Profitability Index For Sires

J. J. Bakker
Cornell University

R. W. Everett
Cornell University

L. Dale Van Vleck
University of Nebraska-Lincoln, dvan-vleck1@unl.edu

Profitability Index For Sires

J. J. BAKKER,[1] R. W. EVERETT, and L. D. VAN VLECK
Department of Animal Science
Cornell University
Ithaca, NY 14853

ABSTRACT

A profitability index for evaluation of sires on predicted lifetime production of daughters and their progeny was developed from sire evaluations for milk yield, fat yield, and stayability. Indexes of milk and stayability for first lactations were used to calculate proofs for stayability in later lactations. Predicted milk yields were adjusted to the actual age when the records would be made. Breed averages, which are required for the procedure, were calculated from records of daughters of 1192 Holstein-Friesian sires in the Northeast Artificial Insemination Sire Comparison. Proofs for stayability through the first lactation and indexes for stayability in later lactations were used to describe opportunities for genes of the sire to be expressed in a specified year of first or later generations over 15 periods, 13-mo each. These opportunities, when discounted and summed, give the expected number of lactations from one conception. Multiplying the expected number of lactations by milk and fat proofs and net profits per kilogram estimates total economic returns from a single conception. Examples show that stayability may be important in evaluation of sires. The correlation between milk proof and economic evaluation was only .77.

INTRODUCTION

Goals of genetic progress in production traits and of minimal total maintenance costs of testing bulls are reasons that evaluation of young sires for artificial insemination is based usually on first lactation performance of their daughters. Total returns from investment in semen, however, are influenced by lifetime production of the daughters, which is determined by both milk production and stayability. Stayability is defined as the fraction of progeny surviving to a certain lactation with stayability at the start of the first lactation 100%.

The literature (13, 15, 16, 17, 19, 25) indicates that direct selection for survival is not worthwhile, but results of Van Vleck (22), Burnside (2), and Korver (12) indicate there are significant differences among sires in lifetime production of their daughters. Everett et al. (7) found genetic correlations ranging from .20 to .55 between production in first lactation and survival at different ages. Other researchers found similar correlations (18, 19). These correlations can be used to calculate indexes from first lactation information to predict lifetime production or lifetime profits of progeny of AI sires. Johnson et al. (11) developed an economic index for selection of sires. Lifetime production of a daughter was a product of the sire's transmitting ability for milk production and expected number of lactations. Survival from one lactation to another was assumed to be dependent on the sire's proofs for conformation (type rating) and milk production. The value of lifetime production was calculated with a quadratic index (26) from the sire's milk and fat proofs. The relationships between stayability and daughters' conformation and milk production used in that index (11) were described by Schaeffer and Burnside (19) and were based on survival of 2-yr-old Canadian Holstein-Friesian cows to become 3-yr-olds. Of the variance in that economic index, 99% could be explained by the sire's proof for milk and fat (23). Although Johnson et al. (11) used the relationship between conformation and survival, other researchers (7, 12) have not found a significant relationship between type and survival rates.

Survival rates of daughters of sires also have been used in the calculation of income over investment in semen (6). This method, however,

Received March 28, 1979.

[1] Department of Animal Breeding, Agricultural University, Wageningen, The Netherlands.

assumes equal expected survival rates for daughters of all sires. Differences in income are dependent on differences in semen cost, conception rate, and milk proofs. These three variables were assumed to be the most useful predictors of differences among sires in economic returns. Gill and Allaire (9) noted that economic returns could be described best by maximizing profits per day of herd life of daughters of AI sires. Expected responses to selection for this trait are greatest with indexes of age at first calving and milk per day in the first lactation and profit per day in the first lactation.

Stayability at 39 mo, which is the fraction of cows beginning a first lactation and surviving to start the second lactation, is easy to measure, and the results are known at the same time as the sire's proof for milk production. Correlations with stayability in later lactations are high. Everett et al. (7) reported genetic correlations between stayability in first and later lactations of .94 for first to second and .58 for first to sixth, while Schaeffer and Burnside (9) reported a correlation of .93 between stayability at different ages for the first three lactations.

