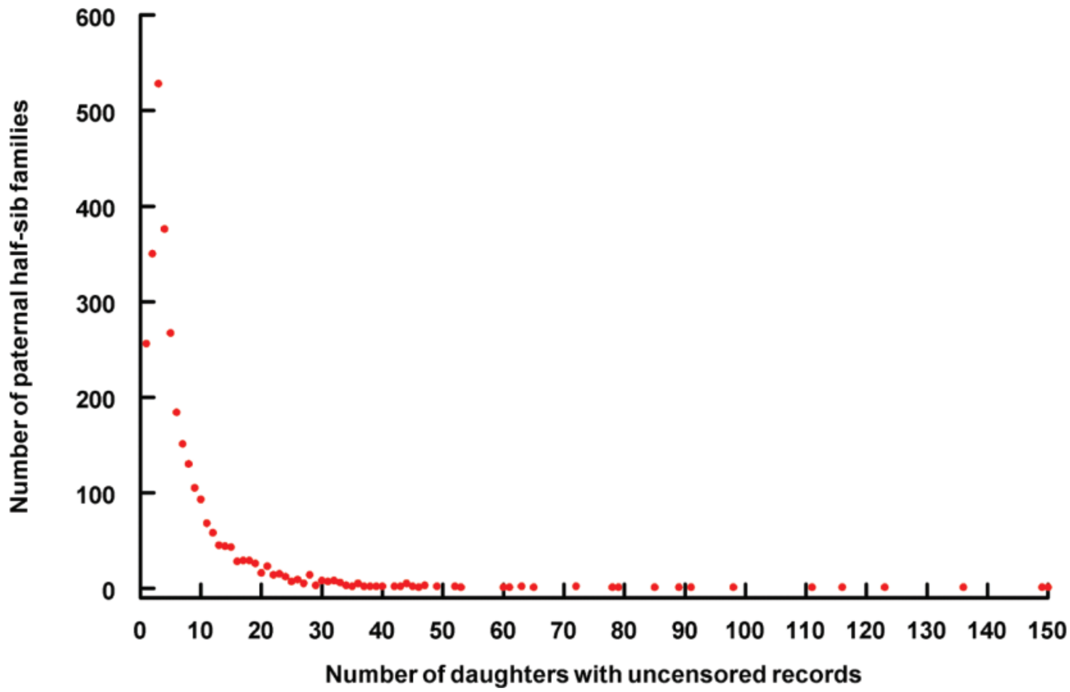

Figure 2. Distribution of paternal half-sib family sizes for daughters with a known failure time. Color version available in the online PDF.

with records to achieve a reliability of 0.5, and only 34 sires have enough daughters to rise above this threshold. A graph of the relationship between reliability and number of daughter records is shown in Figure 4.

The survival analysis accounts for failure to reproduce for reasons that are deemed unrelated to inherent fertility. Foremost among these would be their being culled for low productivity. In addition, those females that experience calving difficulty are more likely to experience an extended postpartum interval as a consequence (Rogers et al., 2004; Tarrés et al., 2005; Szabó and Dákay, 2009). This extended postpartum period would make them more likely to appear as though they had not sustained reproductive success, irrespective of