The purpose of this study was to develop an economic index for sires from milk and fat proofs and differences in survival during the first lactation. To estimate survival during later lactations, correlations between survival at different ages and correlations between milk production in the first lactation and survival at different ages up to six lactations (7) were used. The products of predicted stayability in each lactation with age-corrected milk proofs, when summed, are a prediction of lifetime production of daughters of a sire. The method of calculation of the economic index is described, and two examples are given. The correlation was calculated between the index and milk proofs, but no other comparisons were with existing sire evaluation methods.

MATERIALS AND METHODS

Economic indexes were computed from Northeast AI Sire Comparison (NEAISC) proofs of milk production and stayability of 1192 Holstein sires used in New York and New England. The proofs of these sires were on at least 10 daughters that started their first lactations between 20 and 35 mo of age. All records were between 1967 and 1977 and were adjusted to 305-day mature equivalent. Only records of between 907 kg and 15,876 kg of milk and 32 kg and 680 kg of fat were included. These were assumptions in developing the profitability index. 1) The ratio of male to female calves is 1:1, .80 of conceptions result in birth, and .85 of heifer calves born alive survive to freshening (20, 27). Therefore, .34 of conceptions result in a female reaching the milking herd. 2) Bull calves and heifer calves of all sires have equal salvage value. 3) The calving interval is 13 mo and is the same for daughters of all sires. 4) Culling is at the end of each lactation. 5) Heritabilities of milk production and stayability are .25 and .097, which correspond with the variance ratios (σ_e^2/σ_s^2) within and among sires of 15 for milk production and 40 for stayability (7). 6) Expected actual lactation milk yield can be calculated by multiplying mature equivalent transmitting abilities of sires by reciprocals of Holstein age correction factors, which are .73, .85, .95, .98, .99, and 1.00 for the expected midpoints of calving ages for first through sixth lactations, (R_1 to R_6) (6). 7) Profits for 15 periods of 13-mo (corresponding to average calving interval) after conception of the mate of the bull and discounted back to conception time at 10% for each 13-mo period are appropriate indicators of total profits. 8) Gross value of milk is \$.223/kg with a change in value of \$.022/kg of milk for a change in fat test of 1% (i.e., each kg of fat is worth \$2.20) (4). 9) Feed cost for each kg of milk is \$.0617 plus \$.0088 for each 1% of fat increase. These costs are based on a requirement of .3084 kg of total digestible nutrients (TDN) per kg of milk at 3.6% butterfat plus .044 kg of TDN for each 1% of fat increase (14) and a price of feed of \$.20 per kg of TDN (4). The foregoing calculation results in a net income per kg of milk of \$.1613 at 3.6% butterfat plus \$.0133 per percent difference from the base fat test of 3.6%. 10) According to the method developed by Wilton et al. (26), income from milk production can be predicted as Income = $P[v_1 + v_2(t-t_b)]$ where P = total milk production, v_1 = \$ per kg of milk, v_2 = \$ per percent above the base fat test, t = fat test, and t_b = base fat test. The milk, fat, and test averages used were 6772.73 kg, 244.93 kg, and 3.6%. These economic relationships result in a predicted net income per lactation of NI = 6758.49 + (SC_m)

(.1134) + (244.94 + SC_f)(1.330) where SC_m and SC_f are sire proofs for milk and fat in kg. 11) The breed average for stayability at 39 mo (S_2) was derived from the data set of daughters of 1192 Holstein-Friesian sires while averages at 52, 65, 78, and 91 mo (S_3 to S_6) of .860, .708, .554, .432, and .324 were based on (8, 1). Stayability at 26 mo (S_1) is 1 for all sires.

To determine discounted net profit of milk production of progeny of service sires, the method Everett (6) developed to determine the value of semen was modified to use sire proofs for stayability as well as for milk and fat. Sires' stayability proofs for 52, 65, 78, and 91 mo of their progeny were calculated from separate indexes, each using the sires' milk and first lactation stayability proofs as estimators.

INDIVIDUAL STAYABILITY PROOFS

Variances and correlations to develop the coefficients to predict stayability up to six lactations (the limit of the correlations reported in (7)) are in Table 1. The indexes are of the form

$$I_t = b_{t1}X_m + b_{t2}X_{s1} ,$$

where

I_t is the index for stayability at age t (t=2,. . ., 6 at 39, 52, 65, 78, and 91 mo; I_1 = 0 for all sires),

X_m is the sire's daughters average for milk, and

X_{s1} is the sire's daughter average for stayability at 39 mo.

Both X_m and X_{s1} are adjusted for herd-year-season effects. If the correction for herd-year-season effects in the sire comparison evaluation is correct, averages of daughters' for milk and stayability can be estimated by multiplying milk and stayability proofs by $(n+15)/n$ and $(n+40)/n$, respectively. The b's are defined by the selection index equations:

$$b_{t1}V(X_m) + b_{t2}Cov(X_mX_{s1}) = Cov(X_mT_t)$$

$$b_{t1}Cov(X_mX_{s1}) + b_{t2}V(X_{s1}) = Cov(X_{s1}T_t),$$

where T_t = $.5G_{st}$ is half the genetic value of the sire for stayability at time t as a deviation from the average stayability.

TABLE 1. Variances and correlations used to calculate selection index coefficients to predict stayability at different ages.

Age (t)[a]	V_t[b]	$r_{g_{M,S_t}}$[c]	$r_{g_{S_{39},S_t}}$[d]
39	.3842	.27	1.00
52	.4665	.41	.94
65	.4995	.55	.82
78	.4625	.51	.62
91	.4330	.51	.58

[a] t is in months.

[b] Variation of stayability records from Everett et al. (7).

[c] Genetic correlations between milk production in first lactation and stayability at different ages from Everett et al. (7).

[d] Genetic correlations between stayability in first lactation and later lactations from Everett et al. (7).

The Expected Number of Lactations

The sires' genetic values for stayabilities at different ages and the sires' milk and fat proofs are used in a model that describes the probabilities that genes of the sire will be expressed in descendants of a certain generation (6, 24). Due to the particular way the model is built, the sum of these probabilities is equal to the total number of lactations expected from one conception. The discounted total number of lactations (TNL) is calculated as

$$[\mathbf{E}(\mathbf{j}_1 + \ldots + \mathbf{j}_m)']'\mathbf{Q1} ,$$

where **E** is an $n \times n$ matrix describing survival rates and age adjustment factors for each daughter group in which the rows and columns each correspond to a 13-mo lactation period, with time of birth corresponding to the first row and column, and n is the number of discounted lactations per generation. The $n \times 1$ vectors $\mathbf{j}_k$ ($k=1,m$) contain the probable expression of the genotype from the preceding generation, and m is the number of generations. The $n \times n$ diagonal matrix **Q** discounts the economic value of the genes in each lactation and generation, and **1** is an $n \times 1$ vector of ones for summing.

Nonzero terms in the E matrix are products of stayability proofs [the sum of breed averages (S_t) and index values (I_t)] and reciprocals of lactation age correction factors (R_t).