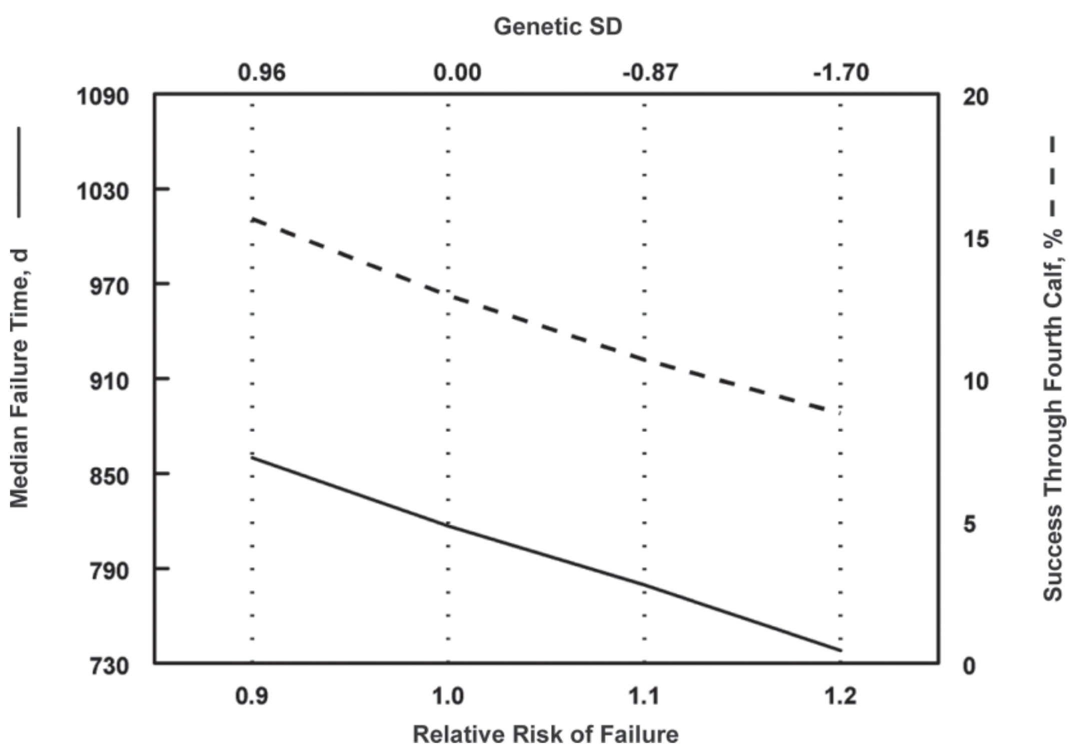

Figure 3. Relationships between alternative expressions of breeding value for sustained reproductive success by daughters of Hereford sires.

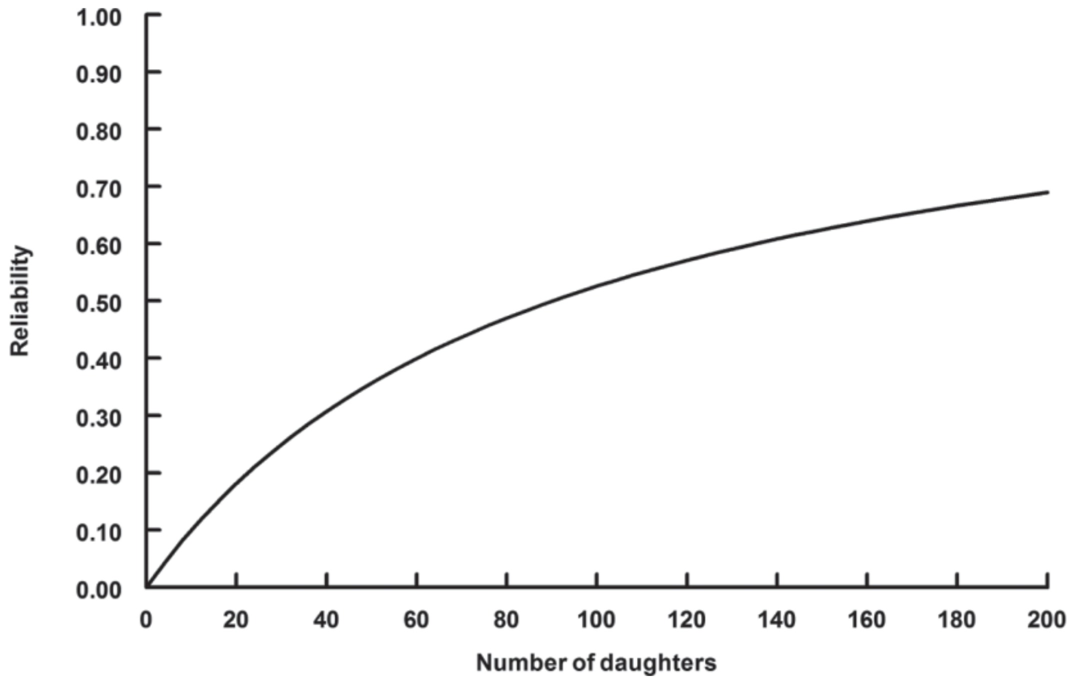

Figure 4. Reliability (a measure of accuracy) of the predicted breeding value of a sire as a function of the number of its daughters.

their innate fertility. Thus, the EPD for maternal weaning weight and total maternal calving ease were incorporated into the genetic evaluation. Unit increases the EPD for maternal weaning weight, and the total maternal calving ease EPD decreased the time-independent risk of failure by approximately 2% ($P < 0.01$).

Given that the productive life of a Hereford cow can easily exceed 5 yr and that collection of the necessary data began in 2002, the process remains in its early stages. Looking ahead, there is no doubt that more data accumulated over time will improve this genetic evaluation. As these data accumulate, there will also be opportunities to refine this genetic evaluation with better quality data and improved methods of prediction. Breeders are encouraged to be conscientious in reporting birth dates of all calves (live or dead), disposal dates, and reasons for disposal to AHA. Because fertility, which manifests as sustained reproductive success and a greater length of productive life, is of great economic importance to the commercial beef industry, results from this evaluation and the evaluation of heifer calving rate will lead to revisions of the Baldy Maternal Index and Brahman Influence Index published by the AHA.

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