The procedure and notation are as described by Everett (6) and Van Vleck and Everett (24) except that in the **E** and **D** matrices, $S_i + I_i$ is substituted for S_i, where S_i is the breed average stayability at age i, and I_i is the predicted difference in stayability from breed average for daughters of the sire. Thus, probabilities of survival are appropriate for daughters of that sire, and

$$
\mathbf{E} = \begin{bmatrix}
0 & 0 & 0 & \cdots & 0 \\
0 & 0 & \cdot & \cdots & \cdot \\
(S_1\quad)R_1 & 0 & \cdot & \cdot & \cdot \\
(S_2+I_2)R_2 & (S_1\quad)R_1 & \cdot & \cdot & \cdot \\
(S_3+I_3)R_3 & (S_2+I_2)R_2 & (S_1\quad)R_1 & \cdot & \cdot \\
(S_4+I_4)R_4 & \cdot & \cdot & & \cdot \\
(S_5+I_5)R_5 & \cdot & \cdot & & \cdot \\
(S_6+I_6)R_6 & \cdot & \cdot & \cdot & \cdot \\
0 & (S_6+I_6)R_6 & \cdot & \cdot & \cdot \\
0 & 0 & (S_6+I_6)R_6 & \cdot & \cdot \\
\cdot & \cdot & 0 & \cdot & \cdot \\
\cdot & \cdot & \cdot & & \cdot \\
0 & 0 & 0 & \cdots & 0
\end{bmatrix}
$$

The probable expression of genes in the F_1 is given by j_1, where $j_1' = (h\ 0\ 0\ 0 \ldots\ldots 0)$, and $h = .34$, the fraction of calves from one conception expected to reach the milking herd. The expression of genes into the kth generation can be written as $j_k = .5hDj_{k-1}$, where .5 represents the halving of the genetic contribution from one generation to the next, which applies to genes for both production and stayability, and where **D** is an $n \times n$ matrix with each column representing probabilities of survival of a corresponding generation ($l, \ldots, m$) in a specified year.

$$
\mathbf{D} = \begin{bmatrix}
0 & 0 & 0 & \cdots & 0 \\
0 & 0 & \cdot & \cdots & \cdot \\
S_1 & 0 & \cdot & \cdot & \cdot \\
S_2+I_2 & S_1 & \cdot & \cdot & \cdot \\
S_3+I_3 & S_2+I_2 & S_1 & \cdot & \cdot \\
S_4+I_4 & \cdot & \cdot & \cdot & \cdot \\
S_5+I_5 & \cdot & \cdot & \cdot & \cdot \\
S_6+I_6 & \cdot & \cdot & \cdot & \cdot \\
0 & S_6+I_6 & \cdot & \cdot & \cdot \\
0 & 0 & S_6+I_6 & \cdot & \cdot \\
\cdot & \cdot & 0 & \cdot & \cdot \\
\cdot & \cdot & \cdot & \cdot & \cdot \\
\cdot & \cdot & \cdot & \cdot & \cdot \\
0 & 0 & 0 & \cdots & 0
\end{bmatrix}
$$

The $n \times n$ discounting matrix **Q** is derived from the technique described by Hill (10).

$$
\mathbf{Q} = \begin{bmatrix}
1/(1+x)^2 & & & & 0 \\
& 1/(1+x)^3 & & & \\
& & 1/(1+x)^4 & & \\
& 0 & & \ddots & \\
& & & & 1/(1+x)^{n+1}
\end{bmatrix}
$$

The interest rate is x and in examples is 10% per 13 mo. The scalar resulting from addition of the n (=15) discounted expressions of the genes from each 13-mo period is equal to the discounted expected total number of lactations. Multiplication of TNL by expected net income per lactation (NI) gives the expected net profits of one conception — the profitability index.

RESULTS

Two Holstein-Friesian bulls (A and B with registration numbers 1540036 and 1510178) were evaluated and compared with a zero

bull to illustrate the magnitude of differences that may be expected and the influence the stayability proof may have on a sire's economic evaluation. Results are in Table 2. Stayability and milk comparisons from first lactations and correlations in Table 1 were used to compute the stayability indexes (I_t) in Table 2a. The first columns of the **E** matrices for the two sires (Table 2b) show the expected difference in mature-equivalent adjusted survival decreases from .782 − .704 = .078 at 39 mo of age to .344 − .315 = .029 at 91 mo. The fractions of genes expected to be expressed over seven generations, values equal to total number of lactations expected, are in Table 2c. These fractions are the outcome of the sum

$$E[\sum_{k=1}^{7} (.5)(.34)Dj'_{k-1}]1' ,$$

where j'_1 = (.34 0 0 . . . 0), and $1'$ = (1 1 . . . 1). The total sum of these fractions, which is the total number of expected lactations, is in Table

TABLE 2. Comparison of the economic evaluation of two sires.

A. Sire comparisons for first lactation stayability, milk, fat, and stayability index values for later lactations (I_3 to I_6).

Sire	Stay. fraction	Sire proof (kg)		Stayability indexes (fraction)					
		Milk	Fat	I_1	I_2	I_3	I_4	I_5	I_6
A	.0597	317.5	−2.72	.0	.0597	.0399	.0352	.0247	.0196
B	−.0315	204.1	14.97	.0	−.0315	−.0194	−.0169	−.0118	−.0093

B. First column of the E matrix.

Sire	Time (mo) after birth of first generation									
	0	13	26	39	52	65	78	91	104	. . .	182
A	0	0	.730	.782	.711	.577	.452	.344	0	. . .	0
B	0	0	.730	.704	.654	.524	.416	.315	0	. . .	0

C. Expected expression of genes in a period corresponding to 15 13-mo lactations after one conception.

Sire	Time (mo) after birth of first generation														
	0	13	26	39	52	65	78	91	104	117	130	143	156	169	182
A	0	0	.248	.266	.368	.448	.511	.548	.479	.504	.435	.377	.325	.282	.245
B	0	0	.248	.239	.349	.406	.458	.492	.413	.430	.363	.312	.264	.225	.192

D. Expected number of lactations and economic evaluation.

Sire	No. lactations	No. discounted lactations	Economic evaluation ($)	Deviation from avg sire ($)	Income due to production as deviation from avg sire ($)	Income due to stayability as deviation from avg sire ($)
A	5.036	2.264	2546.03	264.47	67.67	196.80
B	4.391	2.004	2275.02	−6.54	89.96	−96.50
Avg Bull	4.593	2.089	2281.56	0		

2d. As the numbers of these expected lactations have to be discounted, each is multiplied by the corresponding discount factor from the Q matrix. When a 10% discount rate per 13 mo is used, the discount factors vary from .909 to .239 with discounting to the moment of investment in semen of the service sire. This results in a sum of discounted lactations of 2.264 and 2.004 for sires A and B. These factors when multiplied by net profit per lactation result in the final economic evaluations in Table 2d. The separation of the fractions of profit due to production of milk and fat with breed average stayability, and stayability, with zero production proofs, shows that the potential impact of stayability on profitability may be as great as the influence of the producing capacity of the daughters and later progeny.

The correlation between milk proof and economic evaluation was .77, between stayability in the first lactation and economic evaluation .80, and between milk proof and stayability in the first lactation .30, as was used in the calculation of stayability indexes. The correlations were from evaluations for the 1192 Holstein sires.

DISCUSSION

Some desirable properties of an index for selection of service sires should be (23) a) to minimize errors of prediction or the expected squared difference between total merit and the index, b) to maximize the correlation between total merit and the index, c) to maximize the average genetic value of selected sires, and d) to maximize the probability of selecting the animal with the higher merit from a pair of animals. Other properties an index should have, but which can be at variance with properties (a to d), are (21) e) it must be in units which are understandable by the dairyman, f) it must use information which can be obtained easily and without great cost, and g) it can be calculated without great cost. First of all, the choice of sources of information is important in meeting these characteristics. In the index which has been developed, only proofs for milk, fat, and stayability from first lactation information are used. Other variables that could be used in an economic evaluation are differences in rearing rates of heifer calves, differences in age at first calving between daughter groups, differences in conception rates and calving intervals of daughters of sires, differences in health costs, differences in value of bull calves and replacements between daughter groups, and differences in average weight and feed cost between daughter groups.

The importance of differences in age at first calving has been reported (9). This trait cannot be used in the present model. Differences in conception rates of daughter groups could be added to the model, for example, by the technique described by Van Vleck and Everett (24), while semen cost of the sire itself simply can be subtracted from the final result. Differences in weight, prices of bull calves and replacements, and differences in feed costs would be especially important for evaluation of dual-purpose cattle.

The literature (13, 15, 16, 17, 19, 25) indicates that genetic variance of stayability or survival to later lactations is almost zero. Therefore, genetic correlations between milk production and stayability may be biased strongly by management factors that may be different between daughter groups. How it is possible for researchers to find in the same data set a low heritability for survival and a high genetic correlation between milk production and survival [see, for example, Robertson and Barker (18)] is not explained but could be due to increased sampling variance when heritability is small. Apparently milk yield is an important genetic determinant of survival, so that the relationship between these two variables may be used to estimate total economic returns of a conception when this leads to a better estimation of these returns than the use of milk and fat yield alone without consideration of survival differences.

The correlation between first lactation milk yield and stayability was .30. In Europe, correlations have been higher; Korver (12) found .543 and mentioned even higher correlations. Robertson and Barker (18) reported correlations of .67 to .92. These correlations, even though possibly biased by selection and management, may be useful in predicting stayability of the daughters of a bull, but such biases could not be expected to follow the pattern of genetic halving that was used in predicting stayability in future generations.

Stayability of the daughters can play an important role in economic evaluation of a sire. There was no attempt to determine if this

method is better than other economic evaluations. The reliability of the index could be determined from the theoretical correlation between the true breeding value for lifetime profits and the index, but through multiplication of the sire's evaluation for milk production with squared and higher order powers of the evaluation for stayability (the **E** matrix times the **D** matrix and the repeated use of rows of the **D** matrix in determining the j vectors), calculation of the correlation becomes difficult. A practical test of the index would be to calculate the correlation within sire between two randomly selected daughter groups of each sire to give an indication of the method's reliability. According to Korver (12), daughter groups of at least 100 animals would be needed. This test was not attempted.

Stayability in later lactations was estimated from milk yield and stayability information in the first lactation. The correlation between type evaluation and stayability also has been used (11). The correlation between type and stayability has been low and different between populations, but type evaluation could be used in such a way that, for example, only legs and udder traits would be used. Burnside and Wilton (3) found a correlation of .28 between sire evaluations for mammary system and for first lactation culling.

Maintenance costs have not been considered. Although it probably makes little difference, these costs should be assigned, since different stayabilities result in different maintenance costs. A more difficult problem is how to assign replacement costs to groups with different predicted stayabilities.

In the examples of the profitability index for two bulls, a planning horizon of 15 times 13 = 195 mo was used. Usually most female descendants of a cow will stay on the same farm. According to Cunningham and Ryan (5), about 98% of all the expected genetic benefits are reached in 15 yr depending somewhat on the discount rate.

The results show that the stayability of a bull's daughters has a potentially large impact on profitability. Further analyses of economic evaluations may show that indexes using information in addition to first lactation milk yield, fat yield, and stayability may be even more useful in sire selection for profitability.

ACKNOWLEDGMENT

This research was supported, in part, by a grant from Eastern Artificial Insemination Cooperative, Inc., Ithaca, NY.

REFERENCES

1 Allaire, F. R., H. E. Sterwerf, and T. M. Ludwick. 1977. Variations in removal reasons and culling rates with age for dairy females. J. Dairy Sci. 60:254.
2 Burnside, E. B. 1967. Do sires differ in dollar returns for production? Holstein-Friesian J. 30:26.
3 Burnside, E. B., and J. W. Wilton. 1970. Anatomical traits as they relate to productive utility. J. Dairy Sci. 53:837.
4 Cornell Dairy Records Processing Lab. 1977. Management factor summary 07/01/77.
5 Cunningham, E. P., and J. Ryan. 1975. A note on the effect of the discount rate and the length of the accounting period on the economic value of genetic improvement in cattle populations. Anim. Prod. 21:77.
6 Everett, R. W. 1975. Income over investment in semen. J. Dairy Sci. 58:1717.
7 Everett, R. W., J. F. Keown, and E. E. Clapp. 1976. Relationships among type, production, and stayability in Holstein cattle. J. Dairy Sci. 59:1505.
8 Everett, R. W., J. F. Keown, and E. E. Clapp. 1976. Production and stayability trends in dairy cattle. J. Dairy Sci. 59:1532.
9 Gill, G. S., and F. R. Allaire. 1976. Genetic and phenotypic parameters for a profit function and selection method for optimizing profit in dairy cattle. J. Dairy Sci. 59:1325.
10 Hill, W. G. 1974. Prediction and evaluation of response to selection with overlapping generations. Anim. Prod. 18:117.
11 Johnson, L. P., E. B. Burnside, H. M. Stewart, R. L. Lang, and K. Thomson. 1977. Evaluation of a service sire index for proven bulls in artificial insemination. J. Dairy Sci. 60 (Suppl. 1):130.
12 Korver, S. 1977. Foktechnische en economische aspecten van de gebruiksduur van milkvee. Pub. no. 3. Afdeling Agric. Econ. Faculteit voor Diergeneeskunde. Univ. Utrecht.
13 Miller, P., L. D. Van Vleck, and C. R. Henderson. 1967. Relationships among herd life, milk production, and calving interval. J. Dairy Sci. 50:1283.
14 National Research Council. 1971. Nutrient requirements of dairy cattle. 4th rev. ed. Nat. Acad. Sci., Washington, DC.
15 Parker, J. B., N. D. Bayley, M. H. Fohrman, and R. D. Plowman. 1960. Factors influencing dairy cattle longevity. J. Dairy Sci. 43:401.
16 Plowman, R. D., and R. F. Gaalaas. 1960. Heritability estimates of longevity in Holstein cattle. J. Dairy Sci. 43:877.
17 Rendel, J. M., and A. Robertson. 1950. Some aspects of longevity in dairy cows. Empire J. Exp. Agric. 18:49.
18 Robertson, A., and J.S.F. Barker. 1966. The correlations between first lactation milk production

and longevity in dairy cattle. J. Anim. Prod. 8:241.
19 Schaeffer, L. R., and E. B. Burnside. 1974. Survival rates of tested daughters of sires in artificial insemination. J. Dairy Sci. 57:1894.
20 Speicher, J. A., and R. C. Hepp. 1973. Factors associated with calf mortality in Michigan dairy herds. J. Am. Vet. Med. Assoc. 162:463.
21 Stewart, H. M. 1975. Culling decisions in commercial dairy herds: a dynamic programming approach. M.S. thesis, Univ. Guelph, Ontario, Canada.
22 Van Vleck, L. D. 1964. First lactation performance and herd life. J. Dairy Sci. 47:1000.
23 Van Vleck, L. D. 1974. Notes on the theory and application of selection principles for the genetic improvement of animals. Cornell University, Ithaca, NY.
24 Van Vleck, L. D., and R. W. Everett. 1976. Genetic value of sexed semen to produce dairy heifers. J. Dairy Sci. 59:1802.
25 White, J. M., and J. R. Nichols. 1965. Relationships between first lactation, later performance, and length of herd life in Holstein-Friesian cattle. J. Dairy Sci. 48:468.
26 Wilton, J. W., and L. D. Van Vleck. 1969. Sire evaluation for economic merit. J. Dairy Sci. 52:235.
27 Young, C. W. 1972. Are top PD bulls your best buy? Hoard's Dairyman. Sept. 10, 1972:981.